J. Michael Spector · M. David Merrill
Jan Elen · M.J. Bishop *Editors*

Handbook of Research on Educational Communications and Technology

Fourth Edition

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A well-known issue of Educational Technology Research & Development in 1994 addressed the question of whether and to what extent media influence learning. Two opposing perspectives were presented in that issue by Richard Clark and Robert Kozma, both of whom have also contributed to this Handbook. One way to think about this Handbook, along with the three previous editions, is to recall that media debate and think about how research and practice have since evolved. We dedicate this Handbook to all the scholars who have contributed so much to explorations and investigations of how technology has and continues to influence the practice of learning and instruction. Many of those who have contributed so much to our understanding of educational technology have since passed away, including such luminaries as Robert Gagné, Robert Glaser, and William Winn among a list much too long to include here. We are deeply indebted to the contributions that so many have made to what we know and have yet to learn about how best to support and facilitate learning.

Foreword

Information and Communication Technologies in Education

In *Learning with Personal Computers* Alfred Bork (1987) promised a revolution in schooling due to the increasing availability of microcomputers. Twenty-five years later, on average, almost every person in economically developed countries is now blessed with one or more computers. However, the revolution that Bork imagined does not yet show definite signs of materializing soon. Upon reflection, we can say that most of us were, in the 1980s, perhaps a bit too optimistic about what information and communications technologies (ICT) could do to promote and improve education. Many are now trying to discern what added value ICT can contribute to the education enterprise, in addition to increasing the convenience of instruction and to motivating students to engage with activities that all too often are trivial. Skeptics have expressed doubts about the utility of technology in the classroom; some argue in favor of maintaining the traditional model of instruction that is exclusively reliant on teachers, print-based textbooks, and blackboards (perhaps a dry-erase whiteboard for the more progressive Luddites).

Increasing numbers of educators and scholars recognize that no technology can automatically benefit education in any significant way. Many realize that it is not about the technology after all—it is about what is done with technology to promote students' learning. When a new technology emerges, what really counts is the educational potential or learning opportunities provided to students, which are often obscured by the novelty of an innovative device. Scholars and teachers have the responsibility to discover and then to reveal those learning opportunities along with the associated potential to transform educational practice.

There is a growing and significant body of research that explores in detail and in depth the impact of new technologies on students' learning. Much of this new research is covered in this *Handbook*, which reviews research about the ways in which technology can significantly impact learning and create profound interactions between and among learners, teachers, and resources. This work is only a small part of a larger picture of ICT in the twenty-first century. The work reviewed in this *Handbook* provides one small glimpse of the revolution that is unfolding (albeit much later than Bork imagined).

There are many kinds of technologies used in present-day schools, some of which were developed specifically for the school context. Examples of commonly used educational technologies include classroom response systems, search engines, word processors, projectors, and interactive whiteboards. All of these and other technologies serve a wide variety of other non-school-based purposes. Most of these technologies were not invented for learning or teaching; however, their application to non-school settings, for which many of them were developed, is different from their use in school settings. For example, consider the word processor. Word processing facilitates the productive work of business by creating the correspondence necessary to conduct affairs. Specific features of the word processor were designed to make such business use both easy and effective. However, when one places a word processor in a classroom context, the use and purpose are not the same at all. Preparing teachers to help primary and secondary school students to make effective use of a word processor is quite different from training an administrator to help clerks and office assistants make effective use of the word processor in a particular office setting.

How shall we treat different uses of the same technology? How can we realize the educational potential of technologies taken for granted in the workplace? A definition of educational technology might emphasize the significant pedagogical or learning uses that technology serves; such a definition acknowledges the principle that uses and training for use should fit the specific purpose. This *Handbook* focuses on these educational uses and purposes.

Of the millions of teachers, educators, and scholars around the world, only a small number are engaged in research concerning the use of ICT in education. One result of this trend is a contrast between developers and educators who may ultimately use the new technologies. Developers create and laud the features of emerging devices and innovative technologies, while educators who want to teach with those technologies may become confused and frustrated with new technologies. It is rare that the two groups exchange views and experiences, and learn from each other. For many teachers, new educational technologies and facilities can cause some discomfort or even feel threatening due to their lack of adequate preparation in effective pedagogical use and integration into teaching and learning. There has been much research on the application of technology in education, as is evident in this *Handbook*. The chapter on TPACK (technological pedagogical and content knowledge) is a case in point. There is almost always initial resistance to a new technology, and the cost effectiveness of new technologies remains controversial (see Chapter 9 in this *Handbook*). Suggestions by technologists for educational application can be general and too distant from actual classroom use; thus these recommendations all too often fall short of the actual needs of teachers. As a result, too many teachers fail to embrace and use the new technologies in constructive ways with their own students.

An encouraging indication of change is this fourth edition of the *Handbook*, which includes a new section that is subject-specific and explores technologies in different disciplines. The first and last sections of the *Handbook* also offer a range of perspectives on technology integration that are aimed at practical use and widespread application.

Educational Communication Technology (ICT for Education)

Educational communication technology is a very dynamic area of research and application; new products can become out of date within a matter of months. The popular press often disseminates stories that dwell on the novelty rather than on the practicality of a new technology. Decision makers and those responsible for procurement are presented with a dilemma regarding acquisition of newer, forward-looking but riskier technologies as opposed to the reliable, older but more mature technologies. As is shown by the many chapters pertaining to emerging technologies, innovations ranging from cloud-based technologies to tablet applications are undoubtedly worthy of our attention due to their educational potential. However, the maturity of a technology and its connection and compatibility with existing technologies and expertise present significant challenges. When venturing to deploy a new technology, there are usually many unknown factors and some risk (Spector, 2012). When a new technology is profoundly different from previous technologies, or when the application of the technology dramatically changes practices, there are bound to be a multitude of unexpected problems.

In addition to the constant change of educational technologies, there is another challenge—namely differences between theory and practice, along with differences between the natural sciences and the humanities. A new educational technology that works well in support of learning physics may not work as well in support of learning philosophy, and vice versa. Moreover, the relevant learning theories and paradigms might be quite different in different areas of application. Effective technology integration requires sensitivity to the potential of various technologies as well as a profound understanding of specific disciplines and associated pedagogical practices. In too many cases, educators adopt without hesitation a new technology only to see it fail in practical use. As a community of professional practitioners, we are slowly coming to the realization that new tools need to be tested in the real and somewhat uncontrolled and chaotic circumstances in which everyday learning and instruction occur. Educational technology researchers and developers should carefully observe, assess, and identify the adaptability and success of the new technologies in light of actual teaching and learning; furthermore, all must keep in mind the opportunities, the benefits, the constraints, and the risks. Compulsive and hasty adoption of a new technology will very likely result in another cycle of sweet expectation followed by bitter disappointment.

Another important issue is the boundary between the two academic disciplines of educational technology and computer science. They are distinct from each other; however, a typical program of educational technology often offers many courses that are also found in a computer science curriculum. A closer scrutiny, however, reveals that educational technology courses are quite different from apparently similar courses in a computer science department. A recent IEEE-sponsored report recommends a very specific, cross-disciplinary curriculum for advanced learning technologists that could, if adopted, reduce the tensions between computer science and educational technology as separate and competing disciplines (Hartley, Kinshuk, Koper, Okamoto, & Spector, 2010). As things now stand, educational technology graduates find themselves at a disadvantage in the job market in comparison with a computer science graduate who appears equally well qualified. This state of affairs affects the growth of the discipline adversely. To avoid this waste of resources and dashed expectations, the discipline of educational technology needs to enhance its own reputation as a separate and credible area of expertise, which is what Hartley and colleagues (2010) encourage. That is to say, advanced learning technology graduates need to command abilities and skills that neither computer scientists nor education degree holders possess. However, they should be able to communicate and collaborate with both computer scientists and professional educators. In short, there is a need for a careful scrutiny of the field and a re-delineation of its academic scope and theoretical systems, along the lines of the Hartley et al. (2010) report, which identified the following domains of competence for educational technologists:

1. Knowledge competence—includes those competences concerned with demonstrating knowledge and understanding of learning theories, of different types of advanced learning technologies, technology-based pedagogies, and associated research and development.
2. Process competence—focuses on skills in making effective use of tools and technologies to promote learning in the twenty-first century; a variety of tools ranging from those which support virtual learning environments to those which pertain to simulation and gaming are mentioned.
3. Application process—concerns the application of advanced learning technologies in practice and actual educational settings, including the full range of life-cycle issues from analysis and planning to implementation and evaluation.
4. Personal and social competence—emphasizes the need to support and develop social and collaboration skills while developing autonomous and independent learning skills vital to lifelong learning in the information age.
5. Innovative and creative competence—recognizes that technologies will continue to change and that there is a need to be flexible and creative in making effective use of new technologies; becoming effective change agents within the education system is an important competence domain for instructional technologists and information scientists.

Growth of the Discipline

Since its establishment, the discipline of educational technology has been through several paradigm shifts and grown remarkably. Informed by theories and concepts from many other disciplines, including education, computer science, psychology, cognitive science, and communications, educational technology has acquired academic respectability. However, some have expressed doubts about the field, raising the issue of educational technology borrowing from other disciplines without creating a coherent and unique discipline of its own. In rebuttal, educational technologists argue that adoption and integration are not merely effortless borrowing tasks; rather, technology integration is a dynamic, innovative, and productive process—a *transdisciplinary* process, as Hideaki Koizumi (2004) put it. According to that Japanese scholar, educational neuroscience is a product of such a transdisciplinary process. The growth of the discipline of educational technology has been a product of a similar transdisciplinary process (see Richey, Klein, & Tracey, 2010). It is through this transdisciplinary process that the discipline of educational technology has made many unique contributions to both theory and practice. The work on cognitive load theory is a recent example of the transdisciplinary nature of educational technology (see, for example, van Merriënboer & Ayres, 2005).

There is a need to reconstruct the theoretical framework for educational technology, and there is an associated need to reconceptualize its academic scope and purpose. Supporting learners and the learning process with appropriate technologies is the fundamental belief of educational technology. Therefore, the design, development and application of technologies capable of such a role should be within the sphere of this discipline, where learning and technology intersect, and numerous other disciplines mingle in creative ways. In this theater of interaction and hybridization, there is both chemistry and synergy, and participants from diverse academic backgrounds and researchers of various segments of educational technology cooperate productively. However, due to their differences in training, skills, and values, these experts view technologies with different lens and may study problems from different perspectives and interest themselves in different dimensions of the same problem. How can they work together optimally?

No doubt, their cooperation needs to be based on the common ground designated by the shared ultimate goal of assisting learning. More is needed; however, mechanisms should be created and deployed to merge horizons and promote synergy among experts from different disciplines, thus removing academic biases, increasing their appreciation of each other's paradigms and interests, and locating the possible points for connection and cooperation. The fourth edition of this AECT (Association for Educational Communications and Technology) *Handbook* represents a creative realization of such an effort.

Global Differences

In addition to overcoming the aforementioned problems, we, as professional practitioners, need to do more if we want the desired educational technology revolution to unfold on a large, global scale. We have yet to scale the formidable barriers created by global differences, which are seen in both economic development as well as in social-cultural interests and habits.

First, economic inequalities have caused disparities in educational investment between countries and regions. Even within one country, especially some large and diverse ones, there can also be seen the full spectrum of differences in educational investment and accrued educational benefits. Underdeveloped countries and regions may acquire educational equipment and facilities by virtue of inter-governmental assistance, NGO (non-governmental organizations) donations and aid, and so on, addressing part of the significant physical digital divide. Nevertheless, these facilities are not usually updated and upgraded in a regular and timely manner as they would be in developed economies. More disconcerting is the gap in human resources and expertise—the non-physical digital divide. Technical expertise that is pedagogically informed is in short supply, making the Hartley et al. (2010) report even more pertinent.

Second, schools and their administration are often constrained as much as enabled by their particular social and cultural settings, which can differ radically because of racial, ethnic, or religious distinctions. Differences in local traditions, community characteristics, and special academic/educational interest can also be determining factors in enabling or inhibiting effective use of educational technology. Consequently there exists a wide range of teaching beliefs;

major disagreements about pedagogy and educational technology may even be found among teachers employed by the same school. Such discrepancies in culture and values can result in conflicting attitudes towards technology. In extreme cases, an educational technology may become an object of distrust or even ridicule. Compared with the hardware gap and infrastructure challenges, social and cultural inequalities are more subtle and difficult to manage.

In spite of those global differences, multinational organizations, especially network technology businesses and other information technology leaders are promoting their new educational technologies and relevant products. One result of this trend is that new technologies are confronted with a huge array of economic, social, cultural, and educational settings. As a result, the performance of the same educational technology can vary from one context to another; we have such failures to replicate findings in the research literature. This phenomenon is not unlike the legendary orange in an old Chinese saying: Grown south of the Huai River, it is sweet; grown north of the river, it tastes bitter and sour. If educational technology researchers and practitioners do not take into account local situations and customize technologies and educational practices accordingly, the promised revolution in schooling due to emerging educational technologies will never take place.

To sum up, there are significant challenges to the effective pedagogical use of technologies and development of new educational technologies based on the following four conclusions:

1. Technological advancement is an endless enterprise, but technological improvement does not necessarily translate into proportionate improvements in educational effect and impact on students' learning.
2. In different economic, social, and cultural environments, the same technology may perform differently.
3. The accelerated development in technology makes more acute the shortage of instructor knowledge about the effective use of technologies; good teachers who are well prepared are always in short supply.
4. Extensive and intensive involvement of teachers and pedagogically knowledgeable instructional designers is essential for progress in educational technology. There is little that educational technology can contribute to improve formal or informal student learning without this critical involvement.

We look forward to the day when a large number of elementary and secondary school teachers become readers and/or authors of the future editions of this *Handbook*; that will be a positive sign that educational technology is penetrating deep into classrooms and adding the synergy to launch the long-awaited revolution. Therefore, let us focus our efforts and work collaboratively across multiple disciplines so that this day may come sooner rather than later. Together we can make a difference.

Shanghai, China Youqun Ren

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Preface

As has been the case with the three previous editions of the *Handbook of Research on Educational Communications and Technology*, this volume has taken about 3 years to develop. The content is new and does not duplicate anything in the previous editions of the Handbook, all of which is available online at no cost to members of the Association for Educational Communications and Technology (AECT; see http://www.aect.org). We have a new publisher, Springer, who has agreed to do the same for this fourth edition. Springer has been most helpful in the development of this volume by making a customized version of Editorial Manager available to support submissions, reviews, and editing.

As we did with the third edition, we asked for guidance from AECT members and other professionals with regard to how best to develop the content and structure of the *Handbook*. We learned that *Handbook* users are typically doctoral students and other researchers new to a particular topic or area of research. They value a short and cogent summary of research in a focused area and especially appreciate the extensive reference sections and the indication of core references (marked with a preceding asterisk and located at the end of each chapter). Those whom we contacted in the first year of this effort also indicated a desire to see more research emphasized in additional areas. In general, there was a desire for short, focused research reviews, long and extensive references, and a discussion about research that could or should be conducted in the future. We provided all of our authors with this guidance, and we believe that they have done an excellent job in providing *Handbook* users with what they want.

Together with a large number of respondents to queries about the Handbook, including one specifically targeting AECT members, we initially developed more than 120 potential chapters. We asked the professional and academic communities to provide an extended abstract and core references for chapters that they would agree to author. The coeditors then examined the various proposals and settled on just over a 100 potential chapters. As the process evolved and potential authors were asked to deliver draft chapters, the list was narrowed to about 87. For a variety of reasons, several authors withdrew or were dropped and we ended up with 75 chapters, divided into nine sections, compared with 56 chapters in six sections in the third edition.

We retained the Foundations section but of course included completely new content with more emphasis on research as had been requested by those we asked for input. In addition to two new chapters on research, there are chapters on neuroimaging and motivation as these are both regarded as foundation areas that can and should inform instructional design and educational technology research. Ethics, human performance technology, and TPACK (technological, pedagogical, and content knowledge) are also treated in the Foundations section.

Section 2 treats qualitative and quantitative tools and methods separately and includes chapters on design-based research, action research, and program evaluation not previously addressed in the Handbook. There is an extensive section on assessment and evaluation with many new topics addressed, including stealth assessment, cost-benefit analysis, and model-based assessments.

Section 4 includes a chapter specifically addressing cultural issues per the advice we received in the initial response to our queries of what to include. Many of the same emerging trends one finds in the New Media Consortium's *Horizon Report* (http://www.nmc.org/publications) and *A Roadmap for Educational Technology* jointly published by the Computing Research Association and the Computing Community Consortium, and the National Science Foundation (available online at http://www.cra.org/ccc/docs/groe/GROE%20Roadmap%20for%20Education%20Technology%20Final%20Report.pdf) are evident in this section—see, for example, Chaps. 35, 36, and 38.

Section 5 represents an entirely new section developed in response to the feedback we received about previous Handbooks. While we were not successful in recruiting as many chapters in this section as we had planned, readers will find very informative chapters on technology in science education, medical training, mathematics, engineering, visual arts, social studies and visual arts.

While Section 7 has been included in previous editions, all the chapters in this section are new for this edition. In addition to new treatments of instructional design models and technology-based instruction, there are topics not previously addressed such as change agency, governmental policies, and curricula for training instructional designers.

The second part of the *Handbook* contains three sections that address respectively emerging technologies, technology integration, and the future of educational technology research. Section 7 is the most extensive section of the *Handbook*, and was designed specifically in response to the feedback we received early in the process. Again we used technologies cited in the NMC *Horizon Report* and in *A Roadmap for Educational Technology* to guide input for this section. Readers will find e-books, pedagogical agents, adaptive technologies, augmented realities, and research on many other new and emerging technologies treated in this section.

Because so many scholars have commented on the ability to make effective use of new and emerging technologies, we decided to specifically address the issue of Technology Integration in a separate section in this edition of the *Handbook*. We included chapters on measuring technology readiness skills and generational differences as well as issues specific to different contexts (formal learning in schools, medical education, multicultural settings, etc.).

The final section of the *Handbook* is entitled A Look Forward and is intended as a precursor for further research. This is another new section of the *Handbook* and is meant as a kind of book-end section to go with the Foundations section. Issues involving the philosophy of science, teacher education, and prospects in developing countries are addressed, among others.

As with the third edition, we made every effort to include research from around the world as this *Handbook* has become an internationally acclaimed standard in the field of educational technology research. The third edition has now been translated into Chinese by a team of university scholars in China led by Ren Youqun. Since he is one of a very few individuals who have read every chapter in the previous edition of the *Handbook*, and because he leads an impressive group of researchers at East China Normal University, we invited him to contribute the Foreword to the fourth edition. We then invited Joost Lowyck who wrote the Foreword to the third edition and who was also familiar with all of that content to write the first chapter in this edition. His chapter provides an historical overview of educational technology aimed at bridging educational theory and practice. Lowyck provides five principles relevant to that enterprise: (1) evolutions in society and education have influenced the selection and use of learning theories and technologies; (2) learning theories and technologies are situated in a somewhat vague conceptual field; (3) learning theories and technologies are connected and intertwined with information processing and knowledge acquisition; (4) educational technologies have shifted learner support from program or instructor control toward more shared and learner control, and (5) learning theories and findings represent a fuzzy mixture of principles and applications. The reader will find an insightful discussion to accompany these five principles. In addition, the editors have taken up these principles in the epilogue and concluding chapter of the Handbook.

We hope that the efforts of the authors, reviewers, editors, and so many others in bringing this Handbook to the educational technology research community will prove useful and result in ongoing productive research. Our final word—enjoy.

2012

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Many others have contributed to this edition of the *Handbook*, including participants at AECT sessions and respondents to queries the editors presented at various venues in the last 3 years. As is the case with any major publication, it is impossible to cite all those who contributed along the way. The order of the editors does not reflect the quantity or quality of contribution; all editors shared equally in the development of the *Handbook*. We are most grateful for having had the opportunity to edit this fourth edition of the *Handbook* and appreciative of all those who helped make it possible.

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Section I

Foundations

J. Michael Spector and M. David Merrill

This first section of the *Handbook* is focused on the foundations that inform educational technology research and development. The purpose of this section is to provide a research-based overview of the foundations of educational technology pertinent to the twenty-first century scholarship and practice. The intent is not to repeat anything explicitly covered in the three previous editions of the *Handbook* (Jonassen, 2004; Jonassen, Harris, & Driscoll, 2001; Spector, Merrill, van Merriënboer, & Driscoll, 2008), all of which are available online at no cost to members of the Association of Educational Communications and Technology (see http://www.aect.org) which sponsors the *Handbook*.

The emphasis in this section is on research linked to new and emerging educational technologies, including the relationships between theories, models, frameworks, perspectives, approaches, and principles. This section should provide those new to this area of research with a comprehensive understanding of the many different areas and perspectives that influence and inform research and scholarship in educational technology.

The section begins with Joost Lowyck's historical overview of educational technology and the interrelationships between theory, technology, research, and practice. The historical overview is followed by two chapters focused on research paradigms (van Merriënboer and de Bruin) and research perspectives (Morrison and Ross); taken together, these two chapters represent the complexity and diversity of views that inform educational technology research. The fourth chapter in this introductory section by Foshay, Villachica, and Stepich elaborates the relationships between human performance technology and instructional design.

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The first four chapters that provide readers with the breadth of views pertaining to educational technology research are followed by five chapters that explore specific foundation areas not addressed in previous editions of the *Handbook*. Chapter 5 by Antoneko, van Gog, and Paas is focused on the implications of neuroscience for educational research. Chapter 6 by Kim and Pekrun addresses research on emotions and motivation that are pertinent to learning, performance, and the design of instruction. Chapter 7 by Branch provides an overview of instructional design models that often are the point of departure for the design of research studies. Chapter 8 by Warren, Lee, and Najmi provides readers with an update of how recent technologies have influenced the design of instruction and educational technology research. Chapter 9 by Koehler, Mishra, Kereluik, Shin, and Graham reviews research in the recently defined area of technological, pedagogical, and content knowledge (TPACK).

These nine chapters represent the breadth and depth of the broad area of educational technology research. By no means do these few chapters exhaust the full breadth of this complex area. The chapters to follow in subsequent sections should make clear that these first few chapters only tap the depth of research in this area. The final section of the *Handbook* (the epilogue) represents the editors' attempt to suggest that this large *Handbook* only touches a few important research areas—there is much we have yet to understand and there are new and emerging technologies that will surely change what researchers and practitioners do.

While all of the chapters in this *Handbook* are new and do not appear in previous editions, several chapters have been added specifically at the request of *Handbook* users. The final chapter by Moore and Ellsworth in this introductory section is one of those—it addresses the important area of ethics and standards educational technology research and practice. A code to guide instructional practice can be found in Spector, Ohrazda, Van Schaack, and Wiley (2005), and AECT has an ethics code, so it is fitting and appropriate that this topic should be included in the Foundations section of the *Handbook*.

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* An asterisk next to a reference entry throughout this Handbook indicates a reference that the author(s) considers to be central to the topic.

Bridging Learning Theories and Technology-Enhanced Environments: A Critical Appraisal of Its History

1

Joost Lowyck

Abstract

In education, retrospection is often used as a method for better understanding emerging trends as documented in many books and articles. In this chapter, the focus is not on a broad description of the history of educational technology but on the interplay between learning theories and technologies. However, neither learning theories nor tools are monolithic phenomena. They are composed of multiple attributes, and they refer to many aspects and facets which render the history of educational technology highly complex. Moreover, evolution in both theory and technology reflects no clear successive breaks or discrete developments—rather, waves of growth and accumulation. When looking closer at learning and technology, it becomes clear that many interactions occur. These interactions will be documented following continuous development after World War II. We do not follow a strict timeline but cluster the critical appraisal in the following observations: (1) evolutions in society and education have influenced the selection and use of learning theories and technologies; (2) learning theories and technologies are situated in a somewhat vague conceptual field; (3) learning theories and technologies are connected and intertwined by information processing and knowledge acquisition; (4) educational technologies shifted learner support from program or instructor control toward more shared and learner control; and (5) learning theories and findings represent a fuzzy mixture of principles and applications. The history reflects an evolution from individual toward community learning, from content-driven learning toward process-driven approaches, from isolated media toward integrated use, from presentation media toward interactive media, from learning settings dependent on place and time toward ubiquitous learning, and from fixed tools toward handheld devices. These developments increasingly confront learners with complexity and challenge their responsibility to become active participants in a learning society.

Keywords

Learning theories • Educational technology • Technology

Introduction

According to Gagné (1974) the main question of educational technology is: How can "things of learning" best be employed to promote learning? In most discussions of technology implementation, learning issues remain relatively tacit (Bransford, Brophy, & Williams, 2000). Searching the relationship between learning theories and technologies is at first

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glance an attractive endeavor given its possible relevance for both educational theory and practice. However, dealing with this issue is quite complex. Indeed, a number of questions arise about the relationship of learning theory and technology, sometimes called a marriage (Perkins, 1991; Salomon & Ben-Zvi, 2006). Do learning theories refer to hybrid constructs or are they rather eclectic containers of more modest models or even common sense practice? How should technology be conceptualized? If a link exists between learning and technology, what is the nature of the relationship? Can we best label developments in the knowledge-base of learning and technology as paradigm shifts (Koschmann, 1996), sequential events (Sloan, 1973), or waves (Toffler, 1980)?

In this chapter we will not reiterate broad accounts of evolutions in educational technology (see amongst others De Corte, Verschaffel, & Lowyck, 1996; Januszewski, 1996; Kozma, 1991; Mayer, 2010; Molenda, 2008; Reiser & Gagné, 1983; Saettler, 2004). We start the quest for linking learning theories and technologies at the moment explicit learning theory enters educational technology. The critical appraisal of the link between learning theories and technologies is structured around the following observations to reduce complexity and fuzziness in that interdisciplinary field: (1) evolutions in society and education have influenced the selection and use of learning theories and technologies; (2) learning theories and technologies are situated in a somewhat vague conceptual field; (3) learning theories and technologies are connected and intertwined by information processing and knowledge acquisition; (4) educational technologies shifted learner support from program or instructor control toward more shared and learner control; and (5) learning theories and findings represent a fuzzy mixture of principles and applications.

Observation 1: Evolutions in Society and Education Have Influenced the Selection and Use of Learning Theories and Technologies

Educational technology influenced in many and often centrifugal ways educational innovation as part of societal development. Successive behaviorist, cognitive, constructivist, and socio-constructivist approaches to learning and the concomitant use of technologies suggest a clear, straightforward contribution to education based on the internal dynamics of that field. However, one may wonder why in the 1960s and 1970s behavioral learning theory, but no others, was selected as the focus of educational technology. Examples of more cognitively oriented theories available at that time are the work of Bartlett (1958) on "Thinking, an experimental and social study," of Bruner (1961) on "The act of discovery," of de Groot (1965, originally published in 1946) on "Thought and choice in chess," of Dewey (1910) on "How to think," of Piaget (1952) on "The origins of intelligence in children," and of Vygotsky (1962, originally published in 1934) on "Thought and language." These theories inspired school curricula and teaching methods but not technology use. Even though Newell and Simon (1972) contend that the appearance of modern computers at the end of World War II gave researchers the courage to return to complex cognitive performances, there was no relationship between early cognitive research and technology for education.

It is clear that more than learning science controls the selection and use of peculiar learning theories and tools. This points to the impact of society on educational technologies in that learning theories are selected to support the technology implementation society drives us to employ (Boyd, 1988). Indeed, society holds strong expectations to solve learning problems with technology. Expectations function as macro-hypotheses that are progressively shaped and falsified during implementation, often resulting in more difficulties and less productivity than initially expected. One waits for the next, more powerful learning theory or tool (Lowyck, 2008).

The influence of the *Zeitgeist* can be illustrated with some examples. At first, audiovisual tools were expected to bring reality into the stuffy classroom and to bridge the gap between school and the world outside the classroom. Mass media (radio, film and television) were proclaimed to refresh education with real-world information presented just-in-time (Dale, 1953; Saettler, 2004). The audiovisual movement was grounded on communication theories that model the flow of interaction between sender and receiver, regulating the transport of information (Kozma, 1991; Levie & Dickie, 1973; Saettler, 2004; Tosti & Ball, 1969). While this movement nicely illustrates the impact of societal expectations on education, no explicit learning theory provided a foundation, so it is not part of our critical appraisal of linking learning theories and technology.

At the end of the 1950s in the aftermath of the Sputnik-shock, Western societies aimed at improving education quality especially in mathematics and science to compensate for the supposed failure of the progressive education movement and teachers' deficient classroom behaviors (Skinner, 1968). In line with the *back-to-basics* movement (Boyd, 1988), curricula were revised and proper, programmed design and delivery of subject-matter was expected to contribute to educational quality based on a genuine science of instruction (Glaser, 1965; Lockee, Larson, Burton, & Moore, 2008). In a similar vein, democratization of education was aimed at giving increased access to education responding to the post-war baby boom which led youngsters in a prosperous economic period to mass education. This, however, raised concerns about individual development though interpreted in multiple ways by Rousseau-inspired romantics to more mechanistically oriented empirical behaviorists (Grittner, 1975). Computer-assisted instruction (CAI) claimed to realize individualization which brought Suppes (1969) to expect that computers could offer individualized instruction, once possible for only a few members of the aristocracy, to all students at all levels of abilities. However, the limited capacity of computers and reductionist instructional design at that time hindered the full implementation of individualization.

In the late 1970s, increasing use of personal computers in professional settings responding to the challenges of an information society created a new argument for the integration of computers in education and emphasis on acquiring computer skills (Dillemans, Lowyck, Van der Perre, Claeys, & Elen, 1998; Mandinach, 2009). This is why policy-makers in most Western countries launched extensive national programs to introduce new technologies in schools (Kozma, 2003). Learning to program computers, for example, was seen as a main task for education in a growing technology-rich society. Teachers and other computer savvy practitioners built instructional materials based on common sense knowledge of classroom teaching and content delivery with simple question-answer-feedback loops, vaguely inspired by behavioral principles (Saettler, 2004). This led to a proliferation of small and isolated CAI-programs, mostly in algorithmic subject-matter domains with little theoretical underpinnings or fundamental goals to achieve (McDonald & Gibbons, 2009). The interplay between behaviorist learning theory and technology ultimately resulted in inflexible and didactic instruction (Shute & Psotka, 1996).

During the 1980s, a cognitive orientation in education was strongly supported by Western governments struggling with increasing worldwide competition in commerce, industry, science and technology. Enhancing learners' common understandings of complex issues, deep learning and complex skillfulness instead of mere subject-matter delivery was perceived as a strategic approach to societal survival (NCEE, 1983; Sawyer, 2006). This shift resulted in more complex forms of cognitive behavior embedded in school curricula, increasing interest in the role of knowledge in human behavior, and an interactionist view of learning and thinking (Resnick, 1981). The ambition to tune education by means of technology to complex changes in society gave birth to a new wave of investments in research and development not only in supplying funds and resources for equipment and network connectivity (Jones, 2003). Many computer microworlds, cognitive tools and instructional programs were produced at research centers, universities and enterprises (Duffy, Lowyck, & Jonassen, 1993). However, most of these computer-based educational systems were not widely adopted or embraced. This was due to both the *not-invented-here syndrome* and the increasing cost of commercial products (Boyd, 1988; Jonassen, 1992).

Intensive electronic networking, and social media reflect more recent changes in society that are expected to add value through a common purpose and deliberate collaborative action in a community of learners and practitioners (Center for Technology in Learning, SRI, 1994). Increasing miniaturization, integrated functionalities, and wireless use comprise a communication hyperspace in a global world that call for new ways of technology use in education. This is why socio-constructivist theories and technology-supported communities of learning and practice have become dominant, at least as a frame of reference within the community of educational technologists.

Summary

Evolutions of learning theories and technologies show internal and autonomous dynamics that lead toward mutual fertilization. Pressure in Western countries to survive in a scientifically and economically changing, competitive world activates governmental initiatives to support technology in schools through financial support and stimulation of research and development. However, policy makers often formulate unrealistic expectations due to lacking knowledge of the multidimensionality of technological solutions for education. Commercial organizations respond to societal demands with little concern about efficiency, effectiveness and relevance of educational products and processes, an observation that brings researchers to request grounded evaluation (Clark, 1983; Salomon, 2002). Schools and educational institutions are involved in lasting and difficult processes of innovation through technologies that impact all organization components (curricula, personnel, finances, infrastructure, etc.), while teachers and learners are challenged to cultivate new competencies, unlearn dysfunctional behaviors and conceptualizations, and build new perspectives on technologies for learning.

Observation 2: Learning Theories and Technologies Are Situated in a Somewhat Vague Conceptual Field

Exploring links between learning theories and technology is dependent on agreed upon conceptual frameworks and concepts within research traditions. Each field of study is filled with ill-defined concepts and terminology that is inconsistently used and leads toward different starting positions. A basic science of learning starts from the insight that little is known and that much has to be discovered, while applied science and technology focus on what is known and applicable in practice (Glaser, 1962). Despite continuous efforts to calibrate conceptual issues (Januszewski & Persichitte, 2008; Reiser & Ely, 1997), and unlike the natural sciences, concepts in the behavioral sciences are rarely standardized

(Halliday & Hasan, 1985). That concepts are used in various ways becomes especially problematic when central theoretical importance is involved (Prenzel & Mandl, 1993).

Learning Theories

Learning as a relatively permanent change in motor, cognitive and psychodynamic behavior that occurs as a direct result of experience is shared by all learning theories. Despite this largely accepted definition, "learning theory" remains a broad term with many perspectives "ranging from fundamental exploratory research, to applied research, to technological development, through the specification of work-a-day methods of practice" (Glaser, 1965, p. 1). Conceptual confusion originates partly from an over-generalization of successive ways of thought that are perceived as the way things are. Observable behavior, mind, information processing, sociocultural theories, genetics and brain research are changes that signal scientific progress but the tendency to over-generalize is often driven by other than scientific considerations (Bredo, 2006). Given the intrinsic limitations of educational research, no single theory encompasses all aspects of learning and learners (Gage, 1972). Consequently, various theories that emerged as researchers focused on different kinds of learning only represent a limited part of the knowledge-base of psychology as a discipline (Bransford et al., 2006). In addition, learning theories do not constitute a monolithic, coherent system but each school of thought represents a collection of distinct theories that are loosely connected (Burton, Moore, & Magliaro, 1996; Dede, 2008) a fact that led to the balkanization into smaller communities with different research traditions and largely incommensurable views of learning (Koschmann, 1996). While behavioral theory and early information processing theory use definitions that are instrumental to experimental research, socio-constructivist theory is complex, eclectic, and multifaceted (Lowyck & Elen, 1993). A possible solution is to take a pragmatic position defining learning theories as an interrelated set of facts, propositions, rules, and principles that has been shown to be reliable in many situations (Spector, 2008). Though this may be helpful to avoid conceptual fuzziness, it seems hard to define valid and precise criteria to differentiate between evidence-based and common sense knowledge in an educational context.

Technology

Educational technology holds a double meaning: (a) application of scientific know-how, and (b) tools or equipment (Glaser, 1965; Molenda, 2008; Reiser & Gagné, 1983). AECT (the Association for Educational Communications and Technology; http://www/aect.org) refers to the "disciplined application of scientific principles and theoretical knowledge to enhance human learning and performance" (Spector et al., 2008, p. 820), which is very close to instructional design as defined by Gagné (1974) as a "body of technical knowledge about the systematic design and conduct of education, based upon scientific research" (p. 3). Technology as the mere application of research findings was highlighted in the years of programmed instruction with procedures for behavioral modification to reach terminal behaviors (Glaser, 1965). Along with an increasing variety of learning theories, different genres of technology-based learning environments covered different functions of educational technology, including intelligent tutoring systems, interactive simulations and games, animated pedagogical agents, virtual environments, and computer-supported collaborative learning systems (Mayer, 2010).

Others focus on the physical aspects of technology via which instruction is presented to the learners. McDonald and Gibbons (2009) refer to this as the *tools approach* which holds the expectation that using technological tools will affect learning outcomes. This led to various gimmicks being introduced in schools as extras not necessarily well aligned with the teaching-learning process (Husèn, 1967). Machines on their own will not bring about any change (Stolurow & Davis, 1965). This statement is close to Clark's (1983) view that method, not media, determines effectiveness. This claim also pertains to the comparison of computer-based environments (e.g., desktop simulation and virtual reality simulation) (Mayer, 2010). The question, however, is not if tools can contribute to learning but how instructional materials in various forms can enhance learning and allow the manipulation of the properties of instruction that impact learning (Lumsdaine, 1963). This reflects the position of Kozma (2000) who emphasizes a nexus of media and method. Indeed, technology allows for methods that would not otherwise be possible, such as interactive multimedia simulations that support the ability to act on the environment and not simply observe it (Winn, 2002) or hypermedia that challenge cognitive flexibility while crisscrossing the information landscape (Spiro, Feltovich, Jacobson, & Coulson, 1992). In times when information and communication technologies deeply penetrate society, the dichotomy between applied science and tools technology has been in favor of synergy. Educational technology involves a broad variety of modalities, tools, and strategies for learning (Ross, Morrisson, & Lowther, 2010).

Linking Learning Theories and Technology

Given the complexity and diversity of conceptualization, it seems difficult to find a direct link between learning theories and technology. Firstly, the relationship is asymmetric; it is common to consider learning theories as leading and technology as following (Salomon & Perkins, 1996). Secondly, although the psychology of learning is a critical foundation area (Spector, 2008), in complex technological environments it shares a place with communication theory, general systems theory, and instructional-curriculum theory (Richey, 1986). In fact, not only learning but organizational issues as well are important in technological environments, with a focus on the availability, accessibility and acceptability of educational resources (Lane, 2008). An analysis of articles in journals on educational psychology between 2003 and 2007 shows that only 5.6 % of the articles addressed the links between learning theory and technology (Nolen, 2009, as cited in Ross et al., 2010).

Summary

Learning theories, technology and their interlinking fields are dependent on specific research traditions, historical artifacts, idiosyncratic frameworks, technology-based functionalities and pragmatics, which necessarily leads to divergence. Calibration of concepts and conceptual frameworks is not merely a philosophical issue but it is critical for cumulative knowledge building. Not surprisingly, rapid changes in learning theories and technologies generate new terminology. However, increased efforts to refine conceptual frameworks for valid theory building are needed to support cumulative domain knowledge in the field of educational technology. Given the conceptual complexity, the expectation that a clear link between learning theories and technology can be built based on agreed upon definitions is in vain. Consequently, a solution has to be found in a more pragmatic approach with a smaller unit of analysis, where (partial) learning theories, models, and principles are connected to specific technological tools in order to overcome conceptual overload.

Observation 3: Learning Theories and Technologies Are Connected and Intertwined by Information Processing and Knowledge Acquisition

Different learning theories and epistemologies (e.g., objectivism and constructivism), lead to various conceptions of information processing and knowledge acquisition that influence technology use. Given the central function of education to help learners acquire declarative, procedural and conditional knowledge, learning theories and technologies are fellow travelers.

Behaviorist Theory and Subject-Matter Decomposition

In the behaviorist tradition, knowing is an accumulation of associations and components of skills that prescribes simpler tasks as prerequisites for more complex ones (Greeno, Collins, & Resnick, 1996). The stimulus-response theory in which knowledge is defined as a learner's collection of specific responses to stimuli that are represented in behavioral objectives is basic in programmed instruction and CAI. Logical presentation of content, requirement of overt responses, and presentation of immediate knowledge of correctness are common characteristics. Subject-matter is decomposed into small units with carefully arranged sequences aimed at specified terminal behaviors (Shrock, 1995). Terminal behaviors are defined as understanding concept formation, concept utilization, and reasoning through variations of the stimulus context (Glaser, 1962), not through direct access to thinking or knowledge organization. Researchers and designers massively invested in refining and shaping the initial principles of content framing and sequencing (Lockee, Moore, & Burton, 2004; Tennyson, 2010).

A frequently cited example of a system based on behaviorist learning theory, is programmed logic for automatic teaching operation (PLATO), a mainframe-based, integrated system of hardware and software with well-designed instructional materials displayed on special terminals connected through satellite links. The PLATO system started in the early 1960s; didactic as well as communication functions were gradually expanded (Molenda, 2008; Saettler, 2004), leading to over 15,000 h of instructional materials available in a variety of disciplines (Simons & de Laat, 2006). Despite its continuous adaptation and extension, PLATO as a closed system had to compete with a steady innovation of subject-matter and didactic approaches in curricula, a paradigm shift toward a cognitive interpretation of learning environments, and a knowledge-building epistemology. Besides evolutions in education, financial issues played an important role since CAI was significantly more expensive than conventional instruction and no return on investment was realized (Saettler, 2004).

Information Processing Theory and Problem-Solving Tasks

Gagné (1974) dates the transition from behaviorist learning toward cognitive theory at the moment learning is conceived of as a matter of students' information processing. Cognitive theory is largely rooted in objectivist epistemology, but unlike the behaviorists, cognitive psychologists emphasize the individual's processing of information and how knowledge is stored and retrieved (Winn, 2004). A human information processing system consists of a sensory register, short-term (working) memory and long-term-memory (Simon, 1978). Information moves through stages in the cognitive system with processes and mental representations that operate at each step (Brown, 1978; Glaser, 1991). Mental processes mediate what is selected, processed, remembered, recalled and generalized (Hannafin & Hill, 2008).

Theory on information processing and problem solving emerged with the development of the digital computer after World War II (Newell & Simon, 1972; Simon, 1978) and is strongly related to content: “If content is a substantial determinant of human behavior—if in fact the message is a lot more message than the medium—then information processing theories have opportunities for describing human behavior veridically that are foreclosed to theories unable to cope with content (Newell & Simon, 1972, p. 11). All problem-solving behavior is framed by the information-processing system, the task environments and the problem space (Simon, 1978).

In a cognitive perspective, knowledge that supports understanding differs from information as disconnected facts and formulas (Bransford et al., 2000). There is a clear shift from information delivery toward student’s knowledge activation since the logical type of knowledge that was associated with a given discipline in a behaviorist approach is replaced by the psychological nature of meaningful knowledge held by learners (Shuell, 1992). Subject-matter is no more fragmented in small parts but organized around problems that activate learner’s prior declarative, procedural, and self-regulatory knowledge in an interconnected way to solve a given problem. Processing and transformation capabilities of computer micro-worlds allow learners to progress unto more advanced models, increasing the number of rules, qualifiers, constraints to be taken into account, and the range of problems that can be accommodated (Kozma, 1991; Seel, 2006). Computer simulations are compatible with a cognitive theory of learning since they present formalized models, elicit specific cognitive processes like hypothesis generation and testing, allow for learner activity in terms of model manipulation, and interact with the underlying domain model. Learners can execute actions like changing the values of input variables, observing the effects in output variables and make or test hypotheses based on the changes in values that foster conceptual change (de Jong, 1991; Winn, 2004).

Cognitive Theory and Knowledge Organization

Knowledge is a complex phenomenon involving such constructs as schema, mental models, symbol manipulation, knowledge construction, and conceptual change (Winn, 2004). Research in cognitive psychology revealed the centrality of knowledge in human performance including content, knowledge structure and context (Cooke, 1999). Knowledge in isolation (inert knowledge) is of little value but knowledge is powerful if highly organized and easily accessible (Greeno et al., 1996; Schraw, 2006). However, reduction of knowledge organization to neat hierarchies and sequences is an oversimplification of the knowledge people construct (Siemens, 2004; Winn, 1993). Indeed, each individual must possess extensive knowledge, organize knowledge into interconnected schemata and scripts, and use that knowledge to construct conceptual mental models of a given subject-matter domain that are used to solve problems and think critically (Schraw, 2006).

Knowledge organization has been supported by different cognitive tools, such as simulations (de Jong, 2010), concept mapping, and semantic networking embedded in computer tools that visually represent a cognitive structure with nodes and links (Jonassen & Reeves, 1996). In the early 1990s, several computer-based tools were developed (Kommers, Jonassen, & Mayes, 1992) challenging learners to analyze structural relationships among the subject-matter. “Learning tool” (Kozma, 1992), “TextVision” (Kommers & de Vries, 1992), and “SemNet” (Fisher, 1992) are examples of software packages that allow users to graphically represent concepts, define relationships and enter detailed textual and graphic information for each concept. However, a graphical representation of knowledge structure is limited both in mirroring knowledge complexity and accessing deep knowledge. The complexity of digging up and representing concepts, nodes and knowledge structures not only accounts for novices with limited domain knowledge but also for experts as has been evidenced by research on expert knowledge acquisition (Cooke, 1999).

Constructivist Theory and Knowledge Construction

Knowledge construction is a generative learning process (Wittrock, 1974). From a constructivist perspective, knowledge is not conceptualized as a body of information based on verified facts but, rather, as individually constructed by observation and experimentation. Knowledge acquisition is dynamic rather than static, multidimensional rather than linear, and systemic rather than systematic (Winn, 1993). The active interaction between an individual and the environment is mediated through cognitive structures of the individual (Jonassen, Mayes, & McAleese, 1993). The knowledge that each student constructs is not predictable from the individual pieces of information in the information landscape or the curriculum but emerges from the sum of the encounters and from the relations established by the student within the knowledge domain.

If the learner is seeking information to solve a problem or build a better understanding, then environments, such as hypertext retrieval systems, can support that need and engage the learner. Information retrieval is supported by the learner's ability to follow a particular path and make decisions about which links to follow within the hypertext information. In order to make learners able to amend the information in some way, many hypertext systems include functions to support the creation or editing of nodes and links and other functionalities (Jonassen, 1992). Learning from hypertext mostly is task driven, in contrast with free browsing. This is why cognitive flexibility that allows crisscrossing the information landscape is not well suited for novices in a given subject-matter domain (Spiro et al., 1992). Browsing in a domain for which no properly developed schemata have yet been constructed by the learner is not likely to lead to satisfactory knowledge acquisition at all (Jonassen et al., 1993).

Socio-constructivist Theory and Distributed Knowledge

The information-processing approach with cognition mainly conceived of as involving internal mental processes came under increasing criticism. The main objection was that knowledge can be viewed as distributed over individuals and their environments rather than as something self-sufficient to an individual. The notions of *distributed cognition* and *distributed knowledge* play an important role as human activity is affected by contextual affordances which include both people and cultural artifacts (Greeno et al., 1996; Hewitt & Scardamalia, 1998; Säljö, Eklund, & Mäkitalo, 2006). Glaser (1991) offers several arguments for integrating the social dimension within a cognitive perspective: (a) available knowledge is extended; (b) the loci of self-regulatory activity are multiplied; (c) learners can help each other in realizing a Vygotskian zone of proximal development; and (d) a social context helps in bringing thinking to an observable status.

The socio-constructivist perspective and the distributed character of knowledge have influenced computer use since about 1990. CSCL (computer supported collaborative learning) serves groups of learners who co-construct knowledge in a given subject-matter context and aim at goals that are externally provided. CSCL technology is used to present or stimulate a problem for study, helping to situate it in a real-world context, mediate communication within and across classrooms, provide archival storage for the products of group work, or enable learners to model their shared understanding of new concepts (Koschmann, 1996).

Computer-supported intentional learning environment (CSILE) and its extension Knowledge Forum are instances of CSCL that encourage structured collaborative knowledge-building instead of focusing on individual learning tasks (Scardamalia & Bereiter, 1994). Students communicate ideas and reflections, ask questions, exchange statements and continuously build up shared knowledge as input in a database. The computer system supports the knowledge organization of individual and community discourse. The target is real world knowledge that is constructed over time and not restricted to a single product or topic (Scardamalia, 2002; Siemens, 2004).

Summary

Conceptions of information processing and knowledge building change over time, depending on epistemological arguments and evolving learning theories. Different computer tools and systems have been designed to contribute to the supposed increase of education quality in terms of knowledge acquisition but most if not all are limited in curriculum coverage. The shift from programmed instructional materials as parts of the school curriculum toward student's individual and collective knowledge organization and knowledge construction tools paved the way for more real-world problems and knowledge. Evaluation studies clearly show that not only the use of cognitive tools but the link with underlying cognitive processes defines a system's or a tool's merits.

Observation 4: Educational Technologies Have Shifted Learner Support from Program or Instructor Control Toward More Shared and Learner Control

A basic tenet in the discussion of the interplay between technology and education is how technology might support individuals and groups to reach learning goals. Depending upon available learning theories and technological tools, different kinds of support have been inserted into instructional materials, programs, and technology enhanced learning environments, while open-ended learning environments suggest *freedom to learn*. This reveals a tension between structured learning support and a learner's self-management with technology.

Intelligent Computer-Assisted Learning and Intelligent Tutoring Systems

In the behaviorist tradition, computers integrate the activities of a display component, a response component and a feedback component of instruction (Gagné, 1974). It was expected that computer-assisted learning could realize maximal learning support through adaptive feedback. However, linear feedback often results in deficient individual support in traditional CAI programs. A solution is sought in the design of a new generation of programs called intelligent computer-assisted instruction (ICAI). They are instances of micro-adaptive instruction that aim at continuously tuning instruction to the needs of the individual learner with branching as a fundamental aspect of design (Wenger, 1987). ICAI systems are behavioristic since they only use the status of student's behavior to adapt instruction (Urban-Lurain, 1996). However, genuine feedback is hard to realize since the source of information is external to the student and takes place not during a learning activity but only after task completion (Butler & Winne, 1995). In addition, limited computer capacity in terms of memory and speed imposed severe restrictions to tune feedback to individual needs of students.

Fine-tuned adaptivity based on a student's cognitive status had to wait for intelligent tutoring systems (ITSs). A cognitively oriented tutoring system or ITS is not a static preprogrammed system but integrates computational models using artificial intelligence and cognitive science to generate interventions. These are generated based on data gathered from a database that includes the nature of errors and cognitive skills that are realized in the form of production rules (Shute & Psotka, 1996). The database is structured around (a) an expert or domain model, (b) a dynamic student model, (c) a tutor or teaching model, and (d) a communication model and user interface (De Corte et al., 1996; Larkin, 1991). Anderson (1983) developed his adaptive control of thought (ACT*) theory in which a learner's knowledge is tracked (knowledge tracing) in order to generate appropriate learning activities.

In ITSs two different lines of evolution can be observed. One is to refine ITSs in order to integrate new knowledge about learning and new programming techniques. The other is the acceptance of limitations since intelligent machines do not have the breadth of knowledge that permits human reasoning given the fuzziness of thinking and permeability of the boundaries among cognitive schemata (Winn, 2004). Progress has been made in ITS development mainly in knowledge-domains with a rule-based, logical structure, such as classical mechanics, geometric optics, economics, elementary algebra, grammar, and computer programming (Sleeman & Brown, 1982; Wenger, 1987). Further development of natural language processing (Graesser, Chipman, & King, 2008) allows the ITSs to make decisions based on qualitative data analysis (e.g., open-ended text responses or annotated concept maps) (Lee & Park, 2008). Implementations of such ITSs are found in (a) adaptive hypermedia systems (AHSs) which combine adaptive instructional systems and hypermedia-based systems (Brusilovsky, 2001; Lee & Park, 2008; Vandewaetere, 2011), (b) affective artificial intelligence in education (AIED) to detect and intelligently manage the affective dimension of the learner (Blanchard, Volfson, Hong, & Lajoie, 2009), (c) Web-based AHSs that adapt to the goals, interests, and knowledge of individual users (Brusilovsky, 2007), (d) intelligent simulation learning environments with advanced help, hints, explanations and tutoring facilities (de Jong, 1991), and (e) sophisticated online courses that incorporate intelligent tutoring systems (Larreamendy-Joerns & Leinhardt, 2006).

Notwithstanding large investments and refined adaptivity, the ITS movement was in decline. Firstly, ITSs can model procedural skill acquisition but they show limitations in simulating student's complex cognitive processes and situated activity. Secondly, computer-based tutoring systems resulted in many highly structured, directive systems due to the limitations of ITSs to simulate ill-structured or not-rule-based domains (Shute & Psotka, 1996). The consequence is that if computer simulation is impossible, then so is intelligent tutoring. This led Kintsch (1991) to launch the idea of "unintelligent" tutoring in which a tutor should not do all the planning and monitoring because these are activities that students must perform in order to learn. In this view, computers tools, though not artificially intelligent, can play a role to support mindful processes in students (Derry & Lajoie, 1993; Jonassen, 2003; Jonassen & Reeves, 1996; Salomon, Perkins, & Globerson, 1991).

Computer-Enhanced Learning Environments and Learner Support

Transition from instructional materials or programs to learning environments brings about a shift in the locus of control from system to learner which influences the role of system intelligence to support the learner (Chung & Reigeluth, 1992; van Joolingen, 1999). Locus of control can be classified as external (program control), internal (learner control) or shared (Corbalan, Kester, & van Merriënboer, 2008; Elen, 1995; Hannafin, 1984; Lawless & Brown, 1997). In contrast to ITSs as a mode of program-based guidance, learning environments allow learners to reify a learning process while maintaining task complexity (Bereiter & Scardamalia, 2006; Collins, 1996; Zucchermaglio, 1993). Learner control allows learners to make instructional decisions on support needed and content to be covered, choosing the estimated optimal level of difficulty, sequencing a learning path, regulating both the kind and speed of presentation, and defining the amount of information they want to process (Dalgarno, 2001; Merrill, 1984; Vandewaetere, 2011).

Multiple descriptions of constructivism suggest divergent ways to interpret and operationalize learner support. Discovery learning, problem-based learning, inquiry learning, experiential learning and constructivist learning are versions of open learning that leads to the perception that almost unlimited control can be given to students (Bednar, Cunningham, Duffy, & Perry, 1991; Honebein, Duffy, & Fishman, 1993; Kirschner, Sweller, & Clark, 2006). This view is rooted in the work of radical constructivists such as Papert (1980) who points to the paradox that new technologies, instead of creating opportunities for the exercise of qualitative thinking, tend to reinforce educational methods whose very existence reflect the limitation of the pre-computer period. In his view, based on his collaboration with Piaget, learning as self-discovery with Logo as a tool can occur without being taught. His strong constructivist position holds that "In the Logo environment … the child is in control: The child programs the computer. And in teaching the computer how to think, children embark on an exploration about how they themselves think" (p. 19). In his opinion, the acquisition and transfer of programming skills induced by Logo would happen to the pupils (De Corte, Verschaffel, Schrooten, & Olivié, 1993). Studies on that cognitive-effects hypothesis of Logo on children did not deliver positive results (De Corte, 1996). Most researchers share the viewpoint that systematic guidance and even direct instruction needs to be embedded in the program with ample room for exploration. In his reaction to the findings, Papert (1987) ascribes the criticism that Logo did not deliver what it promised to a technocentrist, rigourous model of research: "The finding as stated has no force whatsoever if you see Logo not as a treatment but as a cultural element—something that can be powerful when it is integrated into a culture but is simply isolated technical knowledge when it is not" (p. 24). This illustrates the lasting problem with constructivism and all its derivatives as an ideology as opposed to a learning theory. Even in a constructivist framework, students have goals to pursue (Clark, Kirschner, & Sweller, 2012; Winn, 1993), be they externally or internally generated.

More moderate conceptions of control can be found with learners as partners in distributed intelligence to enhance cognitive and metacognitive knowledge and strategies (Salomon et al., 1991). Examples of constructivist learning environments with explicit learner support are cognitive apprenticeship and situated cognition (Collins, Brown, & Newman, 1989), anchored instruction (Cognition and Technology Group at Vanderbilt, 1993), and simulation learning environments (de Jong, 1991). They contain advanced help, hints, modeling, coaching, fading, articulation, reflection, and exploration to support the process of increasing learner control. In order to counter helplessness in multimedia, standard pop-up help systems, animated guides or intelligent agents that monitor browsing patterns of learners are designed (Dalgarno, 2001).

Learner support has been realized in different computer-based learning contexts from which two are exemplified: (a) use of computer tools that originated outside education (De Corte et al., 1996; Duffy et al., 1993), and (b) dedicated tools embedded in the environment (e.g., pedagogical agents) (Clarebout, Elen, Johnson, & Shaw, 2002). Publicly available computer tools have been inserted into many learning environments (e.g., word processors, calculators, spreadsheets, database programs, drawing and composition programs) to free students from the intellectual burden of lower-level operations, present a familiar structure for performing a process, and trace states and processes so as to contribute to the quality of a student's thinking and learning (Jonassen, 1992). The supply of tools has been enlarged with WebQuests, simulations and games, micro-worlds, blogs, and wikis (Molenda, 2008), and social media (Säljö, 2010) that allow for high levels of interactivity, interactive data processing, symbol transformation, graphic rendering, information storage and retrieval, and communication (Dalgarno, 2001; Kozma, 2000; Mayer, 2010).

Animated pedagogical agents illustrate endeavors to embed learner support in interactive learning environments to enable the system to engage and motivate students by adapting support to individual students and providing students with nonverbal feedback (Johnson, Rickel, & Lester, 2000). Functionalities of learning support delivered by animated pedagogical agents include supplanting, scaffolding, demonstrating, modeling, coaching and testing, but metacognitive support is lacking (Clarebout et al., 2002). A possible explanation for the absence of metacognitive support is that the design of pedagogical agents stems from the ITS tradition with a strong focus on domain specific knowledge and single solution procedural tasks (Clarebout et al., 2002).

Open-Ended Computer Environments: Conditions to Be Met by Learners

Advances in computer technology and multimedia allow learning experiences with authentic, real-world problems in which learners have control over activities, tools and resources (Reiser, 2001). When constructivism is considered to be a learning theory, most authors interpret it as individuals who have to create their own new understandings (Resnick, 1989) though this does not necessarily imply unguided or minimally guided learning (Mayer, 2004; Winn, 1993). Learning environments are goal oriented, which makes learner's self-regulation and external support crucially dependent upon a student's ability. Student use of support in open learning environments is not an objective nor an external measure, but it is mediated by many characteristics and processes such as prior knowledge of subject matter, self-regulating capacity and perspectives on learning environments and support (Elen & Lowyck, 1998; Lowyck & Elen, 1994). High achievers who are knowledgeable about a subject-matter area can benefit from a high degree of learner control whereas learners who lack knowledge about the structure of the domain and metacognitive knowledge and strategies make poor choices (Collins, 1996). Initial schema development and knowledge acquisition normally must be guided more than advanced knowledge acquisition since a domain for which no properly developed schemata have yet been constructed is not likely to lead to satisfactory knowledge acquisition at all (Jonassen et al., 1993). Freedom of movement in hypermedia can cause inexperienced learners to get lost in hyperspace (Spiro et al. 1992). Functionalities of learning environments, including learner support, seem effective when learners are in tune with the intentions of the system and make use of available support (Winne, 2004). Students do not react to objective or nominal stimuli but to transformed, interpreted stimuli which commonly leads to a suboptimal use of instructional interventions (Lowyck, Lehtinen, & Elen, 2004). Students' perspectives on learning environments and their epistemological beliefs (Bromme, Pieschl, & Stahl, 2010) may affect outcomes. Gerjets and Hesse (2004) hypothesize that a multiplicity of factors besides the attributes of the learning environment may play a role (e.g., knowledge prerequisites, learning styles, learner preferences, motivational orientations, attitudes, epistemological beliefs, and instructional conceptions). This emphasizes the role of student's perspectives, perceptions and instructional cognition that mediate between a designed computer-enhanced environment and student's use of it.

Summary

Learner support in technology rich environments is crucial for learning. Depending upon learning theories and available technologies, different kinds of scaffolds have been designed. CAI only used linear sequences, a limitation that has been overcome in ICAI and ITSs. The advent of cognitive and socio-constructivist approaches shifted the focus from program control to learner and shared control. The complexity of theoretical frameworks and operational interventions results in many different support tools. The expectation that open-ended learning environments in and of themselves would result in learning is questionable. The zone of proximal development concept needs to be considered. A technological learning environment is not effective by itself; it has to be adopted by learners in line with their ability, self-management and perspectives on technological learning environments.

Observation 5: Learning Theories and Findings Represent a Fuzzy Mixture of Principles and Applications

The proposition that a science of learning is fundamental to educational technology has been broadly accepted but it is unclear how bridging both fields can be realized. There are, however, arguments to assert that a direct transfer of theory into practice can no longer be expected. Firstly, the nature of learning sciences and instructional technology reflects two separate endeavors with different conceptual frameworks, methods and goals, often labeled as fundamental versus applied which brings Glaser to contend that "the progress of basic science does not insure systematic and fruitful interplay between basic knowledge, applied research, and subsequent technology" (Glaser, 1962, p. 3). Learning theories build a descriptive knowledge base while educational technology needs theoretically valid prescriptions to optimize learning (Elen, 1995). Secondly, building a unified base of knowledge about learning seems unrealistic since successive learning theories show noncumulative characteristics (Elen & Clarebout, 2008) and new technologies have a tendency to get disconnected from findings obtained with older technologies (Hannafin & Young, 2008). Though learning theories as an emerging set of notions rather than as a set of empirical findings and microtheories can help us to understand complex systems (Calfee, 1981), they are mostly used as a source of verified instructional strategies, tactics and techniques. Behaviorism, for example, is grounded in experimental psychology that delivers laboratory findings, and early information processing theory is based on rich data about individual problem solving, both with high internal validity. Constructivism and socio-constructivism find their origins in externally valid ecological settings that reflect multiple perspectives, which renders theories complex, multifaceted and divergent. The former theories (behaviorism and cognitivism) resemble rivers flowing in a riverbed while the latter (constructivism and socio-constructivism) resemble a river delta spreading out into many channels.

Learning Theories, Findings, and Principles

Theories supply findings that are the starting point for applied research and the development of instructional principles and devices (Ertmer & Newby, 1993; Glaser, 1962). A principle or basic method reflects a relationship that is always true under appropriate conditions regardless of program or practice prescribed by a given theory or model (Merrill, 2002). A principle makes a statement about the outcomes instruction aims at, the conditions required, and the methods that can be used (Winn, 1993). Evolution of learning theories, findings, and principles reflect different transitions from theory into practice, ranging from convergent to divergent.

Behaviorist Learning Theories, Findings, and Principles

Behavioral theory focuses on basic laws of behavior modification. From experimental behaviorist learning theory it was expected that principles based on the analysis of simple performances tested in laboratory conditions could be extrapolated to complex forms of learning (Glaser & Bassok, 1989). Skinnerian operant or instrumental conditioning based on the relationship between stimuli that precede a response (antecedents), stimuli that follow a response (consequences) and the response (operant) itself has been broadly accepted in instructional technology (Winn, 2004). Reinforcement, contiguity and repetition are pivotal in the acquisition of behavior (Burton et al., 1996) which can easily be translated into behavioral control principles. These principles led to agreed upon specifications for instructional materials like analysis of terminal behaviors, content, objectives, criteria-referenced assessment, learner and behavior characteristics, sequencing of content from simple to complex, and frame composition (Andrews & Goodson, 1980; Ertmer & Newby, 1993; Lockee et al., 2004; Montague & Wulfeck, 1986, Tennyson, 2010, Winn, 1993). Programmed instruction and CAI are organized in small, easy steps to let the learner start from an initial skill level and gradually master a task while reducing prompting cues along the path to mastery. More evidence has been collected on the prompting aspect rather than the fading aspect (Lumsdaine, 1963).

Despite intensive and lasting efforts to implement behavioral principles in instructional environments, the narrow focus on links between stimulus and response led to a reductionist and fragmented perspective. However, criticism should not only be directed at the behavioral foundation but also at the poorly developed software (Cooper, 1993).

Cognitivist Learning Theories, Findings, and Principles

The invalid expectancy that stimulus-response can account for complex human behavior (Tennyson, 2010; Winn, 2004) challenged cognitive learning theory to open the black box of mental activities (Glaser, 1991). Stimulus-response as the unit of behavior is replaced by a cognitive interpretation with emphasis on planning and hierarchical organization of the mind. Early cognitive learning theories focus on problem-solving and information processing based on Miller's work on chunking and the limited capacity of working memory (Miller, 1956) and the TOTE unit "test-operate-test-exit" (Miller, Galanter, & Pribram, 1960). Though problem-solving and information processing are interconnected fields (Newell & Simon, 1972), findings are translated into separate principles for problem-solving and information processing.

Problem-solving theory was initially elaborated for processes of relatively well-structured puzzle-like problems in laboratory settings in which a given state, a goal state and allowable operators are clearly specified (Simon, 1978). This led to the following principled sequence: (a) input translation that produces a mental representation, (b) selection of a particular problem-solving method, (c) application of the selected method, (d) termination of the method execution, and (e) introduction of new problems (Newell & Simon, 1972). Studies on complex problem solving revealed some core instructional principles, such as (a) develop skills within specific domains rather than as general heuristics (domain-specific), (b) restrict problem-solving skills to a limited range of applicability (near-transfer principle), and (c) integrate different kinds of knowledge within guided problem-solving tasks (integration principle) (Mayer & Wittrock, 2006). These principles can be used in designing micro-worlds or simulations but they hold no indication how to link principles to tools. Translation of findings into principles and instructional technology is highly dependent on an instructional designer's decisions and available technologies.

Information processing systems describe how people perceive, store, integrate, retrieve, and use information. Findings from information processing theory mirror principles for educational technology. They focus on the load that performing a task causes to a learner's cognitive system (Mayer, 2010; Paas & van Merriënboer, 1994; van Merriënboer & Sweller, 2005). Cognitive load theory is based on assumptions about dual-coding (Paivio, 1986), limited working memory and chunking (Miller, 1956), and cognitive processing for meaningful learning (Mayer & Moreno, 2003). Examples of such principles are as follows: (a) if the visual channel is overloaded, move some essential processing from the visual to the auditory channel; (b) if both visual and auditory channels are overloaded, use segmenting and pre-training; (c) if one or two channels' overload is caused by extraneous material, use weeding and signaling, and if caused by confusing presentations, align and eliminate redundancy; (d) if one or both channels are overloaded by representational holding, synchronizing and individualizing are useful (Mayer & Moreno, 2003). These principles are close to the information processing theory and can be empirically tested (van Merriënboer & Sweller, 2005).

The cognitive orientation effectuated a shift from materials to be presented in an instructional system to students' goal-oriented and self-regulated processes and dialogue with the instructional design system (Cooper, 1993; Merrill, Kowalis, & Wilson, 1981; Merrill, Li, & Jones, 1990; Tennyson, 1992). This shift leads to more general principles to build cognitive learning environments, like activation of learner's involvement in the learning process through learner control, self-monitoring, revising techniques, cognitive task analysis procedures, use of cognitive strategies, and allowing students to link prior and new knowledge (Ertmer & Newby, 1993). In addition, theories and concomitant principles are dependent on evolutions in technology. While, for example, early attempts to implement cognitively oriented instruction in technology tools were inappropriate or ineffective, increased hardware speed and capacity allowed us to implement cognitive-based learning using hypertext, hypermedia, expert systems, and so on (Cooper, 1993).

(Socio-) constructivist Learning Theories, Findings, and Principles

Information processing adapts an objectivist epistemology and represents a mechanistic view of learning with ready recall of information and smooth execution of procedures (Perkins, 1991). Increasing complexity and situatedness of learning led to dissatisfaction with the computational view of cognition and the restriction of learning to internal mental representations. This leads to a constructivist perspective on learning as the creation of meaning based on experience-in-context (Bednar et al., 1991; Duffy et al., 1993). Constructivism as an umbrella term holds many perspectives and approaches, including situated cognition, realistic learning environments, social negotiation, multiple perspectives, and self-awareness of the knowledge-production processes (Driscoll, 2000). Any analysis of constructivism is difficult because there is a great range of ideas and a variety of theoretical positions and differences in perception of the instructional implications of this basic tenet. In addition, "the move away from the computational view brought about the move away from learning and cognition as the central focus of educational research in *any* form" (Winn, 2004, p. 80).

Principles deduced from constructive theories are numerous and divergent. Though characteristics of constructive learning as active, constructive, cumulative, collaborative, situated and goal directed are canonical (Bednar et al., 1991; De Corte, 2010; Shuell, 1988; Simons, 1993), any learning inherently shows this constructive character (Perkins, 1991). Given the divergence in interpretations of constructivism, ranging from radical to moderate (Lowyck & Elen, 1993), a lack of precision in defining principles for instructional interventions makes new prescriptions highly probabilistic (Winn, 1987). Nevertheless, scholars derived constructive principles to guide the design of so-called powerful learning environments. Driscoll (2000), for example, formulates these principles: (a) embed learning in complex, realistic and relevant environments; (b) provide for social negotiation as an integral part of learning; (c) support multiple perspectives and the use of multiple modes of representation; (d) encourage ownership in learning; and (e) nurture self-awareness of the knowledge construction process. Ertmer and Newby (1993) suggest these: (a) anchor learning in meaningful contexts; (b) actively use what is learned; (c) revisit content at different times, in rearranged contexts, for different purposes, and from different conceptual perspectives; (d) develop pattern-recognition skills presenting alternative ways of presenting problems; and (e) present new problems and situations that differ from the conditions of the initial instruction. Merrill (2002) elaborated *first principles* that focus on knowledge building and suggest that learning is promoted when: (a) learners are engaged in solving real-world problems; (b) existing knowledge is activated as a foundation for new knowledge; (c) new knowledge is demonstrated to the learner; (d) new knowledge is applied by the learner; and (e) new knowledge is integrated into the learner's world. These three examples illustrate that generalized principles reflect divergent findings which renders operational advisement almost impossible.

In contrast, the Jasper series (Cognition and Technology Group at Vanderbilt, 1993) use concrete operationalization of principles that involve video-based formats, narratives with realistic problems, generative formats, embedded data designs, problem complexity, pairs of related adventures, and links across the curriculum. These seem to be descriptions of specific types of interactive instructional material rather than theoretically derived and empirically validated prescriptive principles (Elen, 1995). The difficulty of detecting and formulating principles for building constructive learning reveals shortcomings in both theoretical precision and convergent modeling. Jonassen and Reeves (1996) suggest eliminating design principles and leaving design in the hands of learners who use technologies as cognitive tools for analyzing the world, accessing information, interpreting and organizing their personal knowledge, and representing what they know to others (i.e., learning by design or design-based learning). Technologies such as databases, spreadsheets, programming languages, visualization tools, micro-worlds, and many others can be used to support such learning. What is at issue is not constructivism as a theory but the learner's ability to cope with design complexity.

Socio-constructivism adheres to the viewpoint that human activity is influenced by affordances, artifacts, and other people (Hewitt & Scardamalia, 1998). In the broad framework of a sociocultural approach, human activities are seen as socially mediated (Dillenbourg, Baker, Blaye, & O'Malley, 1996; Lowyck & Pöysä, 2001). Socio-constructivism adds theoretical complexity while integrating learning, epistemological, sociological, anthropological, and educational theories (Koschmann, 2001). Winn (2002) offers the following principles for implementing the findings of socio-constructivism: (a) technology may sometimes be a necessary condition for the creation of learning communities but is never a sufficient condition; (b) simply creating an interactive learning environment is not sufficient to bring about learning; (c) practitioners should create a social context for learning in technology-based learning environments; (d) effective learning communities often include experts from outside education; (e) students should be encouraged, when appropriate, to create or modify the learning environment; and (f) partnerships among students, teachers, and researchers should be encouraged. However, these "should" statements are a source of inspiration rather than an account of outcomes of research. CSCL principles include these: (a) support educationally effective peer interactions; (b) integrate different forms of discourse; (c) focus students on communal problems of understanding; (c) promote awareness of participants' contributions; (e) encourage students to build on each other's work; and (f) emphasize the work on the community (Hewitt & Scardamalia, 1998). Again, these principles and suggestions for application of theoretical findings are framed in general terms rather than in concrete links between theory, findings, principles, and prescriptions.

Summary

Evolutions in learning theory are translated into findings and principles that possibly guide the design of technological tools. In most cases, it remains difficult if not impossible to detect a direct link between theory, and its operationalization into technological tools or environments. The transitions between theory, findings, principles, and concrete implementations are problematic. Different research findings lack documentation of the transition steps between descriptive and prescriptive knowledge, which also caused problems in building tools for automated instructional design (Spector, Polson, & Muraida, 1993). Most principles are formulated at a general level, which supposes translation into very concrete situations, environments and tools. Consequently, the expertise of designers, learners, and learner communities will define effectiveness and efficiency of these translation efforts.

Conclusion

The quest for understanding the links between learning and things of learning started from the rather optimistic expectation that a close and natural relationship could be documented. This expectation is suggested by the term "educational technology." However, in-depth scrutiny reveals high complexity in both conceptualization and realization. This led to the decision to represent the complexity in terms of a limited set of observations to guide a critical appraisal of the relationship between learning theories and technology. These observations are subjective, based on selected sources, and aim at further discussion. Within the limits of this approach, a few main conclusions can be drawn.

Firstly, learning theories and technology show internal and autonomous dynamics that lead toward mutual fertilization. Their relationship is interdependent though not parallel, and each can draw inspiration from the other. A tight empirical liaison, however, cannot be created. Ambitions of policy-makers, researchers, and practitioners to innovate education with new learning theories and powerful technologies, yielded a myriad of isolated products, projects, and environments that were expected to impact education, learning and learners in an effective and efficient way. The aim to build evidence-based knowledge about educational technology mostly got stuck in idiosyncratic, divergent, and nebulous frameworks. In contrast, interesting and worthwhile examples of links between learning theories and technology have been found at a more fine-grained level of interaction in which both learning principles and technological characteristics are documented. These seldom led to valid theoretical propositions that transcend the particularity of findings or settings.

Secondly, tuning learning theories to technology and vice versa requires consistency and stability. Both domains show intrinsic constraints that influence modes of interaction. On the one hand, learning theories can call for complex processes that cannot be realized due to the limited capacities of technology, as documented in the case of ITSs. On the other hand, powerful technologies can be used for lower-level learning goals, such as information delivery. In order to foster, the elaboration of a suitable conceptual framework that focuses on interaction variables is urgently needed.

Thirdly, the relationship between learning theories and technology is part of a complex educational system that calls for synergy at the macro-, meso-, and micro-level. In addition, several parts of the system influence the use of technology for learning, which makes learning theories one of several technology partners. Sociological, political, anthropological, epistemological, financial, economic, and organizational and other issues play an important role in an educational system. The question is if and to what degree an interdisciplinary approach supports educational technology theory and development. In the field of educational technology, isolation and balkanization of learning theories and technologies hinder development of a linking discipline.

Fourthly, both learning theories and technology are empty concepts when not connected to actors, such as instructional designers, teachers, and learners. Many aspects of human activity buffer the effectiveness and efficiency of educational technology. Deep understanding of learning theories and technology as well as their relationship is a condition to activate potential interplay and foster mutual fertilization. Teachers and learners need metacognitive instructional knowledge and motivation to tune their (mental) behaviors to the nominal stimuli of the environment or to guide their own process of learning in technology-enhanced learning environments. To put it in a slogan, teachers and learners are co-designers of their learning processes which affect knowledge-construction and management as well as products that result from collaboration in distributed knowledge environments.

Lastly the interplay between learning theories and technology needs a transition science. Learning theories deliver descriptive findings that fill the knowledge base of *knowing that*, while educational technology, if not considered as tools technology is a prescriptive field that defines *knowing how*, to use Ryle's (1949) terminology. Instructional design as a connecting field mediates between knowing that and knowing how. Strange enough, learning theories and technology become disconnected if instructional design does not consider evolutions in learning theories. This is why strong behaviorist principles that originated in early instructional design hindered adaptation of models and principles to more cognitive and constructivist approaches. Hopefully, evolutions in learning theories and technologies will lead to more coherence and synergy than has been illustrated with selections of the literature. This calls for a community that not only designs and develops products and environments but that invests in theory building through continuous refinement of *knowing that* and *knowing how* to bring about synergy in the complex and divergent field of educational technology.

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
T.S. Eliot, Four quartets

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Research Paradigms and Perspectives on Learning

2

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Abstract

What is the most important factor influencing human learning? Different instructional theories give very different answers to this question, because they take different perspectives on learning and thus focus on other desired learning outcomes, other methods affecting learning processes, and other conditions under which learning takes place. This chapter describes how eight prevailing research paradigms have influenced and still strongly influence theory development in the field of educational communications and technology. According to the perspective of Gestalt psychology, the most important factor influencing learning is insight and understanding; according to behaviorism and neo-behaviorism, it is reinforcement; according to developmental psychology, it is the learner's stage of cognitive development; according to cultural-historical theory, it is interaction with the world; according to information processing theory, it is active and deep processing of new information; according to cognitive symbolic theory, it is what the learner already knows; according to cognitive resource models, it is the limited processing capacity of the human mind, and according to social constructivism, it is the social construction of meaning. It is argued that research is typically done within one particular paradigm, but that researchers should be conscious of the fact that paradigms heavily affect their research methods and findings. Moreover, researchers should be open to alternative theories and paradigms because new developments often take place at the interface between paradigms.

Keywords

Research paradigm • Gestalt psychology • Behaviorism • Developmental psychology • Cultural-historical theory • Information processing theory • Symbolic cognitive theory • Cognitive resource theory • Social constructivist theory

Introduction

Instructional theories are concerned with instructional methods that affect learning. Learning refers to the act, process, or experience of gaining knowledge, skills, and attitudes and as such, learning is inherent to all human life. People learn by doing, by exploring, by listening, by reading books, by studying examples, by being rewarded, by discovering, by making and testing predictions, by trial-and-error, by teaching, by abstracting away from concrete experiences, by observing others, by solving problems, by analyzing information, by repetition, by questioning, by paraphrasing information,

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by discussing, by seeing analogies, by making notes, and so forth and so forth. Learning is an extremely broad concept and this makes it hard to answer the question of what the main factors influencing learning are, and thus to identify instructional methods that optimize learning. Taking a particular perspective on learning helps to identify relevant factors. The main question that is answered in this chapter is this: "how do perspectives on learning and research paradigms help researchers in the field of educational communications and technology to develop instructional theories?"

The first section of this chapter takes a closer look at instructional theories which relate instructional methods to learning outcomes and also identify conditions that affect the relationships between methods and outcomes, such as characteristics of the learners, of the learning tasks or learning domain, and of the context in which learning takes place. Different instructional theories typically focus on different sets of desired outcomes, different methods, and different conditions under which learning takes place. The second section explains how the development of theories takes place within particular research paradigms. Eight prevailing paradigms in the field of educational communications and technology are discussed. Within the same paradigm, theories can be compared with each other and theories with the strongest explanatory power are likely to survive. In contrast, theories originating from different paradigms are very hard to compare with each other because they have little in common. Yet, a reconciliation of paradigms might be possible after deep revisions, leading to new developments and research lines. The third Discussion section examines implications for doing research in the field of educational communications and technology.

The Infinite Universe of Instructional Theories

Instructional theories relate instructional methods to each other and to learning processes and learning outcomes. The main elements of instructional theories are thus instructional methods, which specify what the instruction looks like, and instructional outcomes, which specify learning outcomes and processes associated with these instructional methods. A further common distinction is between descriptive instructional theories, which primarily explain the relationships between instructional methods and learning outcomes or processes, and instructional design theories, which prescribe the best instructional methods helping learners to reach desired outcomes (also called "prescriptive" theories). Most instructional theories distinguish different categories of instructional methods or deal with only one or a few of those categories. Reigeluth (1983), for example, makes a distinction between (a) organizational methods, which deal with the way in which instruction is arranged and sequenced, (b) delivery strategies, which are concerned with the media that are used to convey information to students, and (c) management strategies, which involve the decisions that help the learners to interact with the activities designed for learning.

Instructional *design* theories typically contain a taxonomy of learning outcomes, which makes it possible to classify the desired outcomes and then to select the most suitable instructional method or methods for helping learners to reach these outcomes. The taxonomies of Bloom and Gagné are still in wide use. In the cognitive domain, Bloom (1956) makes a distinction between knowledge, comprehension, application, analysis, synthesis, and evaluation and he describes suitable methods for teaching each of these outcomes. Gagné (1968) makes a distinction between five domains (perceptual-motor skills, attitudes, verbal information, cognitive strategies, and intellectual skills), and in the intellectual skills domain, he makes a further distinction among discrimination, concrete concepts, defined concepts, rules, and higher-order rules. Like Bloom, he describes instructional methods for helping learners to reach each of these outcomes. More recent instructional design models have further refined taxonomies of learning (e.g., Merrill's performance-content matrix, 1983) or, alternatively, focused on helping students learn highly integrated sets of qualitative different outcomes (i.e., *complex learning*, van Merriënboer, Clark, & de Croock, 2002; van Merriënboer, Kirschner, & Kester, 2003).

Although instructional theories deal with the relationships between instructional methods and learning processes and/or outcomes, it should be stressed that these are never straightforward relations. There are numerous conditions that affect the relationships between methods and outcomes. These conditions deal, for example, with the characteristics of the learners, with the nature of the learning domain or learning tasks, and with the context in which learning takes place. Relevant factors with regard to the learners are prior knowledge, general ability, age, limitations, and learning styles. For example, students with low prior knowledge learn more from studying examples than from solving the equivalent problems, but this pattern is reversed for students with high prior knowledge (Kalyuga, Ayres, Chandler, & Sweller, 2003). Relevant factors with regard to the learning domain or tasks are potential dangers, tools used, the epistemology of the domain, task complexity, and standards. For example, a safe task is better practiced on-the-job than in a simulated environment, but this pattern is reversed for a dangerous task. Finally, relevant factors with regard to the context are available time, money, equipment, culture, and setting (e.g., military, school, business). For example, inquiry methods may be superior to expository methods if ample instructional time is available, but this pattern is reversed with limited instructional time.

In the field of education, there are simply no instructional methods that either work or do not work regardless of conditions.

At best, there are some methods that help learners to reach particular learning outcomes under particular conditions. Berliner refers in his article *Educational research: The hardest science of all* (2002) to this problem as the *ubiquity of interactions*, leading to a combinatorial explosion of factors influencing learning. Consequently, the universe of instructional theories is practically infinite and each instructional theory can only try to describe a small fraction of this whole universe. This is where research paradigms come into play. Such paradigms help us to determine the limits of "our" fraction of the universe, and to develop families of competing instructional theories that can be sensibly compared with each other.

Paradigms and Perspectives on Learning

In his book *The structure of scientific revolutions*, Kuhn (1996) introduced the term paradigm to refer to a set of practices that define a scientific discipline or sub discipline. The practices refer, amongst others, to what is studied, the kind of research questions that are posed and how these are structured, how and with what tools studies are conducted, and how results are analyzed and interpreted. In short, a paradigm is a specific way of viewing reality, excluding alternative ways of viewing reality. Consequently, different paradigms are incommensurable, meaning that no meaningful comparison between them is possible without fundamental modification of the concepts that are an intrinsic part of the paradigms being compared. The same is true for the theories developed within a particular paradigm. Within the same paradigm, theories can compete with each other and the theory with the strongest explanatory power is likely to survive. But theories developed in different paradigms cannot be sensibly compared with each other without far-reaching modifications because they represent fundamentally different ways of looking at reality. Yet, a reconciliation of paradigms after necessary deep revisions may lead to a novel perspective on learning and new research lines.

The remainder of this section briefly discusses eight prevailing paradigms in the field of educational communications and technology and their central perspective on learning: Gestalt psychology, behaviorism and neo-behaviorism, developmental psychology, cultural-historical theory, information processing theory, symbolic cognitive theories, cognitive resource theories, and social constructivism.

Gestalt Psychology

Gestalt psychology originated in the early twentieth century in Germany, with Wertheimer, Koffka, and Kohler as most important representatives (Ash, 1998). The word "Gestalt" refers to the essence of an entity's complete form, and the phrase "the whole is greater than the sum of its parts" is often used when explaining Gestalt theory. Gestalt psychologists analyze perceptual and thinking processes as reorganizing or relating one aspect of a problem situation to another, which may result in structural understanding. This involves restructuring the elements of a problem situation in a new way so that a problem can be solved. In this process, it may be important to give hints to the problem solver to help him or her break out of old ways of organizing the situation (called "Einstellung"). The new way of looking at the problem is accompanied by "insight," the "magical flash" or "Aha-erlebnis" that occurs when the solution suddenly falls into place. Gestalt psychologists hold that positive transfer from one task to another is achieved by arranging learning situations so that a learner can gain insight into the problem to be solved. This type of learning is thought to be permanent and reorganized knowledge may yield deep understanding and thus transfer to new situations.

Luchins (1961) described the implications of Gestalt psychology, and in particular the work of his teacher Max Wertheimer, for the field of educational communications and technology. Wertheimer stressed the importance of thinking about problems as a whole and introduced the distinction between productive thinking, which is an unplanned response to situations and environmental interactions yielding insight and understanding, and reproductive thinking, which is solving a problem with previous experiences and what is already known. Productive thinking is seen as the most important goal of education (*see* Wertheimer, 1982). Central to Wertheimer's approach is that learners are conceptualized as active constructors of knowledge rather than passive recipients of information; they actively seek to make sense of the environment by imposing structure and order on stimuli encountered through direct perception and experience. In this view, instruction and teaching should help to "… illustrate clear-cut structures as well as various degrees of structurization; present hints as to the next step in proceeding; pace the learning; illustrate required elements; point to gaps in the learning process, and illustrate sensible, productive ways of dealing with a particular task in contrast to stupid ways" (Luchins, 1961, p. 27). If researchers working in the Gestalt tradition were asked what the most important factor influencing learning is, their answer would be: "*reaching insight and understanding through restructuring*."

Behaviorism and Neo-behaviorism

During the first part of the twentieth century, partly in parallel with the florescence of Gestalt psychology in Europe, the intellectual climate in the USA emphasized the individual's possibilities to develop and achieve great things (the American Dream).

The idea that behavior is malleable and education can foster excellence made learning one of the paramount concerns of American psychology. According to behaviorism, which was flourishing in those days, learning at all levels, be it a monkey learning to collect candy by pushing a lever, or a child in elementary school learning to subtract, is guided by a set of basic laws. Two of these main laws are termed classical conditioning and operant conditioning. Classical conditioning refers to the phenomenon that a neutral stimulus (a bell) can lead to an automatic response (salivation in a dog) after it is associated a number of times with a stimulus that in itself triggers the automatic response (food). Ivan Pavlov (1927), the discoverer of this phenomenon, termed this automatically learned association a conditioned reflex. In contrast, operant conditioning happens when the learner's behavior is stimulated (usually referred to as reinforced) by a positive outcome, or is punished by a negative outcome (Thorndike, 1911). Consider a cat inside a cage trying to get out. It shows all sorts of random behavior, for example, biting the bars, jumping up and down, and pushing a lever. The latter behavior opens the cage, but only after repeated execution of that behavior is there enough reinforcement for the cat to learn the association between the lever and the opening of the cage. Skinner (1938) insisted on a sharp distinction between classical conditioning and operant conditioning; in the former the conditioned response is set off automatically by an external stimulus, whereas in the latter behavior is voluntarily executed by the learner.

Behaviorists agreed that most of learning is guided by these relatively simple laws, and that cognitive processes played a minor role, if any role at all. They viewed the child's mind as a blank slate, and emphasized the all-decisive effect of the environment (Fontana, 1984). Reinforcement, and to a lesser extent punishment, shapes learning and should be used by educators to create desired behavior and prevent unwanted behavior. In the field of educational communications and technology, *programmed learning* was based on behaviorist insights (Skinner, 1968). It consists of small learning steps ("frames") that the learner goes through in a self-paced way. Each frame contains a segment of information and a question on which the learner will be provided feedback. Behaviorists' answer to the question what the most important factor influencing learning is, would simply be: "*Reinforcement!*"

Developmental Psychology

The most influential scientist in the history of developmental psychology still is Jean Piaget. He was the first to study what is now termed cognitive development, focusing on how children learn to understand the world and how their cognitive abilities expand during childhood. He was influenced by Gestalt psychology and its study of how structural understanding develops. His theory departed from the idea that cognitive development follows qualitatively different stages, each with its own distinctive characteristics. Until then, children were mainly viewed as miniature adults, but Piaget created room for the idea of a separate life phase. Piaget described four developmental stages, following a similar age line across individuals (Piaget & Inhelder, 1962). During the first stage, the sensorimotor stage (0–2 years), children learn through sensorimotor experiences, e.g., seeing, kicking, and hitting objects. Children learn to realize that their actions can influence the world, and by the end of this stage they have acquired the ability to mentally represent objects in their heads. Children in the preoperational stage (2–7 years) show an enormous increase in the ability to mentally represent objects, illustrated mostly by the development of language. The third stage, the concrete operational stage (7–11 years), is marked by an increased flexibility of these mental representations; children's thinking becomes more flexible, logical, and organized than before. A major milestone is solving the conservation task: Children understand that the amount of liquid in a glass does not change when poured from a tall glass into a short, wide glass. The final stage, the formal operational stage (11 years and beyond), is characterized by the development of abstract, scientific thinking. Whereas children in the concrete operational stage can reason about objects in the real world, formal operational children are able to do so about abstract situations.

When transferring insights from cognitive development to learning, it is clear that education should be adapted to the characteristics of the specific stage the learner is in. A one-year-old infant should be encouraged to physically stimulate his environment in order to learn. The pre-operational child, moreover, will only learn when confronted with real-life examples involving limited reasoning. The concrete operational child can be challenged with more complex examples, for instance, classifying objects according to a rule, as long as the examples are concrete and close to the child's experiences. Abstract reasoning is reserved for the formal-operational child. Piagetians emphasize active discovery learning, adapted to the child's developmental level. Developmental psychologists would argue that the most important factor influencing learning is: "*the cognitive-developmental stage the learner finds himself in*."

Cultural-Historical Theory

Cultural-historical theory is rooted in dialectical materialism, the official philosophy of Communism claiming that everything is material and that change takes place through the struggle of opposites (i.e., thesis-antithesis-synthesis). Lev Vygotsky (1978) is the founding father of cultural-historical theory in the 1920s. His theory focuses on human development as the interplay between the individual mind and society, as expressed in his famous statement "the mind grows through interaction with other minds." On a broader scale, cultural-historical theory stresses that human beings live and learn in an environment transformed by the activity of prior members of their species; the transformations from one generation to the next generation are the result of the human ability to create and use artifacts. Furthermore, cultural mediators such as words, signs, and symbols enable the development of higher mental functions in this transformative process. As a result, the specific knowledge gained by children in this process also represents the shared knowledge of a culture—a process known as *internalization*. A popular theory in the cultural-historical tradition is activity theory, which was founded by Leont'ev and further developed by Engeström (*see* Engeström, Miettinen, & Punamaki, 1999), who proposes a scheme of activity containing three interacting entities—the individual, the objects and tools, and the community.

With regard to educational communications and technologies, cultural-historical theories stress the importance of social interaction with the world. A central concept in this respect is Vygotsky's zone of proximal development. The basic idea is that children (and adult learners) learn by interacting with the world and with others, that is, by performing meaningful tasks. At the lower limit of the zone of proximal development are tasks that the learner can perform independently; at the upper limit of the zone are the tasks that the learner can only perform thanks to the support and guidance offered by others, such as a teacher, parent, or more experienced peer. Thus, the zone of proximal development captures the skills that are in the process of maturing, and learning is optimized if tasks are in this zone and can be accomplished only thanks to support and guidance provided by others. A closely related concept is scaffolding, meaning that the given support and guidance gradually decreases as learners acquire more knowledge and skills. Over the course of a learning process, a more-skilled person thus adjusts the amount of guidance to fit the learners' current performance. In the cultural-historical perspective, dialogue is an important tool in this process because spontaneous concepts of the learner are then confronted with the rational and more useful concepts of the teacher or a more experienced peer. If researchers in the cultural-historical paradigm were asked what the most important factor influencing learning is, their answer would be "*social interaction with the world and with others*."

Information Processing Theories

The analogy between the human mind and a computer is drawn from information processing theories, which were mainly developed in the 1950s and 1960s. Concepts that are still used daily in psychology, such as memory storage and retrieval, find their origin in the information processing approach to cognition (Broadbent, 1958; Neisser, 1967). Where behaviorism stressed the importance of the environment, the information processing approach puts a strong emphasis on the internal cognitive state of humans, and aimed to study the complexity of their cognitive processes. Information processing theorists viewed the human mind as an information processing device containing distinct components: A sensory register, a short-term memory, and a long-term memory. The sensory register is an extremely short-term buffer of information, long enough to determine (unconsciously) whether information should be passed on to short-term memory or, alternatively, be discarded. Short-term memory is comparable to the central processing unit of a computer, being all that is in the direct and immediate attention of the individual, limited in capacity and duration. Short-term memory integrates information from long-term memory and the current environment. Long-term memory refers to all the knowledge that is stored in the human brain for long-term use. Knowledge in long-term memory that is not currently used is inactive, but can be retrieved and manipulated in short-term memory when necessary.

The implications of information processing theories for education lie in the supposed three-component architecture of the human mind. Educators therefore need to take into account the computer-like structure of the human mind, not only receiving information, but actively processing it as well (Craik & Lockhart, 1972). Grouping information into meaningful parts (referred to as chunking) increases the chances of remembering the information and reduces short-term memory load. Moreover, instruction should focus on rehearsal of information in short-term memory to enable storage in long-term memory. When a learned procedure is rehearsed often enough, it becomes automatized and can be executed without effort. Finally, learners should be stimulated to actively retrieve information from long-term memory when necessary and use it in short-term memory. Information processing theorists would argue that the most important factor influencing learning is: "*the active mental processing of information*."

Symbolic Cognitive Theories

Symbolic cognitive theories build on the computer metaphor introduced by information processing theories, but describe knowledge in such a way that meaning is conveyed. A basic distinction is between models that describe declarative knowledge and models that describe procedural knowledge. Declarative knowledge refers to representations of the outside world and is typically modelled in semantic or propositional networks (Quillian, 1967), which may vary from plain facts, via simple schemas (e.g., concepts, principles), to highly complex schemas (e.g., conceptual or causal models of a complex domain). This notion reflects ideas from schema theory as introduced by Piaget (1975, original work 1929) and Bartlett (1932). Procedural knowledge refers to cognitive processes that operate on these representations; it is typically modelled in productions or cognitive rules (Anderson, 1993), which link particular conditions to cognitive or motor actions (IF condition THEN action). Symbolic cognitive theories make it possible to give a highly detailed description of to-be-learned knowledge in a process of Cognitive Task Analysis (CTA; Clark, Feldon, van Merriënboer, Yates, & Early, 2008) and to develop computer programs that model this knowledge.

An example of an instructional theory largely based on symbolic cognitive theories is van Merriënboer's four-component instructional design model (4C/ID; 1997, 2007). This model describes learning environments aimed at complex learning as built from four components: (1) learning tasks, which provide the backbone of an educational program, (2) supportive information, which provides the information helpful to perform nonroutine aspects of learning tasks (e.g., problem solving, reasoning), (3) procedural information, which provides the just-in-time information helpful to perform routine aspects of learning tasks, and (4) part-task practice, which helps to automate selected routine aspects of learning tasks. Components 1 and 2 are based on theories of schema construction or declarative learning, in particular, models of inductive learning (i.e., learning from different concrete experiences) for learning tasks, and models of elaboration (i.e., learning by connecting new information to what you already know) for supportive information. Components 3 and 4 are based on theories of schema automation or procedural learning, in particular, models of knowledge compilation (i.e., embedding new information in cognitive rules) for procedural information, and models of strengthening (i.e., automating cognitive rules by repetition) for part-task practice. A learning environment built from the four components thus promotes four simultaneous learning processes in a process of complex learning. Those learning processes will be more effective as the learner has more knowledge to begin with, and instructional methods that may be effective for learners with little prior knowledge will often be ineffective for learners with high prior knowledge (i.e., the "expertise reversal effect"; Kalyuga et al., 2003). If researchers working in the cognitive symbolic paradigm were asked what the most important factor influencing learning is, their answer would be similar to the well-known statement of Ausubel (Ausubel, Novak, & Hanesian, 1978): "*The most important factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly*."

Cognitive Resource Theories

Like cognitive symbolic models, cognitive resource theories build on the computer metaphor of the human mind. But in contrast to symbolic cognitive models, resource models do not refer to semantic representations in memory that convey meaning but limit themselves to a specification of human cognitive architecture and, especially, the capacity of memory systems. Most resource models make a distinction between working memory and long-term memory to explain why available cognitive resources for learning and performance are limited. Whereas the capacity of long-term memory is virtually unlimited, working memory is very limited in duration and in capacity. Information stored in working memory and not rehearsed is lost within 30 s (Baddeley, 1992) and the capacity of working memory is limited to Miller's (1956) famous 7 ± 2 elements or, according to more recent findings, even 4 ± 1 element (Cowan, 2001). The interactions between working memory and long-term memory are even more important than the direct processing limitations of working memory itself (Sweller, 2004). The limitations of working memory only apply to new, yet to be learned information that has not been stored in long-term memory. When dealing with previously learned information stored in long-term memory, the limitations disappear because constructed schemas in long-term memory can be handled as one element in working memory.

In the field of instructional design, cognitive load theory (Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005, 2010) is a popular theory based on cognitive resource theories. The main assumption is that effective instruction should limit extraneous or ineffective cognitive load on working memory, so that the available resources can be used for genuine learning, that is, the construction and automation of schemas in long-term memory. One process that causes a high extraneous cognitive load is, for example, conventional problem solving. For novice learners, problem solving is only possible thanks to means-ends analysis, which requires the student to consider differences between the goal state and the given state of the problem, and to search blindly for solution steps to reduce those differences. This process is exceptionally expensive in terms of working memory capacity and bears no relation to schema construction processes concerned with learning to recognize problem states and their associated solution steps. Problem solving and learning to solve problems are thus two very different and incompatible processes! For teaching problem solving, cognitive load researchers devised more effective problems formats such as goal-free problems (Ayres, 1993), worked-out examples (Renkl, 1997), and completion problems (Van Merriënboer, 1990). If researchers working in the cognitive resource paradigm were asked what the most important factor influencing learning is, their answer would be: "*The limited processing capacity of the human mind*."

Social Constructivist Theories

Social constructivism has its roots in developmental psychology (Jean Piaget, 1896–1980†), cultural-historical theory (Lev Vygotsky, 1896–1934†) and, to a somewhat lesser degree, Gestalt psychology (Max Wertheimer, 1880–1943†). Jean Piaget was the first to emphasize the constructive nature of the child's mind: The child actively attempts to construct understanding of the outside world. Wertheimer stressed the importance of productive thinking as a reconstructive act. Vygotsky, who was also influenced by Gestalt psychology, independently came to similar conclusions as Piaget with regard to the importance of constructivist action to promote learning (*see* Dockrell, Smith, & Tomlinson, 1997). Social constructivism deviates from Piaget's idea of constructivism, in that it stresses, like cultural-historical theory, the importance of *social* interaction to achieve understanding (Palincsar, 1998). It argues that knowledge and even our idea of reality arise through social relationships and interactions. That is, everything we know we have learned by communicating and interacting with others, either personally or through multimedia. The social constructivist is interested in how an individual learns as a result of these interactions. Radical constructivism (Von Glasersfeld, 1995) takes these ideas a few steps further, stating that all knowledge is created by the human mind and therefore it is impossible to know to what extent this corresponds to ontological (true) reality.

Social constructivism was developed in the 1990s and is very popular in education and educational research today. It is not surprising that it puts a strong focus on student discussion and learning through multimedia. Many popular educational formats such as problem-based learning and computer supported collaborative learning (CSCL) have their roots in social constructivism. According to social constructivism small or large group discussion increases student motivation, and builds a deeper understanding of what students are learning. It also provides support for self-regulation of learning, as students can test the quality of their knowledge on that of peer students. Jonassen (Jonassen, Carr, & Yueh, 1998) advocates the use of cognitive tools or mindtools from a social-constructivist perspective. Cognitive tools refer to computer tools that are designed to foster information gathering and learning. These include concept mapping software, spreadsheets, but also internet forums and Google. They are preferable for teacher-centered education as they actively engage the learner and improve students' sense of ownership of their knowledge. Social constructivist theory discourages the use of traditional lectures, because of the minimal opportunities for communication and discussion with the teacher and fellow students. According to social constructivism the most important factor influencing learning would be: "*The construction of meaning and knowledge through the interaction with others*."

Discussion and Conclusions

Instructional theories relate instructional methods to each other and to learning processes and learning outcomes. The relations between methods and outcomes are, however, never straightforward. There are numerous conditions that affect the relationships between methods and outcomes: This ubiquity of interactions leads to a combinatorial explosion of factors influencing learning. Consequently, the universe of instructional theories is practically infinite and each instructional theory is dealing with only a small fraction of the whole universe. Scientific paradigms determine which fraction of the universe theories developed within this paradigm are looking at. Eight dominant paradigms in the field of educational communications and technologies were discussed, each with their own perspective on learning and their own focus on one or more particular factors influencing learning. Gestalt psychology focuses on how learners reach *insight and understanding*; behaviorism and neo-behaviorism focus on the effects of *reinforcement* on learning; developmental psychology focuses on the *stage of cognitive development* of the learners; cultural-historical theory focuses on the learners' *interaction with the world*; information processing theory focuses on *active mental processing* by the learners; symbolic cognitive theories focus on the learners' *prior knowledge*; cognitive resource theories focus on the *limited processing capacity* of the human mind, and social constructivism focuses on the *social construction of meaning* by learners.

Because the paradigms and theories developed within these paradigms have little in common, it is often difficult if not impossible to compare them. The different ways of looking at reality may produce different results. For example, researchers working in the neo-behaviorist paradigm report consistent positive results of reinforcement on learning outcomes (e.g., Flora, 2004), while researchers working in the social constructivist paradigm also report negative effects because external reinforcements may harm intrinsic motivation (e.g., Sivan, 1986). Both claims are based on sound research but nevertheless reach different conclusions because research questions, methods, and interpretations of results are fundamentally different. This also makes it difficult to reconcile the different claims (but see Cameron & Pierce, 2002). In this respect, Berliner (2002) also refers to "decade by findings interactions," meaning that results may also be different depending on the period in which the research has been done. For example, in the 1960s sound research was done on differences in achievement motivation between boys and girls. Nowadays, these results are worthless because the feminist revolution has worked its way through society—changes in context have changed the results of the interaction under study.

Whereas different paradigms may have little in common, progress in one particular paradigm is often made by lending ideas from other paradigms. For example, Piaget's developmental psychology is influenced by ideas on structural understanding from Gestalt psychology; cognitive symbolic theories and cognitive resource models both build on information processing theory; cognitive symbolic theories acknowledge the importance of limited working memory and also include ideas from schema theory originally developed by Piaget (1929) and Bartlett (1932), and social constructivist theories include ideas from developmental psychology, cultural-historical theory, and Gestalt psychology. Especially some of the newer paradigms have borrowed from many of the older ones. The influential report *How people learn* (National Research Council, 2000) reflects much of the current thinking in these newer paradigms.

Research paradigms have clear implications for both research and design. Researchers in different paradigms do research on different things because they focus on different learning outcomes, methods, and conditions. Consequently, they will also focus on the design of different instructional measures, such as hints (Gestalt psychology), rewards (behaviorism), discovery learning (developmental psychology), dialogue (cultural historical theory), programmed instruction (information processing theory), learning by doing (symbolic cognitive theories), example-based learning (cognitive resource models), or collaborative knowledge building tools (social constructivism). Yet, although different ways of looking at reality may produce different results, they do not exclude the identification of basic principles in learning, just as a biologist doing research on ecosystems on Earth and an astronomer doing research on the climate on Mars might reach the same conclusions on conditions for life on a planet. Merrill's work on "first principles of instruction" (2002), for example, shows that five principles are quite common over different paradigms, including paradigms that are often contrasted with each other such as symbolic cognitive theories and social constructivist models. The first principles state that learning is promoted when learners: (1) work on meaningful problems, (2) activate previous experience, (3) observe what is to be learned, (4) apply what has been learned, and (5) integrate what has been learned into their everyday life.

What are the implications of the existence of different paradigms and perspectives on learning for doing research in the field of educational communications and technology? First, it should be clear that educational researchers should be conscious of the paradigm they are working in, including its opportunities and limitations. Second, within this paradigm, they should deliberately contribute to theory development because researchers without a theory are like wanderers in the desert and their research results will be blown away like sand. Third, researchers should always have an open mind for research based on competing theories and paradigms, because radically new ideas and perspectives will most likely develop at the interface between paradigms.

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Research-Based Instructional Perspectives

3

Gary R. Morrison and Steven M. Ross

Abstract

Instructional technology research is broad both in terms of topics and explorations of basic and applied research. In this chapter, we examine various types of stimulus materials that instructional technology researchers have used to study different phenomena. Specifically, we discuss and illustrate how the choice of stimulus material (e.g., actual lesson content, pictures, prose, etc.) directly influences the internal validity (rigor) and external validity (generalizability) of the findings. While randomized experiments are considered the so-called gold standard (Slavin, Educational Researcher 37(1):5–14, 2008) of educational research, particularly for evaluating the effectiveness of instructional strategies, these studies may employ artificial or novel stimulus materials that can limit generalization of the results. Since one goal of instructional technology research is to provide evidence that allows the instructional designer to generate heuristics easily applicable (i.e., generalized) to new situations, studies with strong external validity should be highly desired. Similarly, there are also instances where initial studies need to be designed with high internal validity, sometimes at the sacrifice of external validity, to control for extraneous variables. Using selected studies as illustrative examples, this chapter examines how validity has been addressed in instructional technology research.

Keywords

Research • Educational psychology • Educational technology • Stimulus materials • Internal validity • External validity

Introduction

The field of instructional technology began developing a rich knowledge base of research studies focusing on instructional technology with the start of *Audio-Visual Communications Review (AVCR)* in 1954. While the field has mostly avoided meaningless media comparison studies in recent years (Clark, 1983), the breadth of topics continues to grow. Our earlier analysis of research methodologies employed in articles published in AVCR, *Educational Communications and Technology Journal (ECTJ), and Educational Technology Research & Development (ETR&D)* (Ross & Morrison, 1996, 2004) found that the trends in the use of methodologies have changed over time. For example, time series studies dominated the first 10 years of AVCR publication, but have all but disappeared from ETR&D. In contrast, we have seen a steady increase of studies employing true experimental designs that was the dominant methodology from 1973 to 2001. More recently, we have examined the number

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of studies classified as intervention research (Levin, 2004), that is, studies designed to compare two different instructional treatments such as immediate feedback compared to delayed feedback. We found a steady decline (Ross et al., 2008) in intervention studies in ETR&D similar to the trend in educational psychology journals (Hsieh et al., 2005).

In this chapter, we focus on how instructional technology researchers have designed the stimulus materials used in their studies to strengthen either the internal or external validity of findings. For readers who desire a more in-depth discussion of quantitative and qualitative methods, we suggest the various chapters in all four editions of this handbook. In the following section, we start with a brief discussion of internal and external validity issues in instructional technology research. Then, we examine the design of stimulus materials in studies with high internal validity and studies with high external validity. Last, we address the issue of generalization of results in instructional technology studies based on both the choice of stimulus materials and the degree to which the study participants mindfully engage with the material to be learned.

Validity Issues in Instructional Technology Research

Experimental research in education and psychology values studies establishing high internal validity to eliminate any unintended variables influencing the results (Ross & Morrison, 2004). According to Slavin (2008), researchers can further maximize high internal validity by using a randomized assignment of participants to treatments to eliminate systematic error. The quest for high internal validity orients researchers to design experiments in which treatment manipulations can be tightly controlled. In the process, using naturalistic conditions (e.g., real classrooms) becomes challenging, given the many extraneous sources of variance that are likely to operate in those contexts. For example, the extensive research conducted on verbal learning in the 1960s and 1970s largely involved associative learning tasks using simple words and nonsense syllables (Paivio, 1971; Underwood, 1996). With simplicity and artificiality comes greater opportunity for control of the variables.

This orientation directly supports the objectives of the basic educational psychology researcher whose interests lie in testing the generalized theory associated with treatment strategies, independent of the specific methods used in their administration. Educational technology researchers, however, are interested in the interaction of medium and method or instructional strategy, or simply the instructional strategy (Bernard et al., 2004; Bernard et al., 2009; Clark, 2001; Kozma, 1991, 1994; Ullmer, 1994). To learn about this interaction, realistic instruction rather than artificial or contrived instruction needs to be used. In other words, external validity becomes as important a concern as internal validity.

Discussing these issues brings to mind a manuscript that one of us was asked to review a number of years ago for publication in an educational research journal. The author's intent was to compare, using an experimental design, the effects on learning from programmed instruction and computer-based instruction (CBI). To avoid Clark's (1983) criticism of performing a media comparison, i.e., confounding media with instructional strategies, the author decided to make the two treatments as similar as possible in all characteristics except delivery mode. This task essentially involved replicating the exact programmed instruction design in the CBI condition. Not surprisingly, the findings showed no difference between treatments, a direct justification of Clark's position. But, unfortunately, this result (or one showing an actual treatment effect as well) would be meaningless for advancing theory or practice in educational technology. By stripping away the special attributes of a normal CBI lesson (e.g., interaction, sound, adaptive feedback, animation etc.), all that remained were alternative forms of programmed instruction and the unexciting finding, to use Clark's metaphor, that groceries delivered in different, but fundamentally similar ways still have the same nutritional value. Needless to say, this study, with its high internal validity but very low external validity, was evaluated as unsuitable for publication.

Stimulus Materials in Studies with High Internal Validity

Studies in instructional technology research that require high internal validity often focus on attributes of a medium such as on the legibility of projected materials (Adams, Rosemier, & Sleeman, 1965; Snowberg, 1973) or the design of CBI screens and materials (Acker & Klein, 1986; Grabinger, 1983; Morrison, Ross, Schultz, & O'Dell, 1989; Ross, Morrison, & Odell, 1988). Similarly, studies examining imagery (McManis, 1965; Noble, 1952) or exploring how individuals learn relationships from a diagram (Winn & Solomon, 1993) may use an experimental design with high internal validity to control for other variables. When designing these studies, the researchers must decide if internal or external validity is of greater importance. For example, consider the text in Fig. 3.1 which a researcher might use to investigate the emotional meaning of a particular typeface. In the first row, a real word is displayed in the two different

Fig. 3.1 Comparison of two types of stimulus materials

typefaces. If the participants indicated that the typeface on the left was light and elegant, reviewers might question the interpretation because of the word jewelry. Similarly, the word muscle printed in a bold, heavy font would also confound the interpretation of the meaning of the typeface. The second row uses nonsense words that have no meaning and allows the researcher to conclude that any meaning derived from the rating is due to the typeface. The first row of words has high external validity because of the use of real words; however, the words may influence the participants' rating of the typeface. The second row has high internal validity, but generalizing the results raise additional questions for application. Specifically, typefaces are rarely used in the absence of words and phrases having meaning. It thus seems highly probable that the emotional valances determined using nonsense words would vary (perhaps even considerably) when the same typefaces were employed with instructional text or popular literature.

Given these options, instructional technology researchers initially may decide to establish a theoretical construct (e.g., emotional connotation of type) by using the second row of stimuli. Thus, internal validity would be emphasized over external validity for this basic research study. After establishing the construct, they may design applied studies using materials with a high external validity to test the application of the construct in a more realistic context. In the following section, we illustrate these trade-offs by examining several studies that focus on media attributes and the type of stimulus materials they employed.

Using Artificial Materials in Studies of Media Variables

An example of a highly controlled study is one conducted by Snowberg (1973) examining the use of background colors in projected media. One of the concerns expressed by Snowberg was that the selection of colors as backgrounds for the slides offers almost limitless possibilities. To address this problem, Snowberg selected a range of color filters that allowed for replication. Additional neutral filters were combined with the color filters so that each background was of the same brightness or luminance, thus avoiding a difference between background colors. Ten letters for the stimulus materials were taken from a Snellen chart to create a chart similar to those used by optometrist to check visual acuity. By controlling the five colors, providing for brightness control, and using standardized letters; Snowberg was able to isolate the legibility of projected letters on various colored backgrounds. If real words were used, the participants could possibly have identified or guessed the word based on a few letters, thus reducing the number of possible answers. By using individual letters, the participant had to distinguish between letters such H, D, N, O, and C. This controlled study allowed the researcher to examine the media attribute, the effect of background color on letter legibility, while controlling for confounding variables.

While these recommendations provide seemingly useful guidelines for selecting backgrounds for the best legibility, other color background variations could provide more aesthetically pleasing colors and larger more readable text. That is, one would seldom need to use a small (minimal legibility) font with black text on a white background, which was found to be the minimally legible combination. Thus, replicating this basic design using realistic materials and other background colors would be a logical extension of Snowberg's study. For a typical classroom, you might not need maximum legibility, but rather acceptable readability and an aesthetically pleasing display. An applied research study might also determine that attentiveness is also contextually (e.g., schools' colors) or gender (e.g., pink vs. blue as a preference) linked. Nonetheless, Snowberg's findings are valuable for establishing basic legibility principles that are minimally contaminated by extraneous variables.

In another study of legibility, Adams et al. (1965) studied the legibility of typewritten fonts projected on a white background. They also used letters from a Snellen chart and created stimulus slides consisting of five different type sizes ranging from 3/32 to 8/32 of an inch. Participants were elementary school students who were asked to judge the slides from distances of 20, 25, 30, and 40 feet from the screen in a darkened room. Adams et al. concluded the two smaller type sizes should be avoided, particularly if the viewing distance was beyond 20 feet. Findings indicated that letters at least 6/32 to 8/32 of inch (about 14–18 points) should be used.

These two studies (Adams et al., 1965; Snowberg, 1973) address questions of legibility of projected visuals. Both focused on recognizing individual letters (legibility) rather than words (readability) (Craig & Bevington, 2006). The results establish the color combination or letter size with the best legibility. Similarly, both Snowberg (1973) and Adams et al. (1965) have identified the *smallest* font one should use. These studies raise the question of whether a study using realistic words and sentences would produce similar results, especially if it examined larger font sizes rather than the minimum specified. How this question is answered directly bears on the external validity of the original (basic research) findings. For example, a typical classroom would not have the lighting controls used by Snowberg (1973) for either projection or ambient light. Thus, assuming that the brighter ambient lighting in a typical classroom would reduce the contrast between the words and lettering, we might find that a larger font size is needed.

An extension of this research (Aslan, Watson, & Morrison, 2011) is a study in progress in which participants use a paired-comparison technique to select the PowerPoint slide design they most prefer. The slides were designed using 20-, 24-, 28-, and 32-point text with realistic material (bonsai art), but unrelated to the interests of the participants. The researchers were not interested in the smallest legible text, but rather an optimal-sized text. As the font size increases, the number of words and the length of each phrase on a line become shorter. Thus, the contextual support is also reduced (Ross & Morrison, 1989) when font size is increased. As an extension of the basic research studies reviewed, additional studies using realistic materials in natural settings are needed to find the balance between the smallest legible font and a readable font that provides adequate contextual support using aesthetically pleasing color combinations.

Using Artificial Materials to Study Learning

To control for prior knowledge, many studies examining serial learning and imagery have used nonsense words (McManis, 1965; Noble, 1952). Instructional technology researchers have adopted other approaches to control for internal validity in applied research. In a study of the effect of concrete-verbal and visual information on mental imagery, Clark (1978) selected abstract geometric figures for participants to reproduce. Participants were presented either (a) picture only, (b) printed instructions for creating the drawing, (c) audio only instructions, (d) audio with pictures, (e) audio and video of the instructor giving directions, or (f) audio instructions while showing the instructor. Participants then reproduced from memory the drawing described in the stimulus materials. The general hypothesis was that dual channel presentations would be more effective. By using abstract geometric figures that were the equivalent of nonsense words, Clark could increase internal validity by controlling for prior knowledge of the image.

When studying the effectiveness of objectives, overviews, or inserted questions, the stimulus materials require one or more pages of meaningful textual information so the participant can answer test questions. However, the meaningful text introduces a confounding variable that can threaten internal validity as the participants may have relevant prior knowledge. Consider the study by Hannafin, Phillips, Rieber, and Garhart (1987) who examined two different types of orienting strategies on learning. Participants received either a behavioral orienting strategy that directed them to focus on a specific name, place, or date; or a cognitive strategy that directed them to focus on a broader topic such as culture. The control group was advised simply to pay attention to the material. Given the nature of this study, careful consideration was needed for selection of the stimulus material. For example, if they were to select a chapter from a science textbook on the solar system, some students might have prior knowledge they could use to answer the items on the pretest. The use of nonsense words or even a foreign language as used in Ho's (1984) or Winn, Li, and Schill (1991) studies is not practical when students must learn from textual materials.

To reduce the threat to internal validity, Hannafin et al. (1987) used a fictitious story that included realistic scientific, cultural, political, and geographic elements to create a plausible story line. This contrived story allowed participants to apply intact scientific knowledge to a novel topic. Results indicated that the behavioral and cognitive strategies were more effective for factual learning while the control group showed superior performance for inferential learning. Two explanations of these results were offered. First, students revert to their own preferred approach for learning and ignore the recommended strategy. Second, the orienting activities were ineffective because the materials included sound design features that reduced the effectiveness or need for an orienting strategy. By using a fictitious, but realistic scenario Hannafin et al. were able to reduce the threat to internal validity from prior knowledge and increase the external validity by using contrived, but realistic appearing materials.

While artificial stimulus material allows the researcher to control for other variables such as prior knowledge, generalization of the results therefore is more limited. To the degree that instructional technology research is expected to inform practice, an impact that some researchers have questioned (Ross, Morrison, & Lowther, 2010), it would seem the use of realistic material in natural settings would be more valuable in using technology as a teaching and learning tool.

Stimulus Materials in Studies with High External Validity

Examples of progressing from highly controlled to more realistic application contexts come from CBI research. CBI tends to present information on individual screens with the learner having the capability to navigate between screens rather than scrolling through the instruction as one might do with electronic text.

From Basic to Applied Research: Contrasting Internal and External Validity

When an individual screen design (or frame) is used to present the stimulus material or the instruction, there is a limited number of characters or words the designer can include on a single frame much like we are limited to how many characters or words we can type on a single sheet of paper with 1 in. margins and 12 point Times Roman font. Grabinger (1983) was one of the first to study screen design layout for CBI. To control for confounding variables, Grabinger created stimulus screens consisting of x's and o's (e.g., XxxxoooxxxxooooXxxooooxxxoo) to control for any meaning the message might include that could influence the participants preference for the design. Participants were shown two different designs on identical monitors side-by-side and asked to indicate which one they preferred. Results were similar to those for printed instruction (Dair, 1967), indicating a preference for large amounts of white space and screens with sparse amounts of text.

Using Grabinger's (1983) research as a starting point, we conducted several studies to extend the original research to realistic materials. In the first study, Morrison et al. (1989) used realistic stimulus materials to test Grabinger's findings. Several authors in addition to Grabinger suggested the use of white space for CBI screen design as the designer was no longer constrained by properties of the printed page (Allessi & Trollip, 1985; Bork, 1987; Hooper & Hannafin, 1986). However, as the amount of white space increases on the screen, the amount of information decreases requiring the reader to read additional screens to obtain the same amount of information. The first study by Morrison et al. examined learner preferences for screen density when realistic instructional materials were used. A lesson from a unit on measures of central tendency was selected. To allow for replication and application, we used a measure of screen density that calculated the maximum number of characters that could be displayed on a screen and then divided the actual number of characters to arrive at a screen density percentage creating four different density levels. Two designs were shown one at a time in a random order for a total of six pairings.

The results indicated that participants preferred the 31% density screen over the others. It appears that participants desired greater contextual support when viewing realistic materials than when viewing artificial designs that lacked meaning. The Morrison et al. (1989) study extended Grabinger's work through the use of high external validity materials to test the assumptions in a realistic setting. Importantly, it supported somewhat different design principles, namely, that density reduction and contextual support need to be balanced to maximize readability.

Comparing Internal and External Validity in a Single Study

The results of the two previous studies raised additional questions. For example, as the density (i.e., number of words on the screen) increases, the number of screens needed to read the same materials decreases. At first glance, it would seem logical to have the participant review *all* the screens for each density level (one to four screens depending on the density level). However, if the participants tended to select the higher density screens, one might conclude it was the easier choice since they only had to review one or two screens. To determine if the number of screens viewed would influence the preference, two additional treatments were added. In the first treatment, participants *only* viewed the first screen for each density level. In the second treatment, participants were required to review all screens for a density level before making a choice. In this study, Ross, Morrison, and Schultz (1995) compared realistic materials, approximation to English (ATE) (nonsense words with same letter pattern as English), and nonsense notation (x's and o's) used by Grabinger (1983). The realistic materials were the same used by Morrison et al. (1989). Four different screen designs consisting of 53, 31, 26, and 22% density were employed, with each requiring 1, 2, 3, and 4 screens, respectively, to present the full content. The resulting design consisted of three types of text, four density levels, and two screen conditions (first screen only or all screens of the density level). The six comparisons of four density levels for a specific text type (realistic lesson, ATE, or nonsense) were presented in a random order and rated until all three text types were judged by each participant. Overall, the higher density screens were preferred for realistic materials while the lower density screens were preferred for the artificial text (ATE and nonsense). The results confirmed our hypotheses that students wanted more information on a single screen when viewing realistic materials, but preferred more white space when viewing nonrealistic or nonsense materials.

Using Realistic Learning Material to Increase External Validity

Tessmer and Driscoll (1986) investigated the effectiveness of a concept tree and narrative text for learning coordinate concepts with high school students taking physics. Stimulus materials that had multiple related concepts were needed for the study. It would have been extremely difficult to create fictitious stimulus materials of this complexity. Therefore, Tessmer and Driscoll selected a physics unit that the classroom teacher judged as unfamiliar to the students based on past performance. The stimulus materials were then created for each treatment based on realistic materials. The participants were given 20 min to read the treatment materials and then completed an immediate posttest followed by a delayed posttest. Participants in the concept tree treatment performed better on concept classification. Although using realistic material increased the risk that students' prior knowledge and experiences in the physics course would bias treatment effects, it significantly increased the external validity of the study and the implication that the concept tree could be a useful applied instructional strategy.

Another example of a study with high external validity is one conducted by Ross and Anand (1987) which used realistic instructional materials and personalized those materials for one treatment group. Participants were fifth- and sixth-grade students who received stimulus materials that taught the procedures for dividing by fractions. The abstract treatment group received examples and problems that referred to items as quantity, fluid, liquid, and so forth. The concrete treatment group received examples and problems that substituted hypothetical concrete referents such as Bill, Joe, English, artist, etc. In the personalized treatment group, personal information collected from a biographical survey was inserted into the examples and problems so the participant saw his or her name, best friends' names, birth date, pet's name, and favorite candy. Participants in all three treatments received the same examples and problems; only the context used for presenting the examples and problems was modified by substitution of words. The results indicated that students in the personalized treatment performed significantly better on the context subtest and transfer test. By using realistic materials, the researchers provided evidence of the potential effectiveness of the personalization strategy for applied classroom use.

More recent examples of the use of realistic materials include the use of an existing problem-based learning unit from science (Song & Grabowski, 2006), a math unit on addition subtraction developed by the researchers (Kopcha & Sullivan, 2008), and the use of two different math units of which one was a commercial product (Roschelle et al., 2009). By using experimental or quasi-experimental designs, these studies combine moderate to high levels of both internal and external validity.

Realistic Materials and Incentives: Are They Adequate?

As researchers, it is easy (and comforting) to assume that if we use realistic materials that are relevant to our participants, such as a unit on momentum for students in a physics class or a unit on writing objectives for pre-service teachers, they will put forth the same effort to learn as they would if studying for a class. Given this assumption and the contradictory results in the research literature on feedback, we decided to explore whether feedback strategies would operate differently under varied incentive conditions for learning (Morrison, Ross, Gopalakrishnan, & Casey, 1995).

The 246 participants in the feedback study were drawn from two pre-service teacher education courses (Morrison et al., 1995). The instructional materials were designed to be relevant to students' academic preparation by focusing on writing behavioral objectives, the three domains of objectives, and the taxonomy of behavioral objectives. Students from each of the two classes were randomly assigned to one of five feedback treatments including knowledge of correct response (KCR), delayed with immediate knowledge of response (e.g., correctness of answer), answer until correct (AUC), questions with no feedback, no questions or feedback. Participants from the first course were in the performance incentive group as they could use the score from the treatment to receive credit for a required unit on objectives. Participants in the second course were classified as the task incentive group as they received five bonus points for participating in the study. It was predicted that participants in the performance incentive group would show greater motivation to learn and mindfully use the feedback, particularly in the more complex (i.e., KCR and AUC) feedback treatments. This assumption was only partially supported. The performance incentive group did learn more and made greater use of the review opportunities after answering a question. However, differences between groups for selecting the option to review were not significant. When participants complete an artificial learning task as the task-incentive treatment, they may show little interest in mastering content or in using the instructional resources such as feedback. One concern for researchers is how to motivate them to go beyond surface processing of the content and engage in a deeper level of processing that produces meaningful learning (or at least emulates real-life learning processes). While the performance incentive (substitute study performance for a course assignment) in the above study did appear to motivate the performance-incentive group to perform well, it was not enough to promote a deeper level of processing or make extensive use of the feedback. Thus, generalizability to real-life instructional contexts, where there is greater accountability for achievement, may be limited.

Conclusion

In this chapter, we have examined the use of stimulus materials in instructional technology research. Depending on the purpose of the research, the stimulus materials can range from artificial using nonsense symbols, to contrived materials using real words or text, and ultimately to realistic using actual lesson content. The selection of the type of stimulus materials is determined primarily by the focus of the research—verifying basic laws and principles of learning using technology or evaluating the effectiveness of applied instructional strategies using technology. Underlying the particular focus and concomitant selection of stimulus materials is the researcher's emphasis on addressing different types of validity concerns. Basic research studies rely primarily on materials that foster high internal validity by controlling extraneous variables relating to the learner characteristics and the learning context. Applied studies place a greater emphasis on external validity to allow for generalization of the results to real-life learning contexts. It is this trade off that often requires researchers to begin a new area of inquiry with a study emphasizing high internal validity to isolate variables and phenomena. As a subsequent step, the laws and principles supported in the initial basic research are tested in realistic settings to determine their utility for different application contexts.

While the design of stimulus material directly influences the absolute and relative strengths of internal and external validity in a research study, the meaningfulness of the evidence obtained also depends on the degree to which the study participants mindfully engage with the instruction. That is, whether the material to be learned consists of nonsense symbols or material straight from the textbook currently being used, if participants' primary incentive is to earn extra credit points that are noncontingent on performance, both internal validity (i.e., appropriate treatment induction) and external validity (realistic learning conditions) are likely to be compromised. Instructional technology research needs to continue to focus on relevant and quality research that addresses issues relevant to the field and to education in general. Studies are needed that help practitioners solve practical problems. But unless the research designs employed establish sufficient rigor, the results may not accurately reflect the uses and impacts of the technology applications examined (Ross et al., 2010).

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Cousins but Not Twins: Instructional Design and Human Performance Technology in the Workplace

4

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Abstract

Instructional design (ID) and human performance technology (HPT) stem from a common origin in systems thinking and behavioral psychology, but today the two fields employ different research bases, system foci, and methods. To contrast these fields, this chapter presents an idealized and abstracted discussion that examines the theoretical origins of the two fields, briefly describes their similarities, and focuses on their differences in terms of analytical frameworks and methods. We conclude that contemporary practice in most contexts combines elements of ID and HPT, particularly when working in cross-functional teams seeking to improve organizational performance. Practitioners of ID are likely to encounter HPT in their work, and they may be called upon to serve as part of a cross-functional team using HPT as a common conceptual framework.

Keywords

Educational technology • Human performance technology • Instructional design • Instructional designer • Performance-based training • Training

Introduction

While they share commonalities, instructional design (ID) and human performance technology (HPT) employ different research bases, system foci, and methods. Practitioners of ID are likely to encounter HPT in their work, and they may be called upon to serve as part of a cross-functional team using HPT as a common conceptual framework. Some ID professionals have successfully broadened their careers to include both training interventions (using ID) and non-training interventions (using an HPT framework and drawing from other fields). The relationship between the two is sufficiently close that some professional preparation programs in ID also offer HPT electives and concentrations. Other programs focus on HPT, with additional coursework in ID. For all these reasons, it is probably a good idea for ID professionals to have at least some awareness of HPT.

To contrast these fields, this chapter presents an idealized and abstracted discussion that examines the theoretical origins of the two fields, briefly describes their similarities, and focuses on their differences in terms of frameworks and methods. The chapter concludes with a description of a "savvy instructional designer" that combines elements of ID and HPT. To avoid presenting idiosyncratic comparisons as generalities, the chapter employs widely cited ("classic") references that provide a representative view of each field. The authors encourage readers to consult these references for more thorough introductions to HPT.

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Origins of ID and HPT

Historical accounts of the origins of systematic ID in the 1960s typically attribute its roots to a combination of the then-dominant behavioral learning psychology, combined with the metaphorical inspiration of general systems theory. This resulted in the endless variations of the analysis-design-develop-implement-evaluate (ADDIE) model (Molenda, 2003), which IDs came to accept as both

- An analytical framework for systems thinking and design in training and education
- A project management structure for development, implementation, and maintenance

Drawing on educational psychology, educational technology, instructional technology, communications, and related fields, IDs now create instruction for a broad variety of populations in different settings. IDs may support populations in educational settings in K-12 schools, colleges, and universities. IDs may also support workplace populations in business, government, military, and nonprofit settings. Aguinis and Kraiger (2009) define "training" as a systematic approach to learning with the goal of improving individual, team, and organizational effectiveness. They maintain that development refers to the acquisition of new knowledge or skills for purposes of personal growth. As it is difficult to determine where one ends and the other begins, this chapter uses the term "training" to describe any instruction occurring in the workplace. Because there is as yet little documented application of HPT in school settings, this chapter examines ID and HPT in workplace settings and excludes educational settings.

ID and HPT share a common analytical framework drawn from operations research and common origins in behavioral psychology (Definition & Terminology Committee of AECT 2007). Historical accounts of ID often fail to mention that similar efforts at systems thinking and systematic development were taking place in a wide range of fields over the same time. Of particular interest are American industrial training specialists and industrial psychologists, who found useful a similar, ADDIE-like framework for systematic analysis and intervention to improve human performance in organizations (for an early example, *see* Gilbert 1996a, 1996b). According to Rummler (2007), the roots of HPT arose in the 1960s, with publications appearing in the 1970s. These publications include the work of early theorists such as Mager and Pipe (1970), Rummler (1972), Harless (1973), and Gilbert (1996a, 1996b). In time, leaders active in what is now the International Society for Performance Improvement (ISPI) came to refer to the many variations of this framework collectively as HPT (Van Tiem et al. 2004). Practitioners now refer to HPT using a variety of terms, including "workplace learning and performance improvement" (Beich, 2008). In addition to behavioral psychology and disciplines related to ID, HPT draws on additional disciplines ranging from organizational development to process improvement. Unlike the research base supporting ID, empirical research in HPT is largely limited to reporting cases studies consisting of various performance improvement solutions.

Contrasting ID and HPT

In workplace environments, ID and HPT practitioners can share a variety of goals, frameworks, methods, and evaluation strategies while differing in subtle but important ways. Four commonalities are apparent:

- *Evidence-based practices* emerge from application of relevant research, observation (reflective practice), and other credible sources of evidence.
- *Goals, standards, codes of ethics* have been established, associated with respective professional organizations (ASTD, n.d.; ISPI, 2002a). For HPT, two professional organizations have developed formal professional certification programs. The ISPI program produces Certified Performance Technologists (CPTs) based on its standards (ISPI, 2002b). The program from the American Society for Training and Development (ASTD) produces Certified Professionals in Learning and Performance certification (CPLPs) based on its competency model (ASTD, 2008).
- *Systemic and systematic approaches* are common to both fields of practice although they vary in scope, as discussed below.
- *Formative, summative, confirmative evaluation* are considered standard practice in both fields, though with some differences in measurement strategy, as discussed below.

While these commonalities are important, there are also important differences in frameworks and many nuances of method. Table 4.1 summarizes the major contrasts between ID and HPT within the context of the workplace. This section describes each of these important differences.

Frameworks

Research Base

Molenda (2010) traces the evolution of ID theory from roots in behavioral learning theory and cognitive psychology, beginning with Bruner and continuing through the four successive editions of Gagne's *Conditions of Learning* (1985), and on to current cognitive learning theory. He points out that this work rapidly matured from an early focus using programmed instruction and computer-based learning to a more generalizable framework for a technology of teaching which could be instantiated effectively in any medium—even classrooms using nothing beyond the familiar lesson plan and standard curriculum materials.

Table 4.1 A comparison of ID and HPT frameworks and methods

		ID	HPT
Frameworks	Research base	• IDs employ behaviorist, cognitive and constructivist approaches, with behaviorism largely eclipsed • Evolution includes ID theory, methodology, and project management	• HPT practitioners employ largely behavioral approaches, with exceptions lying in the use of cognitive psychology in the area of performance support for knowledge work • Evolution influenced by both ID and other non-training fields
	Systems view	• Instructional systems comprised of learners, objectives, methods, and evaluation (Morrison et al., 2007)	• Performance systems comprised of interacting components operating at multiple levels: individual, team, organization, enterprise, and society • Performance systems may include instructional subsystems
Methods	Core processes	• IDs use different variations of the ADDIE model to create instructional systems • IDs may choose to use rapid prototyping and participative design to decrease development time while improving quality	• HPT practitioners use the HPT model to close gaps between actual and desired performance • Aside from the development of performance support systems and eLearning, HPT practitioners typically do not employ rapid prototyping
	Performance analysis	• Analysis in ID presumes an instructional solution to a given problem or opportunity • Analysis activities include the specification of broad learning goals, learner characteristics and workplace contexts, learning hierarchies, and job tasks	• HPT practitioners begin with understanding the required performance and its organizational setting. They will analyze the organization and the larger environment. They will specify a gap between existing and desired performance and make sure the gap is worth closing before proceeding further
	Cause analysis	• In presuming an instructional solution to a given problem or opportunity, analysis in ID does not investigate causes of a performance gap • The closest that IDs get to cause analysis lies in determining whether learners should be able to use job aids during their training and in the workplace	• Having aligned a performance gap with organizational business goals and determined that the gap is worth closing HPT practitioners will conduct a cause analysis to identify environmental and individual sources of the performance gap • In conducting cause analyses, HPT practitioners use a troubleshooting sequence that investigates environmental sources of the gap before investigating knowledge and other sources of the gap lying in the personal repertory
		• Create effective learning as learning is good and more learning is better. In workplace settings, training serves this learning function	• Deliver workplace performance in ways that meet organizational missions and business goals. In workplace settings, HPTers will employ a solution-agnostic process to ensure they understand performance requirements and causes of performance gaps before they create solutions to close them
	Intervention selection	• Focuses on the selection of training media and perhaps job aids • Training is viewed as the default solution to any gap between actual and desired performance	• HPT practitioners match the interventions they select to the sources of a performance gap arising from a cause analysis • As interventions that address environmental sources of performance gaps tend to be less expensive and faster to create, HPT practitioners will use them in place of interventions that address the personal repertory when they can
	Measuring results	• If conducted, evaluation focuses on the extent to which the training delivered some sort of return on the organization's investment • Isolating effects of training is an important part of a credible evaluation report • Often conducted contrary to Kirkpatrick's and Phillip's guidance to start at higher levels and work backwards	• Isolating out the effects of training, within a larger HPT intervention, interests some HPT practitioners but not others • May use a Kirkpatrick/Phillips model if decision-makers are interested in the return on their investment in training, but will do so in the order these authors recommend, beginning with higher levels and working backward • Will use program evaluation approaches to investigate other questions decision-makers may have

Molenda also traces the development of ID methodology. He attributes its origins to the application of operations research to training development in the military, where the emphasis was on training as part of integrated operational systems, such as weapons systems. Thus, training was provided as part of a larger system that defense contractors delivered to the military. The methodology for this systems view of training was developed at Florida State University as the Instructional Systems Development (ISD) model. The methodology was in itself a systematic method for development of training, which embodied both

- *Project management* principles (such as a work flow using the ADDIE steps)
- *Design processes* intended to proceduralize the best available decision-making principles for application of the emerging technology of instruction

Thus, ISD was originally defined as both a *systems approach* to creating training and a *systematic approach* to managing training development projects. ISD also had the goal of *systematic design* by incorporating procedures for design of the training itself. IDs completed phases and activities that became project deliverables. These deliverables became inputs for subsequent phases and activities.

As HPT branched from ISD, the development of HPT theory followed a substantially different course. Rosenberg, Coscarelli, and Hutchison (1999) state that from ISD, HPT took the systems analysis framework, but it was substantially broadened: they attribute to Mager (1988) the point that "In the HPT suprasystem, instructional technology is a subsystem, and HPT is a subsystem in the overall management suprasystem" (Rosenberg et al., p. 25). Thus, while the focus of ISD was on the training (sub) system within the context of operational systems, the systems framework took HPT in a different direction: HPT's focus is on the entire organization's performance, and within that the performance of work groups and individuals. Work groups range in size from small teams to larger departments to global enterprises.

More recently, while learning theory evolved from a behavioral to a cognitive learning theory perspective, HPT has retained much more of a behavioral orientation (although the Rosenberg et al. discussion of the field's origins does include cognitive engineering). HPT practitioners creating custom software solutions that provide on-demand access to information, advice, tools, and learning also draw on cognitive psychology to create performance support systems. Creating systems that help knowledge workers recognize situations, make decisions, and solve problems, HPT practitioners may use cognitive task analysis to ensure that the user interfaces they create match both the mental models (i.e., "thoughtflow") and workflow that exemplary performers use to complete their job tasks (c.f. Villachica & Stone, 1999; Villachica, Stone, & Endicott, 2006).

The evolution of HPT methodology also diverged from ISD's systematic methodology. In HPT, attention was at first on the major analytical frameworks. Process models of the problem-solving process or the project management system of the sort contemplated by ISD came later, with the work of Mager and Pipe (1970), Rossett (1987), Rosenberg (1990), and Hutchinson (1990). It is probably fair to say that the defining focus of HPT has remained on the analytical frameworks, rather than on standardization of procedural methodology. For example, the standards which define ISPI's CPT are performance-based and do not require the use of any particular methodology (ISPI, 2002b).

The evolutionary trends of HPT development are substantially different from those influencing ID. As HPT practitioners view training as only one of many possible interventions to improve performance, the field has been influenced by a wide range of fields and the interventions they create. Rosenberg et al. (1999) include information technology, ergonomics and human factors, psychometrics, behavioral feedback systems, organizational development, and change management. Each of these fields has had its own influence on the evolution of theory and practice of HPT.

Systems View

The concept of a "system," is a cornerstone in both ID and HPT. Brethower (2006) defines a system as "a collection of elements and relationships held together by a purpose in common" (p. 124). As an example of a system, consider an automobile assembly plant. The plant is made up of a collection of elements (people, machinery, processes, etc.) combined to accomplish the purpose of producing finished automobiles that can be shipped to dealers throughout the world.

Starting with this cornerstone concept, a systems view has three essential characteristics (Anderson & Johnson, 1997; Brethower, 2006; Meadows, 2008):

- *It is holistic*. A systems view attempts to encompass all of the system's elements—both tangible elements (people, buildings, and machinery) and intangible elements (workflow processes, organizational culture, company policies, and safety regulations). However, the system is seen as more than the simple sum of its parts. For example, in the automobile assembly plant, the people cannot produce automobile without the machinery and the machinery cannot produce automobiles without the people.
- *It focuses primarily on the interactions among the elements rather than on the elements themselves*. The tangible and intangible elements of the system interact in ways that are complex, dynamic, and interdependent. Small changes in one element may ripple throughout the entire system, influencing all of the other elements. Elements of

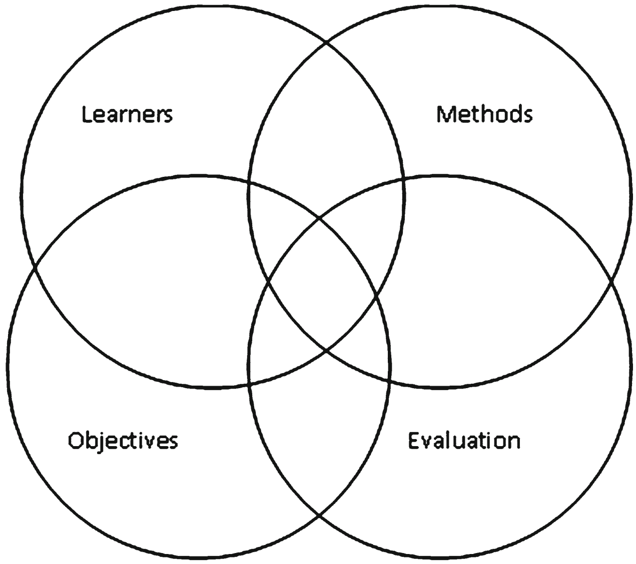

Fig. 4.1 Components of an instructional system (Morrison et al., 2007)

Table 4.2 Gilbert's (1996a, 1996b) behavior engineering model (BEM) (p. 88)

	Information	Instrumentation	Motivation
Environmental supports	*Data*: Information about expectations, guidance during performance, and feedback the extent to which performance met expectations	*Instruments*: Tools, time, and materials required to perform the task	*Incentives*: Financial and nonfinancial rewards for performing the task; consequences for nonperformance
Person's repertory of behavior	*Knowledge* (*and Skills*): The internalized know-how required to perform the task	*Capacity*: Innate physical, cognitive, and emotional capabilities required to perform the task	*Motives*: The interest and desire to perform the task

the system may interact in ways that produce unexpected consequences. For example, in the automobile assembly plant, a new piece of machinery will often result in changes in workflow processes, organizational culture, and safety regulations.

- *It views systems as "nested," with larger systems made up of smaller ones*. For example, one smaller system within the automobile assembly plant is the building, which is in turn, made up of smaller systems—lighting, heating, and ventilation. Conversely, the assembly plant itself is part of a larger system of the manufacturer, which is in turn part of an industry that is part of national and global economies.

Both ID and HPT begin with this systems view. However, they apply it to different systems. ID considers an "instructional system" while HPT considers a broader "performance system." Each system has the same three essential characteristics. However, the purpose and elements of the systems differ. The ID process creates an instructional system, the purpose of which is to promote the acquisition of specified knowledge or skills. Morrison, Ross, and Kemp (2007) present one view of an instructional system that consists of four interdependent elements (*see* Fig. 4.1):

- Learners—characteristics of the individuals who will participate in the instruction
- Objectives—the knowledge or skills the learners are to acquire
- Methods—the means that will be used to help the learners learn
- Evaluation—the means to be used to determine the extent to which learning has occurred

Other descriptions of instructional systems appear within Dick, Carey, and Carey's (2009) ID model, Smith and Ragan's (2005) ID model, Gagne's nine events of instruction (Gagne, Wager, Golas, & Keller, 2005), and Merrill's (2002) first principles of instruction. Each instructional system is made up of a different set of elements. Within in each system the elements interact to promote the acquisition of specified knowledge or skills. In contrast to ID's focus on instructional systems, HPT focuses on producing performance systems that promote the consistent performance of a specified job or task in ways that meet organizational expectations. Gilbert (reprinted in 1996a, 1996b) presents one view of a performance system comprised of six interdependent elements (*see* Table 4.2). According to Gilbert, worthy performance occurs when both environmental supports and a person's repertory of behavior work together to produce consistent performance that meets organizational expectations. This systemic view stresses multiple elements working at different levels in ways that produce competent human performance.

Other performance systems arising from HPT include Kaufman's (1983) organizational elements model, Langdon's (2000) language of work model, Marker's synchronized analysis model (2007), and Rummler's (2006) anatomy of performance model. Each performance system is made up of a different set of elements operating at levels of individuals, work groups, departments, enterprises, and even societies. But in each system the elements interact to promote the consistent performance of a specified job or task towards goals that organizations value.

Methods

Owing to similarities and differences in their frameworks, ID and HPT use a variety of similar methods but sometimes in different ways.

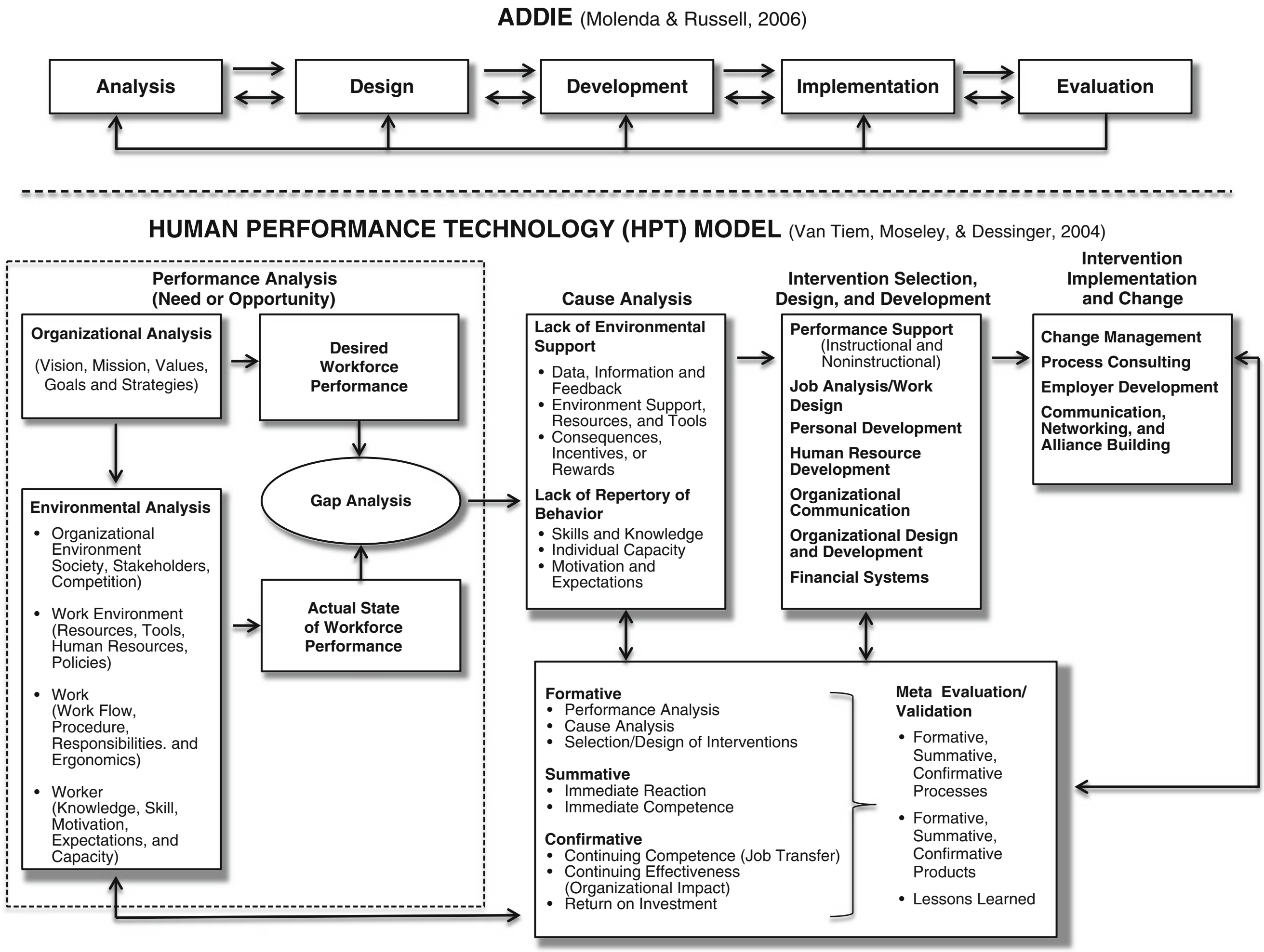

Fig. 4.2 A comparison of ADDIE and HPT models

Core Processes

As depicted in Fig. 4.2, both ADDIE and HPT are linear, systematic models. Both models help practitioners address complexity inherent in these efforts by ordering their phases and component activities. IDs and HPT practitioners completing these phases and activities produce deliverables that become inputs for subsequent phases and activities. Both models employ aspects of analysis, design, development, implementation, and evaluation. While both ADDIE and HPT embed evaluation throughout all phases, HPT can be heavier on analysis, with phases addressing both performance and cause analysis. HPT also specifies both implementation and change management. Where ADDIE separates Design and Development, HPT combines them. An ID creating training will complete all or part of the ADDIE phases. HPT practitioners creating performance improvement systems will complete all or part of the phases and activities comprising the HPT model, depending on the nature of the project they are working on. In both ID and HPT settings, senior project personnel typically complete aspects of analysis, design, and evaluation. Less experienced personnel often address development and implementation. Unfortunately, Both ID and HPT models commonly omit a maintenance phase. This omission makes it impossible to calculate trustworthy life cycle costs and benefits associated with these efforts.

As depicted in their models, both ADDIE and HPT employ linear, “waterfall” core processes, where the completion of one phase leads to the beginning of the next. The exception lies in evaluation, which provides feedback informing all of the phases in the model. ID has seen the emergence of prototyping-based models that employ iterative mock-ups created collaboratively with end users. Baek, Cagiltay, Boling, and Frick (2007) describe how rapid prototyping and participative design overcome the bureaucratic and linear nature of ADDIE, speeding up its otherwise slow design and development processes. Ross et al. (2007) mentions the role of prototyping in design research and natural work settings. Aside from a discussion of rapid application development (RAD) in creating performance support systems (Villachica et al., 2006), rapid prototyping and participative design do not appear in the most recent edition of the *HPT Handbook*.

Performance Analysis

One of the major contrasts between ID and HPT lies in the area of analysis. Typically in response to some formal or informal request for training, IDs completing the analysis phase of the ADDIE model specify broad learning goals as well as learner characteristics and workplace contexts. IDs may also specify learning hierarchies and job tasks during the analysis phase. IDs subsequently use the outputs of the analysis phase to form instructional objectives during the design phase. In contrast, HPT practitioners begin with a performance analysis targeted at specifying the nature of the problem or opportunity. The performance analysis consists of three different analytical activities: organizational analysis, environmental analysis, and gap analysis. This phase of the HPT model ensures practitioners align any gap between actual and desired workplace performance with the organization's missions and business goals at the levels of the organization, work, and worker. HPT practitioners will use a statement like this to describe the performance gap itself:

- What we want our (insert target population here) to do is (insert expected behavior here) at (insert expected measurement here)
- What our (insert target population here) are doing now is (insert existing behavior here) at (insert existing measurement here)

Use of this convention tends to clearly specify the performance problem as well as when it will be solved: when others in the organization meet the desired performance. During the performance analysis, HPT practitioners will also make sure the specified performance gap is worth closing.

Harless (1973) coined the term "front-end analysis" to refer to these activities, and he addressed what is now the performance analysis phase of the HPT model in the first of his 13 "smart questions":

1. Do we have a problem?
2. Do we have a human performance problem?
3. How will we know when the problem is solved?
4. What is the performance problem?
5. Should we allocate resources to solve it (p. 231)?

To answer these questions and complete the performance analysis, HPT practitioners will partner with clients, sponsors, and other stakeholders.

Cause Analysis

In focusing on knowledge, skills, and attitudes, IDs do not employ a cause analysis to investigate the sources of a performance gap. The closest they may get might be to determine whether learners meeting a particular objective might use a job aid (e.g., Mager, 1997; Morrison et al., 2007). In contrast, HPT uses a solution-neutral troubleshooting approach that refrains from specifying a treatment—whether it is training, other changes to environmental support, or other changes to the personal repertory—until the diagnosis of the performance gap is complete. Cause analysis focuses on identifying *all* possible environmental and personal sources of the performance gap, and HPT practitioners expect to see multiple, interacting sources of any given performance gap.

In diagnosing the sources of a gap, HPT practitioners will address potential sources arising from inadequate environmental support before those arising from an inadequacy in people's repertory of behavior. The reason lies in the concept of leverage (Chevalier, 2003, 2006; Gilbert, 1996a, 1996b). Environmental sources of performance gaps tend to be more common, anecdotally accounting (by a common "rule of thumb") for roughly 75 % of all performance gaps (Dean, 1997). HPT practitioners will consider a lack of skills and knowledge as the source of a given performance gap only *after* ruling out all environmental sources of a performance gap.

Intervention Selection

In ID, intervention selection focuses on the selection of training media and perhaps supplementing it with job aids as their default solution. In addition to many workplace executives, managers, and supervisors, IDs tend to presume that learning is good, and more learning is even better. This perception leads to the widespread belief that training is the default solution for any gap between actual and desired performance in the workplace. In contrast, HPT practitioners will investigate all potential sources of a performance gap and then use all potential means to close it (Molenda & Pershing, 2007; Rummler & Brache, 1990). In HPT, sources of performance gaps arising from the cause analysis lead to recommended interventions to close the performance gap. HPT practitioners refrain from recommending solutions (or interventions) until they have identified the source(s) of the performance gap. In specifying only those solutions that address corresponding sources of a performance gap, HPT is "solution agnostic." In selecting interventions associated with multiple causes of performance gaps, HPT practitioners are more likely to create, implement, and maintain solution systems, rather than isolated interventions.

As interventions fixing sources of performance gaps that lie in the environment tend to be faster and less expensive to create, implement, and maintain than those involved in changing behavioral repertories, HPT practitioners tend to view instructional interventions as among the most costly and least desirable of performance solutions. This perception is sharpened by Dean's (1997) anecdotal observation that only 10.5 % of performance gaps arise from a lack of required skills and knowledge, meaning that training that enables learners to acquire such skills is a special case of HPT, appropriate for closing a relatively small number of performance gaps.

Measuring Results

While both ID and HPT emphasize evaluation, the approaches most commonly used differ. In ID, the focus is on training. Perhaps the most commonly used analytical framework is Kirkpatrick's with Phillips' extensions (Kirkpatrick and Kirkpatrick, 2006). The purpose of the model is to demonstrate return on investment for training, using a 4- (or 5-) level analytical framework. However, the top levels of the model have been criticized as difficult to develop, and aimed at the wrong target: isolating the effects of training (Watkins, Leigh, Foshay, & Kaufman, 1998)—a goal of interest to trainers, but often not to the business. In fairness, we believe some of this difficulty comes from the experience of practitioners who often implement the model starting with the lowest level, rather than the highest, and thus find themselves focusing on outcomes which are of least importance. When this happens, the measures used can be highly misleading.

By contrast, the HPT approach resolves from the start the challenge of measuring important outcomes: the focus of front end analysis in HPT is on closing the performance gap with real business consequences to be measured in ways which are meaningful to the client (Moseley and Dessinger, 2010; Winiecki, 2006). There is no intent to isolate the impact of each performance improvement intervention, including training. Thus, development of meaningful business impact measures is not an added, artificial exercise; it is an inherent part of the initial problem definition (Brinkerhoff, 2006; Pershing, 2006). This approach has the added advantage of assuring the sponsorship to gather the data for the measures of results, because they are part of the business' normal work, and not an added, artificial step.

True Confessions: Limitations of the Preceding Comparisons

Thus far this chapter has presented only an abstracted comparison of the "classical" analytical frameworks used by ID and HPT. Both fields are undergoing constant evolution, drawing both on practitioners' reflections and advances in underlying theory. IDs and HPT practitioners constantly adapt these fields to meet their own, clients', and stakeholders' requirements. Accordingly, in any real-world ID or HPT project, the devil is in the details. The authors would like to explore two such issues of evolution and context here: the rise of a cross-disciplinary approach to design thinking and the emergence of savvy IDs who blend elements of ID and HPT in improving workplace performance.

The Rise of Design Thinking

Conversations about the nature of design in instructional systems development (e.g., Boling & Smith, 2007; Ertmer et al., 2008; Rowland, 1993; Silber, 2010) also involve conversations about the design process and design thinking (e.g., Brown, 2008; d.school, 2010; Lawson, 2006; Myerson, 2001). This broad conception of design cuts across

- Disciplines, including architecture, engineering, community planning
- Professions such as graphic design, product design interior design, and textile design (Lawson, 2006)

Jonassen (2004) maintains that design involves ill-structured problem solving in the face of vague goal statements and few constraints. There are multiple, undefined criteria, with no right or wrong way of solving the problem, only better and worse ones.

Elements of design thinking are beginning to make inroads into both ID and HPT. As depicted in Table 4.3, Baek et al. (2007) apply them in their discussion of user-centered design in ID. Villachica and Stone (1998, 2010) have discussed elements of design thinking in creating both instruction and performance support systems based on the use of Martin's (1991) RAD. Readers wishing additional information on this topic may want to review Susan McKenney and Jan Herrington's chapter on Design Research appearing in this Handbook.

The Savvy Instructional Designer

In workplace settings, IDs creating training would be wise to adopt a performance-based approach that mixes elements of ID and HPT (Sims & Koszalka, 2007). This approach lends itself to improved transfer of learned skill and knowledge to workplace. In this setting, training that closes a skill gap removes a barrier to meeting a business goal or enables an organization to meet some aspect of its mission. Training professionals who fail to align their efforts with business goals or consider non-skill sources of performance gaps and non-training solutions proceed at risk, with these factors being the top two reasons contributing to the failure of training and development efforts in the workplace (Phillips & Phillips, 2002). Like their HPT counterparts, savvy IDs align their efforts with meeting the needs of their workplace sponsors in ways that focus on results, take a systems view, add value, and establish partnerships (Addison, Haig, & Kearny, 2009).

A savvy instructional designer:

- Collaborates with others in the organization to
  - Identify performance gaps
  - Align them with missions and business goals to focus on valued performance
  - Determine whether the gaps are worth closing
- Identifies all possible causes of given performance gaps and collaborates with others to address them
  - IDs often address knowledge gaps by creating training and guidance gaps by creating job aids

Table 4.3 Design thinking elements in ID and HPT

Aspect	d.school bootcamp (2010)	Baek et al. (2007)	Villachica and Stone (1998, 2010)
Mindsets	• Show, don't tell • Focus on human values • Craft clarity • Embrace experimentation • Be mindful of process • Bias toward action • Radical collaboration	• User participation • Contextual analysis • Iterative design • Rapid prototyping	• Collaborative analysis and design • Rapid prototyping • Usability testing • Timeboxing • SWAT teams
Phases	• Empathize • Define • Ideate • Prototype • Test	• Not specified	• Alignment • Joint requirements planning • Design reviews • Prototyping • Usability testing

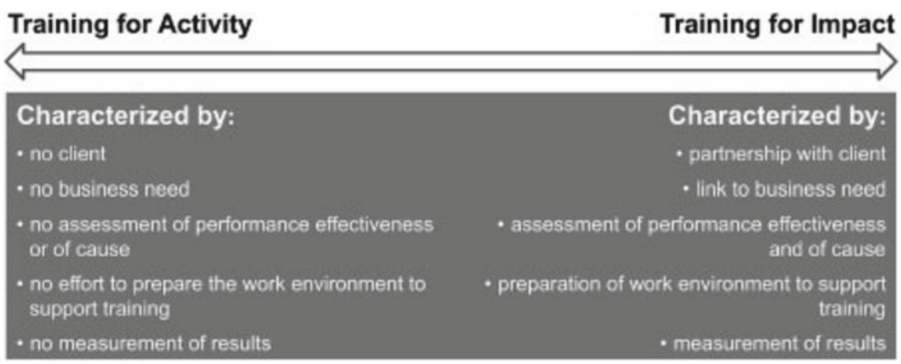

Fig. 4.3 Training for activity and impact. From Robinson and Robinson (1990)

  – IDs partner with other professionals to address other sources of gaps, knowing that the training department is often blamed for any unclosed gap
  – IDs may employ strategies associated with either the performance support or the technology integration literatures. Readers wishing more information about the latter may want to review Mark Lee's chapter on Technology Integration Work Settings appearing in this Handbook.
- Collaborates with others to ensure that training transfers to the workplace. This involves asking for executive and management support for transfer before and after the training (Broad & Newstrom, 1992)
- Partners with others in the organization to ensure that the different components of the solution system integrate in ways that close the gap
- Employs rapid prototyping and participative design to shrink development time while improving quality
- Reports the extent to which the solution system closed the performance gap
- Collaborates with others to conduct needs assessments and evaluations to answer other questions that keep decision-makers up at night

This recommendation for performance-based ID corresponds to Robinson and Robinson's (1990) concept of training for impact. As depicted in Fig. 4.3, a continuum of training approaches lies between training for activity and training for impact. In the former, a requestor typically asks for some sort of training. IDs create the training. Once delivered, the activity is finished. This form of topic-focused instruction often fails to transfer to the workplace. While training for activity is unfortunately commonplace, this approach does not prepare people to perform their jobs. Robinson and Robinson contrast this approach to training that produces a positive impact in the workplace. Performance-based training is designed to produce such a favorable organizational impact.

Robinson and Robinson (2006) later refine this continuum to compare traditional to performance-centered approaches, where the former is characterized by focus on learning produced in a firefighting mode largely independent of collaboration with the client group. In this approach, implemented learning equates with success. In a performance-centered approach, the focus is on what people need to do in the workplace, with learning and other solutions being means to this end. Practitioners of this performance-centered approach are solution-neutral, partnering both proactively and reactively with client groups to identify causes of gaps and potential solutions. In the performance-based approach, success means closing performance gaps. In workplace contexts the practice of ID should be informed by HPT. While the two fields are not twins, they should be cousins in practice.

Conclusion

Clearly, it is conceptually possible to do ID without using an HPT framework, and it is equally possible to do HPT without doing ID. The two fields shared common theoretical roots and methodologies more than a generation ago, but they have different goals and have evolved in very different ways into different professions. That said, it is increasingly common (except perhaps in academic settings) for ID to be done within an HPT framework which coordinates a broad range of training and non-training interventions, using cross-functional teams, and to evaluate the overall success of the project in terms of improved organizational performance, as HPT requires. We believe that (at least in nonacademic organizations), the trend will continue of training departments redefining their mission in organizational performance (HPT) terms. Thus, we believe the fields will continue to cross-fertilize and evolve their theoretical structures and methodologies. For example, the emerging interdisciplinary field of design is an influence on both ID and HPT. However, we believe ID and HPT will remain distinctly different fields of professional practice. The savvy ID practitioner, therefore, should develop the conceptual flexibility to work effectively within an HPT framework, on a multidisciplinary team.

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Implications of Neuroimaging for Educational Research

5

Pavlo D. Antonenko, Tamara van Gog, and Fred Paas

Nicht das Gehirn denkt, sondern wir denken das Gehirn
(The brain does not think, we think the brain.)

Friedrich Nietzsche

Abstract

Neural functions are fundamental to learning, instruction, and performance. Although tremendous progress has been made in neuroscience in the past two decades, its applications in educational research are just beginning to be realized. This review focuses on selected technologies, methods, and findings from neuroscience that have important implications for educational sciences. Specifically, this chapter discusses conceptual and empirical research on the use, implications, and limitations of neuroimaging techniques such as continuous electroencephalography, event-related potentials, and functional magnetic resonance imaging in the domains of language and reading, mathematics learning, problem solving, cognitive load, and affective processes in learning. Neuroimaging has enabled scientists to open "the black box" of neural activity that underlies learning. It seems timely, therefore, to consider how educational researchers may employ the increased understanding of brain function to explore educational questions.

Keywords

Neuroscience • Neuroimaging • EEG • ERP • fMRI • fNIRS

Introduction

Developing learners' cognitive capacities to confront and resolve real-life, cross-disciplinary situations is a key goal of educational research (National Research Council, 2005). Cognitive function has also been a central issue in neuroscience, which examines the complexity of human perception, cognition, emotion, and action based on the neural activity of brain cells. Human brain consists of about 100 billion neurons. Information is transmitted from neuron to neuron via electrical signals passing through the axons and generating the release of chemical neurotransmitters from the neural connectors called synapses (Bear, Connors, & Paradiso, 2006). Analysis of the patterns of neural activity allows scientists to map brain functions associated with performing a variety of

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tasks. The resulting knowledge of the neural structures that underlie macro-level processes, such as perception, attention, cognition, and learning, can be of interest to psychologists and educators.

Since "The Decade of the Brain 1990–2000" (Jones & Mendell, 1999), the study of the brain has been driven by substantial government investments, which resulted in the development of new methods and technologies (e.g., brain–computer interfaces) and research "collaboratories" like the Japan–US Brain Research Cooperative Program and the European Union's Promemoria Consortium (Tosetti, Nagy, & Bernard, 2008). The membership of the Society of Neuroscience has doubled in the past 20 years (Minnery & Fine, 2009), with many of the new members representing fields outside of neuroscience, such as psychology, education, and human factors.

A survey of the recent literature in neuroscience reveals that one of the focus areas of the current research is improving our understanding of cognitive, affective, and social functions of the brain during learning. The implications for education and behavioral sciences generated through this line of inquiry are outlined in the recently created journal "Mind, Brain, & Education" (*Fischer et al., 2007) and publications like "Brain lessons" (Jolles et al., 2006), "Understanding the brain: The birth of a learning science" (*Office of Economic Cooperation and Development, OECD, 2007), "Explorations in learning and the brain" (De Jong et al., 2009), and "Handbook of neuroscience for the behavioral sciences" (*Berntson & Cacioppo, 2009). However, how much of this knowledge is "usable" to educators remains the subject of debate (Fischer, 2009; Goswami, 2009; Varma, McCandliss, & Schwartz, 2008). Even what is considered by many to be the most salient finding in neuroscience—the "critical periods" for synapse formation or synaptogenesis (e.g., Carnegie Task Force, 1996)—has been subjected to well-deserved skepticism and critique in terms of its relevance to informing educational practice (Bruer, 1997, 2006). In this chapter we try to refrain from making irresponsible extrapolations and propagating educational "neuromyths" (OECD, 2007); instead, we focus on describing neuroscience techniques and the findings that the application of those techniques has already generated for the education research community (e.g., De Jong et al., 2009; Goswami, 2006; OECD, 2007) in the domains of language and reading, mathematics learning, problem solving, cognitive load, and affective processes in learning.

A Primer on Neurotechnologies

Much of our brain activity is not available for conscious introspection and neuroscientific evidence has made it clear that nonconscious neural activity is essential for controlling our behavior (Kringelbach, 2009). Empirical research in neuroscience has been driven by methods and technologies that enable researchers to collect data on nonconscious processing and compare these data with observable behavior. The basic assumption in neuroscience research is that tasks make specific demands on the brain and these demands cause changes in the chemical and electrical neural activity. These changes result in a host of physiological responses affecting cerebral blood flow, heart rate, muscle activity, electrodermal responses, eye movements, pupil size, blood pressure, respiration, oxygen consumption, salivation, skin temperature, immune function, endocrine function, and others (*Andreassi, 2007). There are multiple technologies and methods to measure such physiological responses but the techniques that have been most successful in advancing cognitive neuroscience, a branch that is arguably the most relevant to the educational research community, including noninvasive tools of two varieties. They either provide high-resolution spatial information and track changes in cerebral blood flow such as functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS) or tools that provide high-resolution temporal information and assess changes in the electrical activity of the brain—electroencephalography (EEG) and event-related potentials (ERPs).

Functional Magnetic Resonance Imaging

The advent of fMRI in the 1990s enabled neuroscientists to "see" changes in brain activity associated with performing an experimental task. This neurotechnology requires inserting the participant into a scanner with a large, tube-shaped magnet (Fig. 5.1), which creates images of the magnetic resonance signal generated by the protons of water molecules in brain cells. Task performance activates certain brain areas which leads to enhanced oxygen consumption by cells in those areas and therefore enhanced blood flow to those cells. With fMRI changes in the oxygenation state of hemoglobin can be registered. This is called the blood oxygenation level-dependent (BOLD) response, which is the outcome measure used in most fMRI studies. The fine spatial resolution of fMRI (1–3 mm) has allowed neuroscientists to analyze brain activation patterns and link them to cognitive functions ranging from discourse comprehension (Martín-Loeches, Casado, Hernández-Tamames, & Álvarez-Linera, 2008) to mathematical problem solving (Anderson, Betts, Ferris, & Fincham, 2011). Yet, despite the obvious advantages over more direct but also more invasive imaging techniques like positron emission tomography, which relies on the injection of radioactive tracers into the bloodstream which are then tracked, fMRI is not without its drawbacks. While most fMRI scanners allow participants to be presented with different visual, auditory, and kinesthetic stimuli, and to make different actions such as pressing a button or moving a joystick,

Fig. 5.1 Varian 4T fMRI, part of the Brain Imaging Center, Helen Wills Neuroscience Institute at the University of California, Berkeley (public domain, Wikimedia Commons)

participants must remain relatively motionless, which limits the range of behaviors that can be studied (an overt verbal response, for example, results in a small movement of the lower part of the head, which could potentially distort the measurement). Participants also have to wear headphones to shield their ears from noise, and this noise also makes the analysis of overt verbal responses difficult, although methods have been developed to filter out the scanner noise (e.g., Jung, Prasad, Qin, & Anderson, 2005). These issues limit the application of fMRI educational research and render fMRI methods impractical in authentic, in situ settings. Furthermore, the cost ($500,000 and up) and expertise required to maintain the equipment as well as collect and analyze data act as barriers to educational researchers looking to incorporate fMRI into their work.

Functional Near-Infrared Spectroscopy

A lower cost noninvasive alternative to fMRI that is gaining popularity among neuroscientists is fNIRS. Like fMRI, the fNIRS signal reflects the dynamics of cerebral blood flow. Unlike fMRI, this neurotechnology penetrates only a few millimeters below the skull and thus, does not reveal the activity of deeper brain structures. Nevertheless, the higher cognitive functions relevant to the study of learning and instruction such as visual-spatial processing, or executive control, are localized within the superficial layer of brain tissue called the cerebral cortex, which is readily accessible to fNIRS. As most neuroimaging methods, fNIRS has its functional and practical limitations. Unlike PET or fMRI, fNIRS cannot measure deep brain structures and it is limited to measuring cerebral blood flow dynamics in the forehead, as hair can introduce noise into the optical signal. Another weakness of fNIRS is its low temporal resolution, as it takes several seconds for an fNIRS sensor to detect changes in blood in the brain. Finally, since most current research in fNIRS concerns validating the tool itself, extensive applications in cognitive neuroscience conducted with brain imaging techniques such as EEG have yet to be implemented with fNIRS.

Electroencephalography and Event-Related Potentials

Tracking changes in cerebral blood flow is only one of several possible ways to measure brain function. While this group of methods has the advantage of high spatial resolution that allows localizing neural events, methods that track the electrical activity of the brain like EEG and ERPs have the advantage of being sensitive to millisecond differences in electrical activity and therefore of being able to provide evidence on the time course of neural processing. EEG and ERP setups consist of electrodes that are fitted over an individual's scalp to record low-amplitude electrical brain activity at the surface of the skull. Recording of the spontaneous natural rhythms of the brain is called EEG. At present, it is believed that electrical activity in the brain generates at least four distinct rhythms (*Basar, 1999). Figure 5.2 shows that brain waves are a continuum from the large, slow delta waves to smaller and faster (i.e., higher frequency) beta waves. Analysis of the amplitude, frequency, and power of neural oscillations within these brainwave rhythms has furthered our

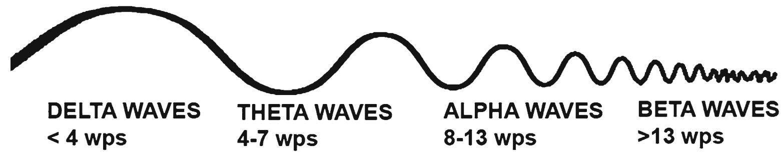

Fig. 5.2 Human brainwave rhythms (waves per second)

understanding of human cognitive architecture and interaction between its components during cognitive tasks. For example, one recent study shows that theta and alpha oscillations during working-memory maintenance predict successful long-term memory encoding (Khader, Jost, Ranganath, & Rosler, 2010). Although the drawbacks of EEG (poor spatial resolution, high susceptibility to electrical noise, and the necessity to conduct multiple trials to isolate the brain activity of interest) limit its utility, recent advances in signal processing and electrode headset design, including wireless EEG, have expanded its range of applications to include research in natural settings like the classroom.

ERPs are measured using EEG and refer to systematic deviations from the natural brainwave rhythms that precede, accompany, or follow events determined by the experimenter. Unlike spontaneous EEG, ERP rhythms are time-locked to particular events designed to study brain function. The different potentials are referred to by a preceding letter indicating polarity followed by the typical latency in milliseconds. For example, P300, N100, P200, etc. mean positive peak at 300 ms, negative peak at 100 ms, and so on. The sequence of observed potentials as well as their latency, amplitude, duration, and distribution are used to understand the cognitive processes underlying the experimental task. For instance, language-related ERP components such as the N400, left anterior negativity (LAN), and P600 have proven useful in understanding the processing of language in children and adults, in native and nonnative language, in normal processing, and in language disorders (Goswami, 2004).

Summary

In summary, measures of cerebral blood flow like fMRI typically have high spatial resolution but relatively poor temporal resolution (5 or more seconds). EEG and ERPs directly measure the brain's electrical activity, yielding high temporal resolution (in the order of milliseconds) but low spatial resolution. As a result, neuroscientists have begun to explore integrated uses of these techniques in order to provide information on both the spatial location and temporal changes in brain activity associated with task performance (e.g., Ullsperger & Debener, 2010).

In order to make effective use of neurotechnologies and link neural activity with educational research, it is important to have a profound understanding of both theories and tools of neuroscience and the cognitive, affective, and social processes that underlie learning. Cognitive neuroscience is a branch of both psychology and neuroscience that uses cognitive theories and evidence from neuroscience to explain and predict cognition and learning based on neural activity. The sections below provide a small yet representative sample of state-of-the-art research in cognitive neuroscience with translatable implications for educational research.

Language and the "Reading Brain"

Learning to read requires the mastery of a collection of complex skills (Mayer, 2008)—morphology (formation of words), orthography (spelling), phonetics (mapping words to sounds), syntax (word order), and semantics (extraction of meaning from words and sentences). In fluent readers, the entire process from visual processing (seeing) to semantic retrieval (understanding) occurs very rapidly, all within about 600 ms (OECD, 2007). Brain imaging research in cognitive neuroscience has made significant strides to advance our understanding of the "reading brain" (Dehaene, 2009). Though certain brain structures are biologically primed for language (e.g., Broca's area and Wernicke's area, 44–45 and 22, respectively, in Fig. 5.3), language acquisition requires the catalyst of experience. There are developmental sensitivities as language circuits are most receptive to particular experience-dependent changes at certain stages of the individual's development. For example, sound discrimination is best developed in the first 10 months of age (Gopnik, Meltzoff, & Kuhl, 1999) and accents are acquired most effectively before 12 years of age (Neville & Bruer, 2001). If the initial exposure to a foreign language occurs between 1 and 3 years of age, grammar is processed by the left hemisphere—as in a native speaker, but when it is delayed, brain imaging reveals an aberrant activation pattern consistent with the behavioral finding that later exposure to a second language leads to significant difficulties with learning grammar (e.g., Fledge & Fletcher, 1992; Neville & Bruer, 2001).

Recent ERP and fMRI studies show that the major systems for reading alphabetic scripts for both children and adults are lateralized to the left hemisphere (Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). The occipital-temporal areas of the brain are most active when processing visual features, letter shapes, and orthography. Activation in these areas also increases with reading skills (Shaywitz

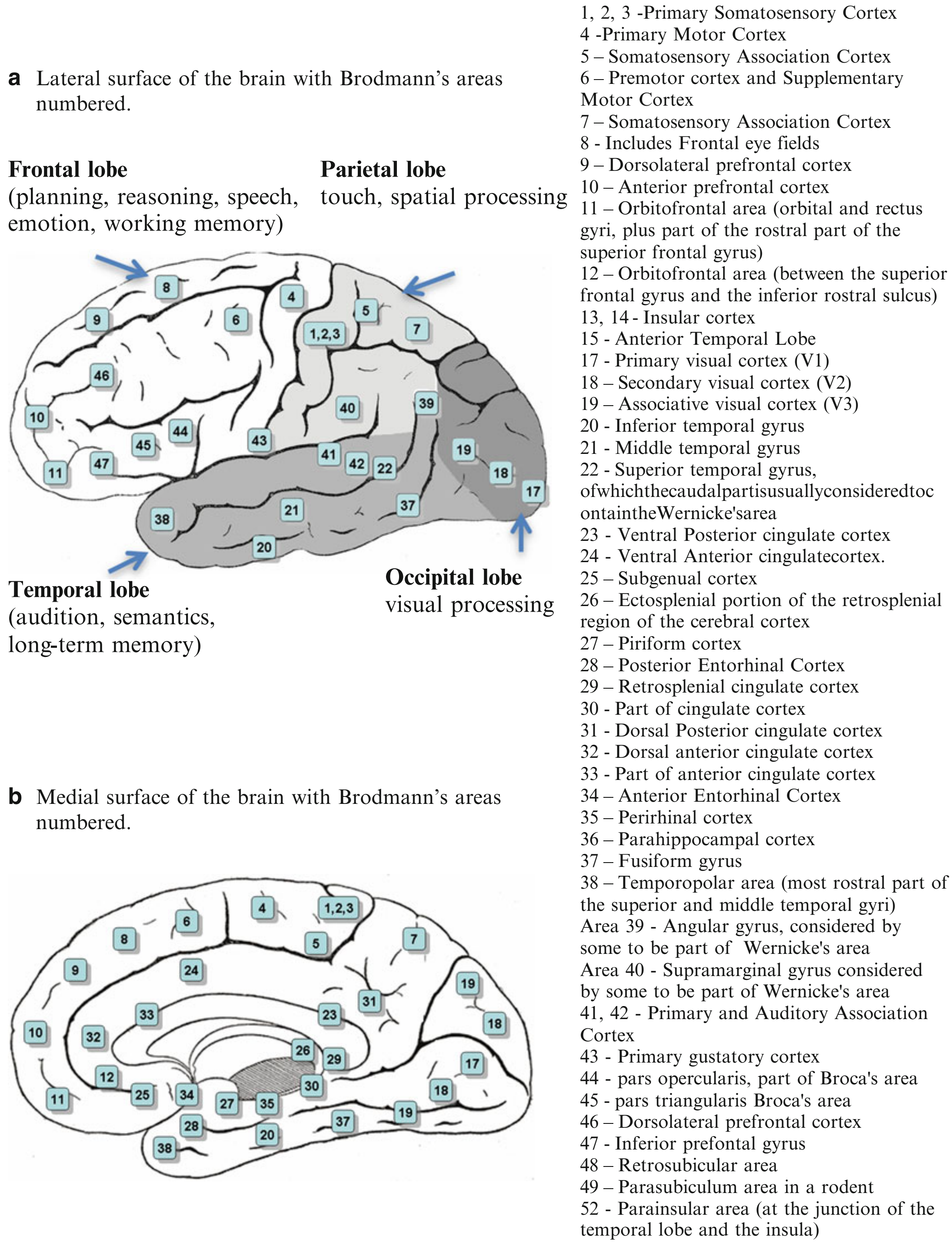

Fig. 5.3 Cytoarchitectural organization of the cortex according to Brodmann (1909). While more verifiable maps have been produced since then, Brodmann's atlas of the human brain is still considered to be the standard reference in the functional neuroimaging community (Thompson & Toga, 2000). (**a**) Lateral surface of the brain with Brodmann's areas numbered. (**b**) Medial surface of the brain with Brodmann's areas numbered

et al., 2002) and is diminished in children with developmental dyslexia (Goswami, 2004). One example of the contributions that cognitive neuroscience has made in understanding orthography is a PET study of the cultural effects on brain function that compared adult readers of Italian and English (Paulesu et al., 2000). The Italian language has a transparent orthography that allows readers to easily convert graphemes into phonemes. On the other hand, English is known for its inconsistent, non-transparent orthography that creates problems for both native and second-language readers. This study demonstrated that Italian readers were faster in reading words and nonwords than English readers (a behavioral finding), and that Italian readers showed greater activation in left superior temporal regions associated with phoneme processing, whereas English readers showed increased activation in the posterior inferior temporal gyrus (area 20 in Fig. 5.3) and anterior inferior frontal gyrus (area 11 in Fig. 5.3), which are associated with word retrieval during reading (a neuro-cognitive finding). These results can serve to corroborate the orthographic depth hypothesis (Katz & Frost, 1992)—a cross-language theory of reading suggesting that readers adapt their reliance on the orthographic (i.e., whole word recognition) or phonological (recoding) strategy, depending on the orthographic depth of the language. The phonological strategy is predominant in readers of languages with a consistent orthography because mapping between letters and sounds is unambiguous, while in an inconsistent orthography readers rely more on whole word recognition (Ziegler & Goswami, 2006).

One of the classic debates in literacy research and education focuses on the role of "whole language" text immersion versus the development of phonetic skills (National Reading Panel, 2000). Neuroscience research aimed at delineating the brain areas that support reading provides useful insights regarding this issue. For example, the so-called dual-route theory provides a framework for describing reading in the brain at the level of the word (Jobard, Crivello, & Tzourio-Mazoyer, 2003). Supported by dozens of neuroimaging studies, this theory proposes that words are first processed by the primary visual cortex (area 17 in Fig. 5.3) and then pre-lexical processing occurs at the left occipito-temporal junction (area 37 in Fig. 5.3). After that, processing follows one of the two complementary pathways (Jobard et al., 2003). The assembled pathway involves an intermediate step of converting letters and words into sounds (grapho-phonological conversion), which occurs in certain left temporal and frontal areas, including Broca's area (areas 44 and 45 in Fig. 5.3). The discovery of this pathway suggests the importance of the phonic approach to reading instruction. In case of the second route, the addressed pathway, information is transferred directly from pre-lexical processing to semantic processing (meaning extraction), which implies the significance of using the whole language approach to teach reading. Both pathways terminate in the left basal temporal area, the left interior frontal gyrus, and the left posterior middle gyrus, or Wernicke's area (area 22 in Fig. 5.3), which is known to be involved in the understanding of written and spoken language. These results confirm the assumptions of the dual-route framework, which helps explain different patterns of activation observed in participants during a reading task. This neuroscience evidence is also consistent with the conclusions of the US National Reading Panel (2000) and National Research Council (Snow, Burns, & Griffin, 1998) that highlight the educational benefits of a balanced approach to reading instruction, which combines whole language and phonics approaches.

Numeracy and the "Mathematical Brain"

Although the neuroscientific research on numeracy is still in its infancy, the field has already made significant progress in the last decade. The mere representation of numbers involves a complex circuit that brings together the sense of magnitude, and visual and verbal representations. As in the case with literacy, development of quantitative skills requires a synergy of physiology and experience. There are brain structures that are believed to be genetically assigned to the numerical sense, as well as supplemental neural circuits that are shaped to fit this function by experience through "neural recycling" (Dehaene, 1997). The number sense system is known to be supported bilaterally by the intraparietal areas, because these regions of the brain are activated during tasks involving number comparison, regardless of the representation format used (e.g., Arabic numerals, dots, number words). Because symbolic notations have no effect on the location of parietal ERP components, the parietal cortex is thought to organize knowledge about number quantities (Goswami, 2004).

Research on the role of the parietal lobe in the processing of quantitative information provides interesting insights as to why some children have good mathematical skills but have trouble reading and processing symbolic notations. For example, evidence from lesion and neuroimaging studies demonstrates that patients with parietal damage know that there are 2 h between nine and eleven but fail to subtract nine from eleven in symbolic notation (Dehaene, Spelke, Stanescu, Pinel, & Tsivkin, 1999). Relatedly, they are not able to answer which number falls between three and five but at the same time they have no difficulty solving a similar task in another domain—like identifying which month falls between June and August (Dehaene, 1997). These findings indicate that mathematics is dissociable from other domains like reading, and even within the domain of mathematics different abilities can be dissociable from one another (OECD, 2007). This conclusion highlights the importance of providing multiple forms of representation and assessment of mathematical knowledge—to include children that may not learn optimally from print text or do not perform well on paper-and-pencil tests.

An interesting series of behavioral and brain-imaging experiments (fMRI and ERPs) was conducted to explore the cognitive and neural activity underlying the linguistic competence and visuospatial representation in mathematics learning (Dehaene et al., 1999; Zago et al., 2001). Language-specific exact arithmetic was shown to transfer poorly to a different language or to novel facts, and use networks involved in word-association processes. Many mathematical problems are rehearsed to such an extent in elementary school that they are stored as declarative knowledge (Goswami, 2004). This result also explains the processing behind drill-and-practice counting exercises and rote learning like the multiplication tables. In contrast, approximate arithmetic was found to be language independent, rely on a sense of numerical magnitudes, and recruit bilateral areas of the parietal lobes (including a distinct parietal-premotor area) involved in visuospatial processing. Zago et al. (2001) found that a region associated with the representation of fingers (left parieto-premotor circuit) was activated during adults' arithmetic performance. Observers note that this result may explain the importance of using finger-counting as a strategy for the acquisition of calculation skills and have important consequences for the developing brain because they partially underpin numerical manipulation skills in adults (Goswami, 2004). The complex interplay of the brain systems responsible for processing and storing the different types of numerical knowledge is believed to result in the development of advanced quantitative skills and mathematical intuition characteristic of experts in mathematics, statistics, and other related disciplines (Dehaene et al., 1999).

Cognitive Load

Cognitive load theory (CLT) proposes a model of human cognitive architecture (Sweller, 2010; Sweller, Van Merriënboer, & Paas, 1998) that helps explain and predict the allocation of working memory resources and the interaction between working memory and long-term memory to deal with (a) intrinsic cognitive load (caused by the intrinsic complexity of information), (b) extraneous cognitive load (caused by ineffective presentation of information), and (c) germane cognitive load (effective processing resulting in deeper learning). In addition to these three types, cognitive load can be characterized in terms of its temporal dimensions such as instantaneous load, peak load, average load, accumulated load, and overall load (Xie & Salvendy, 2000). Researchers working in the context of CLT have been concerned with analyzing the effects of cognitive load types on learning and devising strategies and tools to help learners maintain an optimal level of load in various learning contexts. As a consequence, measurement of cognitive load plays a key role in research (Paas, Tuovinen, Tabbers, & Van Gerven, 2003).

Cognitive neuroscience provides tools that may prove useful in advancing the measurement of cognitive load and CLT (Clark, 2010, provides a detailed review). Neurotechnologies like EEG, ERPs, fMRI, and fNIRS have been employed to measure mental workload in human factors and ergonomics (Gevins & Smith, 2008; Wilson & Russell, 2003) and assess cognitive load in educational research (Antonenko, Paas, Grabner, & van Gog, 2010; Stevens, Galloway, & Berka, 2007). For example, the high temporal resolution of EEG can provide useful insights regarding the changes in cognitive load over time. Schultheis and Jameson (2004) employed the novelty P3 methodology (Friedman, Cycowicz, & Gaeta, 2001) and showed that the amplitude of P300 reflected cognitive load required to process difficult text. A recent review by Antonenko et al. (2010) suggests that event-related desynchronization percentage (ERD%) of alpha and theta band power over frontal and parietal regions of the brain can serve as an online, continuous measure of instantaneous cognitive load, which can help explain the effects of instructional interventions when measures of overall cognitive load fail to reflect such differences in cognitive processing. In the case of ERD%, each participant serves as his/her own control because this measure compares the brainwave power of individuals during the baseline period when the participant is relaxed to the test period when the participant is engaged in the learning task (Pfurtscheller & Lopes da Silva, 2005). Empirically, ERD% of alpha and theta coupled with the results of learning tests has been shown to be sensitive to changes in extraneous load associated with split attention in learning from hypertext (e.g., Antonenko & Niederhauser, 2010) and explains the differences in processing video, textual, and pictorial information by gifted students in multimedia learning (Gerlic & Jausovec, 1999).

Another study used EEG to compare learners' mental workload (cf. cognitive load) while solving science problems in a multimedia learning environment (Stevens et al., 2007). This study employed a wireless EEG headset and software that quantifies alertness, engagement, and mental workload in real time using linear and quadratic discriminant function analyses with model-selected power spectral density variables, event-related power, and wavelet transform calculations. As expected, workload increased when students were presented with problem sets of greater difficulty. Less expected, however, was the finding that as skills increased, the levels of workload did not decrease accordingly, suggesting that significant mental effort may be involved during strategic refinement (Stevens et al., 2007).

Neuroscientists are also beginning to explore the possibility of measuring cognitive load using a combination of neurotechnologies with high temporal and spatial resolution such as EEG–fNIRS (Hirshfield et al., 2009) and EEG–fMRI (Ullsperger & Debener, 2010). A growing body of literature discusses assessment of cognitive load using online psychophysiological measurement tools like pupil dilation (e.g., Marshall, 2007), galvanic skin response (Shi, Ruiz, Taib, Choi, & Chen, 2007), and electrocardiogram's median absolute deviation (Haapalainen, Kim, Forlizzi, & Dey, 2010).

In order to successfully interpret the findings from neuroscience and translate them into instructional design, however, it is important to analyze the evidence in the context of the concepts and learning tasks used in the original study. For example, neuroscience research on "working memory load" may not always have translatable implications for "cognitive load" research because studies on working memory load are purposefully designed to use tasks that do not rely as much on prior knowledge and interactions with long-term memory (e.g., indicate when a certain letter is repeated in a sequence of letters, as in the n-back task) as the more complex and less structured learning tasks used by educators in cognitive load research (e.g., read a passage and recall information from that passage).

Problem Solving

Much of the recent research in cognitive neuroscience has focused on the development of insightful problem solving (De Jong et al., 2009). Unlike the traditional, plug-and-chug textbook problems, insightful problems are authentic, real-life challenges that among other things require the learner to overcome a mental impasse, restructure the problem, reconfigure the understanding of the problem, and experience the suddenness of the solution (Sandkuhler & Bhattacharya, 2008). Jung-Beeman et al. (2004) used fMRI (Experiment 1) and EEG (Experiment 2) to explore brain activity during insightful and non-insightful solving of verbal problems. These problems required the participants to compare three different words (e.g., pine, crab, sauce) and find a single word that could be used in combination with them (e.g., apple). Participants reported whether they experienced insight or not, and the differences in responses were compared to the differences in their neural activity. The first experiment showed that insight solutions (59 %) were associated with increased activation in the right-hemisphere anterior superior temporal gyrus or RH aSTG (area 22 in Fig. 5.3), part of Wernicke's area, which is known to reflect the semantic processing of distant relations (e.g., Bowden & Beeman, 1998). Experiment 2 used the fine temporal resolution of EEG to determine whether insight really occurs suddenly (e.g., Metcalfe, 1986). A burst of high-frequency gamma band activity was observed over the RH aSTG about 0.3 s before the button was pressed to indicate the solution that was insightful—confirming the researchers' hypothesis. As in Experiment 1, no differences were observed between insightful and non-insightful solutions in the left hemisphere. As De Jong et al. (2009) note, these findings indicate that increased cognitive processing in the RH aSTG reflects the importance of semantic integration processes involved in the analysis and synthesis of the various problem features in verbal problems.

A related study cited in the De Jong et al. (2009) meta-analysis explored neural activity associated with the processes of overcoming the mental impasse, restructuring the problem, improved understanding of the problem, and abruptness of the solution in a compound association task (Sandkuhler & Bhattacharya, 2008). This EEG study found that mental impasse was correlated with increased gamma activity in the parieto-occipital cortex (selective attention) and enhancements in the theta band in the same region (working memory). This result suggests that both top-down attentional control and increased memory search lead to mental impasses. Gamma band frequencies in the parieto-occipital cortex (Fig. 5.3) were also found to be stronger for correct solutions than for false-positive solutions that were incorrect. Problem restructuring involved improvements in the alpha band frequency in the right prefrontal cortex, which is known to reflect the brain's executive function (Stuss & Knight, 2002). Activity in the right hemisphere (parieto-occipital regions) was also related to the suddenness of the solution, as demonstrated by changes in the power of the theta band. Thus, alpha, theta, and gamma activity in the prefrontal and parieto-occipital regions of the cortex appears to be a useful indicator of insightful problem solving.

Neural activity in the prefrontal and parietal areas of the brain was also explored in a recent study on mathematical problem solving (Ravizza, Anderson, & Carter, 2008). This fMRI study examined whether activity in these regions tracked with subsequent errors in solving algebraic equations. Unlike previous studies that used recognition paradigms (e.g., decide whether $2+2=5$ is correct) to assess the relationship of neural functioning with performance, participants in this study were asked to generate an answer themselves. The prefrontal region, which in previous studies exhibited activity modulated by retrieval demands, exhibited activation that was greater when equations were solved correctly, with no errors. More intense activity in this region was observed for successful problem solvers. However, the parietal cortex that has been associated with representing the number of transformations to the equation (e.g., Qin et al., 2004) showed no significant differences in activation between poor and effective problem solvers. This finding suggests that successful mathematical problem solving is related to retrieval abilities rather than to difficulty in representing or updating changes in the equation, as it is being solved.

Ravizza, Anderson, & Carter (2008) results are consistent with a previous study of error detection in mathematical processing. Using a verification task, Menon, Mackenzie, Rivera, and Reiss (2002) reported effects of accuracy in the prefrontal cortex whereas parietal regions were not affected by the accuracy of the equation. Instead, parietal cortex was modulated by the number of operands in the equation, consistent with previous work showing activation increases with increases in the number of mathematical steps that are required to solve the equation (Qin et al., 2004). Taken together, these results imply that students may be better served practicing equations with varying levels of retrieval demands rather than working with large quantities of equation operands, in order to master algebra.

The common limitation of most studies in cognitive neuropsychology, including the ones reviewed in this chapter, is their low ecological validity. Tasks used in neuroscience research are short, decontextualized, and isolated, while in educational research tasks are lengthy, content-rich, diverse, and embedded in complex social environments. Obviously, real-life problem solving can't be reduced to the association tasks described above. Educational neuroscience research involving "real" learning contexts is in its infancy; however, the recent technological advances enable educational researchers to collect neural activity data in actual classrooms. For example, a wireless EEG system allowed Stevens, Galloway, Berka, Johnson, and Sprang (2008) to begin the development of a rapid, neuroscience-based assessment of students' understanding of complex problem spaces. In this study, teams of novices and experts encoded chemistry problem spaces by completing online problem-solving simulations. Memory encoding was verified by comparing their strategies with established probabilistic models of strategic performance from a database of over 700,000 problem-solving performances (Soller & Stevens, 2007). For memory retrieval, researchers used the Rapid Sequence Visual Presentation method (Gerson, Parra, & Sajda, 2005) to show students stacks of images that represented sequences of chemical reactions. Then, the researchers probed the neural correlates of the encoded problem space by measuring differential EEG signatures that were recorded in response to rapidly presented sequences of chemical reactions that represented different valid or invalid approaches for solving the chemistry problems. Results showed that experts completed performances in stacks more rapidly than did novices and they also correctly identified a higher percentage of reactions. Furthermore, ERPs revealed increased positivities in the 100–400 ms range following presentation of the image preceding the decision when compared with the other stack images. This neural activity was used to explore reasons why students missed performances in the stack. One situation occurred when students appeared to have a lapse of attention characterized by increased power in the 12–15 Hz range, a decrease in the ERP positivities at 100–400 ms after the final image presentation, and a slower reaction time. A second situation occurred when the students' decisions were almost entirely the reverse of what was expected. These responses were characterized by ERP morphologies similar to those of correct decisions suggesting that the student had mistaken one set of chemical reactions for another. This study demonstrates that lapses of attention and correct use of incorrect content knowledge are common problems among novices in chemistry.

Emotion and Affect in Learning

According to Plato, "all learning has an emotional base" (Goleman, 1995). Yet, the emotional aspect has long been neglected in formal education (Boekaerts, 2003; De Jong et al., 2009). Recent contributions of neuroscientists are helping to rediscover affective learning by revealing the emotional dimension of human behavior. The term "affect" refers to a conscious and subjective interpretation of the complex psychophysiological reactions known as emotions. In situations of intense anxiety, stress, anger, or fear, social judgment and cognitive performance suffer through compromise to emotional regulation. For example, the human body's response to stress includes secretion of catecholamines and cortisol, and, as neuroscience research demonstrates, highly elevated levels of these hormones modulate cognition by influencing learning and memory (Sapolsky, Romero, & Munck, 2000). In extreme cases, exposure to negatively charged emotional experiences may result in permanent neuronal loss in the hippocampus (Kerr, Campbell, Applegate, Brodish, & Landfield, 1991). Thus, if learners are continuously exposed to stressors like school bullies, aggressive teachers, or incomprehensible learning materials, their cognitive functions may be impaired.

Catecholamines are also known to modulate memory consolidation, the process through which encoded information is transformed from its initially labile, transient to a more stable form (Dash, Herbert, & Runyan, 2004). Neuroscience research demonstrates that emotionally charged experiences result in stronger memories. For example, one such study had the participants rate a series of pictures as pleasant, unpleasant, or neutral (Dolcos & Cabeza, 2002). Participants were then asked to recall what was shown in the pictures and the results showed that the recall performance was better for the images that were rated either as pleasant or unpleasant. The results of ERP measurements demonstrated differences in the processing of emotional and neutral visual stimuli, which, coupled with the results of the recall test, suggest the importance of emotional anchors during the encoding and retrieval of memories. Simpson et al. (2000) conducted an fMRI study to compare participants' cognitive task performance, while they viewed either neutral or negative images. Results showed that different neural circuits were activated during task performance accompanied with neutral versus negative images, and use of negative imagery resulted in decreased task performance. These findings underline the importance of providing students with positive emotional experiences and emotionally safe learning environments that support rather than hinder knowledge acquisition.

Neuromyths

The term "neuromyths" was coined to refer to the growing number of misconceptions about the brain, its functions, and implications of neuroscience for research and practice in other domains such as parenting, early childhood education, marketing, and others (OECD, 2002). Many of these myths were developed in an attempt to explain and predict human learning. Neuromyths are difficult to debunk because they are typically rooted in valid neuroscience and psychology literature, but reflect extreme extrapolations beyond evidence and are presented through a lens that focuses only on evidence that fits the theory.

An exhaustive discussion of neuromyths is beyond the scope of this chapter; however, below is an examination of what is probably the most persistent neuromyth in education—"the myth of the first three years" (Bruer, 1999). The basic assumption behind the myth of the first 3 years is that most synapses (and hence most of the critical brain functions) are developed from birth to the age of 3 years, and if this critical period is missed, these brain functions may never develop. The neuroscientific origins of this myth are numerous. From the neuroscience perspective, learning can be defined as the creation of new connections between neurons (synapses), or the strengthening of existing synapses. It is known that after 2 months of growth, the synaptic density of the brain increases exponentially and exceeds that of an adult, peaking at 10 months of age. There is then a steady decline until age ten, when the "adult number" of synapses is reached (OECD, 2007). There have also been studies demonstrating that rats living in "enriched" environments (i.e., cage with other rodents and objects) had increased synaptic density and were thus better able to perform the maze learning test than rats living in "poor" or "isolated" environments (Diamond, 2001). The seemingly important implications for educational practice stemming from these findings have led teachers and parents to generalize, exaggerate, and extrapolate far beyond the actual scientific evidence resulting in new approaches to parenting and early childhood education that involve brain-stimulating music, videos, and gymnastics for newborns.

On the other hand, empirical research in education suggests that learning can't be reduced to the creation of new brain synapses in highly artificial contexts, characteristic of laboratory experiments. For example, a number of studies in education show that even children growing up in what could be defined as an "impoverished" environment (e.g., a ghetto) may over time come to excel in school and go on to higher education (e.g., Bruer, 1999). There are simply too many social, environmental, affective, and experience-dependent factors to take into account when defining what an "enriched" environment should be for the majority of students. While grammar is indeed learned faster and easier at a young age, the capacity to enrich vocabulary actually improves throughout the life span because it depends heavily on experience (Neville & Bruer, 2001). Also, contrary to the common belief that the brain loses neurons with age, the number of neurons in the cerebral cortex was found to be not age dependent (Terry, DeTeresa, & Hansen, 1987), and certain parts of the brain—like the hippocampus—can actually generate new neurons with age (OECD, 2007). "Understanding of the brain: The birth of a learning science" (OECD, 2007) provides a systematic discussion of the origins, common exaggerations, oversimplifications, and extrapolations, as well as evidence that helps refute this and the other popular neuromyths.

Conclusions

This chapter merely scratched the surface of neuroscience and its methods, challenges, and implications that are relevant to the education community. Each of the areas reviewed here—language and reading, mathematics learning, problem solving, cognitive load, and affective learning—lies at the intersection of neuroscience and education; however, caution must be exercised in drawing conclusions for learning, instruction, and performance. Neuroscientists examine cognitive functions at such a fine level of detail that their findings are frequently deemed unusable by educational researchers (e.g., Bruer, 2006). Most current neuroscience methods limit access to such important educational considerations as context; localizing cognitive functions to different brain areas does little to inform actual educational practice; and it is very easy for educational researchers to resort to reductionism and propagate neuromyths (Varma et al., 2008).

While educators are often disappointed that neuroscience findings do not lead to direct and straightforward applications, no such direct application exists in other fields (Ansari & Coch, 2006). For example, in medicine, basic research in fields like epidemiology and actual practice of health care interact to produce tangible and mutual benefits. Doctors' observations stimulate new research, the results of which can, in turn, improve medical practice. In the case of education, a growing number of scholars representing various domains of educational research discuss educational applications of neuroscience with optimism. De Jong et al. (2009) report new and exciting developments in cognitive, affective, and social neuroscience relative to the neural activity underlying metacognition and self-regulation, multimodal processing, and social cognition. Use of fMRI to develop cognitive models to explain and predict complex problem solving is explored by Anderson et al. (2008). Goswami (2009) argues for the integration of educational, cognitive, and neuroscience research paradigms and illustrates the application of this integrative framework using the concept of biomarkers, or cognitive signatures, that can potentially help identify children with learning difficulties very early in their development.

Interaction of neuroscience and education can be facilitated in many ways. Most current reviews discussing the implications of neuroscience for education conduct post hoc interpretations of neuroscience findings, trying to identify results of most relevance to the education community. This process consumes time and resources but, as practice shows, it does not always result in usable knowledge for educators. Instead, real interdisciplinary research should be fostered, for example by developing laboratories including neuroscientists, psychologists, and educators, who can collaborate and conduct experimental work on educational neuroscience from the early stages of experiment conceptualization to the final interpretations. Innovative designs produced as part of such interdisciplinary efforts can allow researchers to study the effects of context and other variables of interest, and update and develop new instructional theories and principles. Finally, establishment of collaborative professional organizations and journals like the recently created Mind, Brain, and Education can improve communication and sharing of the relevant ideas and findings.

Direct translation of research in neuroscience to inform instruction can still be problematic (Bruer, 2006; Varma et al., 2008). However, advances in neurotechnologies like wearable, wireless EEG (e.g., http://www.b-alert.com and http://www.neurosky.com) and signal analysis techniques that remove irrelevant artifacts and automatize most of the data processing make neuroscience tools and methods more and more usable, useful, and accessible to educational researchers. Even policy-makers are enthusiastic about the possibilities of using neurocognitive findings to inform learning and instruction. The USA's National Council for Accreditation of Teacher Education (NCATE) has recently issued a report that urges teacher education programs to integrate neuroscience findings about human development into their curricula (NCATE, 2010). Observers note that incorporation of educational neuroscience discoveries into educational policy and practice will shape the twenty-first-century teaching and learning in ways that are analogous to the contributions of educational psychologists like John Dewey, B.F. Skinner, and Jean Piaget in the twentieth-century education (Sylwester, 2010). The collective work of neuroscientists and educational researchers must, therefore, continue. The stakes are high for all parties involved, but, most importantly—for students.

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6 Emotions and Motivation in Learning and Performance

ChanMin Kim and Reinhard Pekrun

Abstract

This chapter reviews theories and research on academic emotions and motivation that can be integrated into the processes of instructional design and development. First, we discuss the impact of emotions in learning and performance contexts. Second, we review theories describing how emotions occur. Third, we discuss how to optimize emotional experiences in learning and performance contexts and review several models and approaches that can be used in instructional design. Fourth, we review instruments and technologies measuring emotions and emotion regulation. We conclude the chapter by suggesting future research directions including reframing motivation research that considers emotions in the realm of educational communications and technology.

Keywords

Academic emotions • Motivation to learn • Cognitive appraisal • Causal expectancies • Causal attribution • Emotion regulation

Introduction

Motivation and emotions play a critical role in learning and performance (Astleitner, 2000; Carver & Scheier, 1990; Goetz, Pekrun, Hall, & Haag, 2006; Op't Eynde, Corte, & Verschaffel, 2006; Pekrun, 1992; Pekrun, Goetz, Titz, & Perry, 2002). When students do not exhibit high motivation, they either do not initiate or discontinue learning tasks. Furthermore, when students have high anxiety, their performance is not ideal. However, instructional designers and researchers often pay little heed to motivation and emotions due to their indirect effects on learning and performance (Schiefele & Csikszentmihalyi, 1995). Additionally, little research examines interventions designed to improve learners' emotional experiences in learning and performance (Astleitner, 2001; Gläser-Zikuda, Fuß, Laukenmann, Metz, & Randler, 2005; Kim & Hodges, 2012). While some studies have examined interventions to reduce learners' motivational problems (e.g., Hodges & Kim, 2010; Kim & Keller, 2008, 2010, 2011), there is little research in which both emotions and motivation are considered in efforts to improve learning and performance. In this chapter, we explore the intersection of motivation and emotions in the learning process, and how to support students in this critical area.

The Inseparable: Emotions and Motivation

Emotions result from "the dynamic interplay of cognitive, physiological, and motivational processes in a specific context" (Op't Eynde et al., 2006, p. 193). In order to understand educational experiences, emotions and motivation need to be considered alongside cognition (Ainley, 2006; Hannula, 2006; Meyer & Turner, 2006; Op't Eynde et al., 2006; Op't Eynde

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& Turner, 2006; Pekrun, 2006; Turner & Patrick, 2008). The interplay among emotions, motivation, and cognition can be understood from the perspective of goals (Ainley, 2006; Dweck, 1992; Linnenbrink, 2006; Linnenbrink & Pintrich, 2002; Op't Eynde & Turner, 2006; Pekrun, 2006; Schutz, Hong, Cross, & Osbon, 2006). For example, a mastery goal orientation can promote positive emotions and sustain motivation whereas a performance-avoidance goal orientation can promote negative emotions and poor motivation (Dweck, 1992; Pekrun, Elliot, & Maier, 2006). Emotions and motivation are enacted while striving to pursue or avoid goals (Carver & Scheier, 1990; Op't Eynde & Turner, 2006).

In addition to their organization around goals, there are bidirectional (reciprocal) influences between emotions and motivation (Kim & Hodges, 2012; Kim, Park, & Cozart, 2013; Pekrun, 2006). Emotions and motivation interact with each other and make each other activated (or deactivated), which directs behaviors (Hannula, 2006; McLeod, 1988; Op't Eynde et al., 2006; Op't Eynde & Turner, 2006; Pekrun, 2006). Some researchers regard motivation as part of emotion processes (e.g., Op't Eynde et al., 2006), whereas others regard emotions as part of motivation processes (e.g., Ford, 1992; Hannula, 2006). Buck (1985) explained the relation between emotions and motivation using the analogy of energy and matter in physics: "Just as energy is a potential that manifests itself in matter, motivation is a potential that manifests itself in emotion. Thus motivation and emotion are seen to be two sides of the same coin, two aspects of the same process" (p. 396). Although emotions and motivation are not inseparable conceptually and empirically, it is difficult to separate them in the contexts of learning and performance (Ainley, 2006; Op't Eynde et al., 2006). An integrative view of emotions and motivation is needed to understand and facilitate learning and performance (Kim & Hodges, 2012; Pekrun, 2006).

The purpose of this chapter is to discuss theories and research on emotions and motivation that can be integrated into instructional design and development. A detailed review of motivation research is not included in this chapter because previous editions of the *Handbook of Research for Educational Communications and Technology* addressed motivation research in multiple chapters (e.g., Park & Lee, 1996; Seel, 2007). Much of this chapter focuses on academic emotions while acknowledging that emotions and motivation are difficult to separate. First, we discuss the impact of emotions in learning and performance contexts. Second, we review several theories describing how emotions occur. Third, we discuss how to optimize emotions in learning and performance contexts and present design strategies that employ emotion regulation. Fourth, we review instruments and technologies that measure emotions and emotion regulation. We conclude the chapter by suggesting directions for future research.

How Emotions Influence Learning and Performance

Emotions impact the quality of learning and performance (Gläser-Zikuda et al., 2005; Goetz et al., 2006; Pekrun, Elliot, & Maier, 2009; Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010). The impact of emotions on learning and performance should be studied in the context where the emotions are occurring. This in turn would improve explanations of how emotions impact learning and performance. The following list overviews what mediates the impact of emotions on learning and performance:

- Emotions influence cognitive processes and strategies
- Emotions influence decision making
- Emotions influence motivation
- The aforementioned influences are reciprocal

Impact of Emotions on Cognitive Processes and Strategies

Emotions influence cognitive processes (Forgas, 2000; Gläser-Zikuda et al., 2005; Linnenbrink, 2006; Pekrun, 2006; Pekrun et al., 2002; Schwarz, 1990, 2000). Information processing can be initiated, accelerated, altered, or interrupted by emotions (Astleitner, 2000; Pekrun, 1992; Pekrun et al., 2002). Emotions can alter how information is stored and retrieved (Levine & Pizarro, 2004; Linnenbrink, 2006; Schwarz, 2000). Memory can be organized differently depending on emotions experienced when the information was stored and/or the information is being retrieved.

Mood-congruent retrieval implies that a person's current emotional state influences the way his/her memories are recalled (Blaney, 1986; Bower, 1981; Levine & Pizarro, 2004; Parrott & Spackman, 2000). For example, in one study, people recalled their experiences about blood donation differently depending on their current feelings about blood donation (Breckler, 1994). In another study, people retrieved memories about their early marriage life differently depending on how happy or unhappy they feel about their marriage at present (Holmberg & Holmes, 1994). This is consistent with the notion that "emotions enhance the availability of emotion-congruent information" (Levine & Pizarro, 2004, p. 537). In other words, people tend to retrieve information that is congruent with their current emotions (Schwarz, 2000). For example, a student may recall enjoyable memories about mathematics while having fun playing Sudoku rather than while taking a mathematics exam in a classroom.

The type of emotion (e.g., positive vs. negative; activating vs. deactivating) can influence the use of cognitive strategies (Pekrun, 2006; Pekrun et al., 2002). People experiencing positive emotions tend to use more general knowledge in heuristic ways whereas people experiencing negative emotions tend to use systematic analyses with more focus on details (Hertel, Neuhof, Theuer, & Kerr, 2000; Levine & Pizarro, 2004; Schwarz, 2000). Research has shown that activating positive emotions (e.g., happiness) facilitates flexibility and creativity (Isen, 2000; Levine & Pizarro, 2004). Activating negative emotions (e.g., anxiety) can lead to the use of narrowly focused, rigid strategies and deactivating negative emotions (e.g., boredom) can lead to superficial information processing due to unfocused attention (Pekrun, 2006). For example, students with high test anxiety could dwell on one exam question with which they are struggling because their use of narrowly focused strategies keeps them from allocating time for all exam questions. The impact of emotions on cognitive processes and strategies influences learning strategies, problem-solving behavior, and performance (Kim et al., 2013; (Op't Eynde et al., 2006; Pekrun, 2006).

Impact of Emotions on Decision Making

Emotions influence decision making (Schwarz, 2000). When making decisions, people intend to minimize the likelihood of negative emotions and maximize the likelihood of positive emotions; therefore, anticipated emotions can influence decision-making processes (Schwarz, 2000). As a negative consequence of such influence, Schwarz (2000) provided the following example:

> Parents may hesitate to vaccinate their child when the vaccine has potentially fatal side effects, even under conditions where the likelihood of a fatal side effect is only a fraction of the death rate from the disease, presumably because anticipated regret looms larger for the act of vaccination. (p. 436)

When parents choose not to vaccinate their children, they make such a decision because they are motivated to avoid the possibility of the anticipated emotion (regret) and also because regret for action (vaccination) is usually more intense than that for inaction (Schwarz, 2000).

Anticipated emotions may also impact decision-making processes in learning and performance contexts (Stephens & Pekrun, 2011). For instance, if Jake decided not to study for the final exam because he thinks he would fail anyway, he may have made such a decision to minimize the likelihood of the negative emotions such as hopelessness and shame that would come from ineffective action.

Past experiences of emotions (i.e., emotional memories) influence decision making as well (Levine & Pizarro, 2004; Schwarz, 2000). In the aforementioned example, Jake may have felt hopeless in the past when he did not perform well on an exam for which he studied. This past, negative emotion (a) made Jake underestimate the probability that studying for the exam would result in success in the exam, and (b) influenced his decision not to study. In Jake's decision-making process, expectancy assessment was involved, which is heavily dependent on memories of prior experiences (Carver & Scheier, 1990). One would then wonder if Jake would never make a decision to study for an exam due to his past experience of negative emotions. "Emotional memories are not indelible" (Levine & Pizarro, 2004, p. 535). Instructional designers can promote positive changes in learners' expectancy assessment processes. For example, goals in tasks should be specified. Without knowing what is expected, it is not likely that learners' expectancy assessment will be constructive. Nonetheless, "goal specificity in itself does not necessarily lead to high performance because specific goals vary in difficulty" (Locke & Latham, 2000, p. 706). Task difficulty needs to be modified per learners' ability; the provision of incremental success experiences can increase learners' assessment of the probability of success in completing tasks.

Impact of Emotions on Motivation

Different emotions correspond to different actions. For example, fear can induce withdrawal or avoidance and anger can induce a physical attack (Frijda, Kuipers, & Schure, 1989; Plutchik, 1980). Action tendencies result from discrete emotions that create specific action impulses. For example, the physical attack (an action) induced by anger (an emotion) is meant to hurt someone (a motivational intention) (Roseman, Wiest, & Swartz, 1994). How emotions influence one's motivation to act in a certain way can be explained in terms of memory and goals. Some researchers view emotion as a kind of information in working memory that could contribute to motivation regulation (Carver & Scheier, 1990; Levine & Pizarro, 2004). In the previous example, Jake's memory of past, negative emotions deactivated his motivation to study, as did anticipatory, negative emotions. As "emotions can cause interruption and reprioritization of one's goals" (Carver & Scheier, 1990, p. 31), the influence of emotions on motivation may also be mediated by goals. As illustrated earlier, students' expectancy assessment can be involved in this process of emotions influencing motivation. Emotions also influence goal pursuit (Seifert, 1995). Emotions along with expectancy assessment are used in monitoring, which leads to either goal-pursuit or goal-disengagement (Carver & Scheier, 1990). The monitoring process can be either conscious or nonconscious (Carver & Scheier, 1990). Through the monitoring process involving emotions, emotions facilitate or impede self-regulatory behaviors toward goals.

Optimizing academic emotions can in turn optimize motivation and ultimately learning and performance. For example, compared with students in the control group, students who received an emotion regulation intervention showed more positive motivation and positive emotions than those in the control group (Kim & Hodges, 2012). To promote optimal learning and performance, instructional designers need to consider not only the content to be learned but also student needs related to academic emotions and motivation during the design of instruction (Pintrich & Schunk, 2002). Also, instructional designers need to consider ways of highlighting intrinsic task value. Autonomy-supportive learning environments can promote learners' curiosity and desire to take on a challenge (Ryan & Deci, 2000). An emphasis on mastery goal orientations helps learners perceive task value beyond instrumental usefulness (Ames, 1992; Covington, 2000).

Reciprocal Effects

Up to now, how emotions influence learning and performance has been explained through the discussions of the impact of emotions on cognitive processes and strategies, decision making, goal-pursuit, and motivation. Cognition, emotions, and motivation are reciprocal (Pekrun, 2006). For example, emotions influence memory but memory also influences emotional reactions (Carver & Scheier, 1990). Emotions can influence goal orientations, but also different emotions are possible when a student displays a particular goal orientation (Dweck, 1992; Linnenbrink & Pintrich, 2002; Schwarz, 2000). In short, emotions influence ongoing behaviors (Carver & Scheier, 1990) and vice versa because emotional processes interact with motivational and cognitive processes (Astleitner, 2000). Second, situational aspects influence this interactive process (Pekrun, 2006). For example, the quality of communications and understanding between students and teachers is influenced by emotions (e.g., empathy) and impacts the interactive process (Goetz et al., 2006; Meyer & Turner, 2002). In the next section, the manifestation of academic emotions is discussed in light of instructional design.

How Emotions Occur

Emotions arise when a person *appraises* a given situation. *The meaning and causal structures* of the situation and *controllability* are cognitively evaluated and expectancy is formed accordingly (Gross, 2008; Pekrun, 2006; Scherer, 1999; Schutz & Davis 2000; Weiner, 1985). This appraisal process, which can be either conscious or nonconscious and either deliberate or automatic, brings about an emotional response (Gross, 2008; Johnson-Laird & Mancini, 2006; Op't Eynde et al., 2006; Pekrun, 2006; Schutz & Davis, 2000, 2010).

A person's expectancy and perceived values of a certain action (or inaction) and its outcomes determine the person's responses to the situation where the person takes (or does not take) the action (Carver & Scheier, 1990; Pekrun, 2006). Motivational and emotional responses occur based on these expectancy and value appraisals. In this section, what forms the expectancy and values is discussed to explain how emotions occur.

The *meaning structure* of a given situation initiates expectancy and value assessment; that is, the subjective controllability and value of the situation (i.e., achievement activities and/or outcomes) are analyzed (Carver & Scheier, 1990; Pekrun, 2006; Schutz & Davis, 2000). For example, Bill just entered a 2-year college and is required to take a remedial math course. Without taking the remedial math course, he is not allowed to take any other course. If he drops the remedial math course, he must drop other courses that are being taken together as well. Bill values the remedial math course in that it can determine whether he can continue to pursue his goal—completing the 2-year college, eventually transferring to a 4-year college, getting a college degree in social work, and becoming a social worker. On one hand, the value of an anticipated outcome—the completion of the remedial math course that leads Bill one semester closer to his dream job—strengthens his motivation to study hard. On the other hand, anxiety could grow due to the extremely important and relevant meaning of the remedial math course to Bill's goal. As discussed in Pekrun's (2006) control-value theory of achievement emotions, this meaning structure analysis involves the appraisal of extrinsic value and intrinsic value. In terms of extrinsic value, Bill values the instrumental usefulness of the remedial course for his goal attainment. In terms of intrinsic value, Bill may value the course itself (if Bill just likes to learn math). However, the meaning structure of the situation alone does not bring about emotional responses; rather, it should be accompanied with the analysis of what controls the situation, one's actions, and their outcomes.

The *causal structure* of a given situation forms the expectancy in part; that is, learners' perceived control (i.e., subjective control over achievement outcomes; perceptions of what the outcome of their action depends on) is critical in their expectancy assessment (Pekrun, 2006; Weiner, 1985). The causal structure of the situation is analyzed and leads to one's perception of the locus of control (internal vs. external) and the stability of control (stable vs. unstable) (Weiner, 1985). In Bill's case, if he perceives that his ability will help him succeed in the remedial math course, his perceived control is internal and stable. If he perceives that he needs luck to be successful in the course, his perceived control is external and unstable. As described in expectancy-value theories, this perceived control influences a person's motivation (e.g., Eccles, 1983). Bill would not be motivated to study for the course when he perceives that his effort would not matter but luck does. At the same time, Bill's emotional experience can also be different according to his perception of the causal structure. For example, Bill would be proud of himself if he thinks that he passed the midterm exam because his effort paid off rather than he was lucky. In contrast, if Bill failed the exam and he thinks that his failure was not from lack of effort but from lack of support by others, he would experience the emotion of anger. As discussed by Pekrun (2006), the process of this causal structure analysis involves causal expectancies and causal attributions: the former is prospective appraisal of the relation of causes to anticipated effects (examples about Bill's course success above), and the latter is retrospective appraisal of the relation of observed effects to causes (examples about Bill's exam results above).

People can perceive the causal structure of the same situation differently for various reasons. Past emotions, memory of prior experiences, task difficulty, goal specificity, and vicarious experience are examples of sources of individuals' different analyses of the causal structure and corresponding different emotional responses (Carver & Scheier, 1990; Locke & Latham, 2000; Pekrun, 2006; Weiner, 1985). Bill may feel hopeless because unpleasant memories of 8th-grade algebra returned (past emotions). He may still be ashamed of his low scores on the college placement test that resulted in a required remedial math course (past emotions). He may be frustrated because taking an online course is new to him (task difficulty; lack of goal specificity). He may be nervous because a friend who had taken the course told him that the exam questions were unpredictable (vicarious experience).

Even when people perceive that they are equipped with internal and stable dispositions that are important to attain success, their expectancies are not necessarily positive. For example, Bill may perceive that his ability is the enabler for success in the remedial math course, but if he thinks that he is not able to exert the required effort due to habitual procrastination, his expectancy of course completion could be low and he might experience negative emotions. Bill's controllability over his own effort would also be critical in the appraisal process. Thus, how people evaluate the *controllability of actions*—i.e., subjective control over achievement activities in Pekrun (2006)—also forms expectancies and drives emotional responses (Weiner, 1985). The concept of controllability is worth mentioning especially because some causes can be viewed as either stable or unstable (Weiner, 1985), and as either controllable or uncontrollable. Ability is perceived as stable and uncontrollable if math ability is regarded as a fixed entity, but it can be perceived as unstable and controllable if Bill thinks that math ability can be acquired over time because math is learnable.

In summary, the appraisal process that forms perceived control, expectancies, and subjective values plays a central role in an emotion process (Levine & Pizarro, 2004; Op't Eynde et al., 2006; Pekrun, 2006; Weiner, 1985). The perceived meaning and causal structure of the situation can be considered by instructional designers to optimize emotional experiences and motivation in learning and performance contexts. It is also important to address learners' needs not only individually but also in groups. As mentioned earlier, vicarious experience from peers can lead to learners' different perceptions of meaning and causal structures of the situation, as shown in research on goal contagion (e.g., Aarts, Dijksterhuis, & Dik, 2008).

How Emotional Experience Can Be Optimized

Understanding learners' emotions implies understanding not only their values and beliefs but also their learning and problem-solving behaviors (Astleitner, 2000; Op't Eynde et al., 2006). However, simply understanding learners' emotions is not sufficient; rather, positive activating emotions should be cultivated since they can lead to positive outcomes such as open-mindedness, effective cognitive strategy use, motivation, self-regulatory behaviors toward goals, academic achievement, psychological growth, and positive career aspirations (Astleitner, 2000; Fredrickson, 1998; Goetz et al., 2006; Pekrun, 2006). Theory-driven interventions can be designed to cultivate learners' positive activating emotions (Astleitner, 2000; Goetz et al., 2006; Kim & Hodges, 2012; Pekrun, 2006). In fact, several theoretically guided models and approaches can be used in instructional design to improve learners' emotional experiences as discussed below.

Models and Approaches for Optimizing Emotional Experience

The FEASP (fear, envy, anger, sympathy, and pleasure) approach was proposed to help design "emotionally sound instruction" (Astleitner, 2000, p. 173):

- *Fear* arising from subjectively judging a situation as threatening or dangerous
- *Envy* resulting from the desire to get something that is possessed by others
- *Anger* coming from being hindered to reach a goal and being forced to an additional action
- *Sympathy* referring to an experience of feelings and orientations of other people who are in the need of help
- *Pleasure* based on mastering a situation with a deep devotion (Astleitner, 2000, p. 175)

A set of instructional strategies can systematically decrease fear, envy, and anger and increase sympathy and pleasure (Astleitner, 2000). For example, strategies for reducing learners' fear include helping learners accept their mistakes as opportunities to learn. Astleitner (2000) argued that the strategies should be implemented by instructional designers and teachers to promote the desired emotional experience of learners. He also emphasizes that strategies should be designed and implemented based on learners' problems and the outcomes should be evaluated. As part of an empirical validation of the FEASP approach, Astleitner (2001) asked both teachers and students how important they thought emotions were in learning and instruction and if and how often the strategies in the FEASP approach were used in classroom. Based on the survey results, Astleitner (2001) concluded that the FEASP approach was “relevant, usable, consistent, and affecting emotions in daily instruction” (p. 209). However, his approach has not been tested in the process of design, development, implementation, and evaluation of interventions aiming to improve learners’ emotional experience. Also, his validation process seems to be limited. A finding that students state that emotions are important in school may be limited by students’ (often) inaccurate understanding of academic emotions. In addition, the functions of emotions for motivation and learning were not elaborated; for example, he defined envy as a maladaptive emotion, which does not address benign envy, as opposed to malicious envy, that can serve as a motivation to study more (for further discussion of benign vs. malicious envy, see Van de Ven, Zeelenberg, & Pieters, 2009, 2011).

Keller’s attention, relevance, confidence, and satisfaction (ARCS) motivational design model (1987, 2010) considers learners’ emotional experiences, although Keller did not explicitly mention design for emotions. The model provides instructional strategies to increase the four components in learners. For example, one motivational strategy for attention is creating curiosity in learners by asking them questions that are not congruent with their current knowledge (e.g., paradoxical questions) (see Keller, 2010). Keller (2010) discussed learners’ emotional states such as anxiety, boredom, pleasantness, and so on, and he provided specific strategies to deal with these emotional states in instructional design. There has not been much research implementing the ARCS model to promote learners’ emotional experience, although there have been numerous studies that applied the model to the design of interventions to promote motivation (e.g., Martindale, Pearson, Curda, & Pilcher, 2005). Keller’s more recent model, called an integrative theory of motivation, volition, and performance (MVP), includes design to facilitate learners’ volition (Keller, 2008). The MVP model has been used in a few empirical studies (Kim & Keller, 2008, 2010, 2011). The model recommends using emotion control as a volitional strategy but lacks specific strategies to promote emotion control.

Park and Kim (2012) introduced an approach to enhance students’ enjoyment and reduce boredom in online learning contexts by promoting interest in course readings. Specifically, the virtual tutee system (VTS) was proposed as a computer-based peer-tutoring environment where learners teach virtual tutees. The VTS was designed based on the concept of *learning by teaching* to increase interest and enjoyment and decrease boredom. Role theory and self-determination theory were used as theoretical foundations. However, empirical validations of the VTS design framework have not yet been published; one study illustrating the positive outcome of applying the VTS framework to a college course is under review.

Emotional scaffolding has been studied in face-to-face classrooms (e.g., Meyer & Turner, 2007; Rosiek & Beghetto, 2009) as well as in online environments (e.g., Aist, Kort, Reilly, Picard, & Mostow, 2002). Emotional scaffolding refers to activities that are tailored to specific aspects of the content of teaching as well as to emotional experience of students in the classroom (Rosiek, 2003). Emotional scaffolding requires teachers’ knowledge of interactions among “curricular content, cultural discourses, community histories, students’ personal histories, and general attitudes about schooling that precipitated students’ emotional response to their lessons” (Rosiek, 2003, p. 406). Also, emotion regulation has been used to promote positive emotions and desired motivational states. Gross (2008) proposed four antecedent-focused strategies (used before the activation of certain emotions) and one response-focused strategy (used during the activation of certain emotions):

- Situation selection—choosing to be in environments that are likely to diminish negative emotions
- Situation modification—changing a certain environment to reduce negative emotions
- Attentional deployment—shifting attention to something else
- Cognitive change—reappraisal; cognitively reevaluating the situation
- Response modulation—suppressing certain emotions activated (pp. 500–505)

Kim and Hodges (2012) designed and implemented an emotion regulation intervention that focused on the renewal of cognitive appraisal processes using three of these strategies (attentional deployment, cognitive change, and response modulation). They intended to help with learners’ conscious and deliberate awareness and reappraisal of the situation.

Schutz and Davis (2010) proposed four emotion regulation processes in test-taking contexts as follows:

- Cognitive-appraising processes related to the goal-directed person–environment transaction involving goal importance, goal congruence, agency, and problem efficacy
- Task-focusing processes
- Emotion-focusing processes involving wishful thinking and self-blame
- Regaining task-focusing processes involving tension reduction and reappraisal (Schutz & Davis, 2010, p. 2)

Schutz and Davis (2010) did not produce an instructional intervention; they examined naturally occurring processes. However, their proposed dimensions for emotion regulation processes, especially the *regaining task-focusing processes*, can be applied to the design of interventions promoting emotion regulation. The effects of emotion regulation may persist beyond the intervention because acquired regulatory reappraisal skills can be transferable to other contexts. This approach of emotion regulation may be worth pursuing since one of the important goals as to educational contexts should be to raise self-regulatory learners who can help themselves outside of class.

A Comprehensive Framework: The Control-Value Theory of Achievement Emotions

Pekrun's (2006) control-value theory of achievement emotions provides a comprehensive framework illustrating four paths that can be used to promote emotion regulation: (a) emotions, (b) appraisals, (c) competences for learning and achievement, and (d) design of tasks and learning environments.

First, the emotion path is *emotion-oriented regulation* that directly deals with emotions. For example, when students feel anxious before an exam, they can try to focus on "tasks to do" before the exam without thinking of "the exam." *Response modulation* and *attentional deployment* can be categorized as emotion-oriented regulation (Gross, 2008). Second, the appraisal path is *appraisal-oriented regulation* that deals with the subjective control and subjective value of a given context. For subjective control, causal expectancies and/or causal attributions need to improve; for subjective value, the perceived intrinsic and/or extrinsic value need to improve. That is, the meaning and causal structure of the situation and controllability, as described in the *How Emotions Occur* section, need to be reappraised. Schutz and Davis' (2010) *regaining task-focusing processes* can be explained by this appraisal-oriented regulation. Gross' (2008) emotion regulation strategy, *cognitive change*, can be categorized as appraisal-oriented regulation. Third, the learning and achievement path is *competence-oriented regulation* that deals with the improvement of learning and achievement. For example, abilities can be enhanced and study skills can be acquired. Keller's (1987, 2010) ARCS model can be used for competence-oriented regulation. Park and Kim's (2012) intervention to increase reading interest through the learning by teaching technique can be regarded as an example of competence-oriented regulation. Last, the environment path is *design of tasks and learning environments* that deals with improvement of learning and performance contexts. Examples include a clarification of course requirements (i.e., a change relevant to the specificity of goal structure and expectations; e.g., Locke & Latham, 2000), adding choices for an assignment completion (i.e., change relevant to autonomy support; e.g., Ryan & Deci, 2000), and so on. Astleitner's (2000) FEASP approach as well as Keller's ARCS model can be used for the design of learning and social environments.

Pekrun (2006) discussed how education should cultivate learners' positive emotions and emotion regulation through these four paths. For example, he argued that positively perceived value of learning should be induced through learners' communications with and observations of people around them, which can be possible in learning environments corresponding to students' needs (Frenzel, Goetz, Lüdtke, Pekrun, & Sutton, 2009; Pekrun, 2006).

How Emotions Can Be Measured

Instructional design starts with needs assessment and instruction is evaluated through formative and summative assessments (Dick, Carey, & Carey, 2008). This means, in order to create interventions cultivating positive emotions and/or emotion regulation, first, there should be an investigation of learners' current emotional states. Also, there should be assessment instruments to evaluate the effect of interventions. In this section, we introduce several instruments and technologies that can be used to measure the types and levels of emotions as well as emotion regulation skills and processes. We also discuss issues with measuring emotions in relation to *situatedness* of emotions in learning and performance contexts.

Measurement Instruments

The Achievement Emotion Questionnaire (AEQ; Pekrun, Goetz, Frenzel, Barchfeld, & Perry, 2011) has been widely used in educational emotion research. The AEQ is a self-report instrument designed to assess students' emotions experienced in academic contexts. The AEQ measures nine discrete emotions relating to attending class, studying and doing homework, and taking tests and exams: enjoyment, hope, pride, relief, anger, anxiety, shame, hopelessness, and boredom. The AEQ scales for assessing emotions in the specific context of test-taking have been called the Test Emotions Questionnaire (TEQ; Pekrun et al., 2004). Other self-report instruments used in educational emotion research but measuring emotion regulation are the Emotion Regulation During Test Taking scale (ERT; Schutz, DiStefano, Benson, & Davis, 2004), the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003), the Cognitive Emotion Regulation Questionnaire (CERQ; Garnefski & Kraaij, 2007; Garnefski, Kraaij, & Spinhoven, 2001), and the COPE scale (Carver, Scheier, & Weintraub, 1989).

Measurement Technologies

The affective computing group at the MIT Media Laboratory, the Emotive Computing Lab at the University of Memphis, and the Affective Learning Companion research group at Arizona State University have developed and tested sensing systems and tools that detect people's psychophysiological responses in order to infer their emotional experience in a variety of contexts (e.g., D'Mello & Graesser, 2010; El Kaliouby, Picard, & Baron-Cohen, 2006; Gonzalez-Sanchez et al., 2011; Picard, 2003; Scheirer, Fernandez, Klein, & Picard, 2002). Such technologies include *Expression Glasses* to collect data of interest, surprise, confusion, satisfaction from facial expressions, *Galvactivator* to collect data of arousal and excitement from skin responses, *Pressure-sensitive mouse* to collect data of frustration and anxiety from mouse-click behaviors, and *AutoTutor* including an automatic affect coding system based on Ekman's Facial Action Coding System (Ekman & Rosenberg, 1997) to detect affective states (for details, see D'Mello & Graesser, 2010; El Kaliouby et al., 2006; Gonzalez-Sanchez et al., 2011).

Another interesting development of a technology detecting learners' emotions is the *Subtle Stone*. It is a wireless, handheld squeezable ball and permits private communications between students and their teacher about emotional experience in real time (Alsmeyer, Luckin, Judith, & Harris, 2009; Balaam, Fitzpatrick, Good, & Luckin, 2010; Kim & Balaam, 2011). The *Subtle Stone* displays different colors and individual students can choose colors to express different emotions; the unique association between colors and emotions is not revealed to peers. The *Subtle Stone* has potential to be used for formative assessments during learning processes that allow not only the redesign of lessons but also teachers' emotional scaffolding for students (Kim & Balaam, 2011).

Problems in Measuring Emotions

Academic emotion research has often been criticized because of its reliance on self-report data and the lack of real-time data collection (Ainley, 2006; Kim & Hodges, 2012; Pekrun, 2006; Picard, 2010; Schutz & Davis, 2010). The development of advanced technologies such as psychophysiological sensing systems reviewed above is expected to resolve some of the issues. However, emotions are only partially observable; individuals' facial expressions or skin reactions, for example, can have different meanings even in the same situation (Buck, 1999; Hannula, 2006). Also, even if such technologies are capable of detecting accurate data related to learners' emotions, still there is the possibility of their interference with emotion processes. For instance, suppose wearable sensors are used to detect emotional states during test-taking. Even if those are lightweight and interruptions are minimal, they could detract on-task behaviors, which brings up ethical concerns as well (Schutz & Davis, 2010). In addition, emotions tend to constantly occur and change rapidly (Buck, 1985; Folkman & Lazarus, 1985; Op't Eynde et al., 2006; Pekrun, 2006; Schutz & Davis, 2010). The points in which changes are occurring or occurred can be difficult to investigate. Moreover, even if technologies, such as embodied conversational agents, relational agents, and affect-aware tutors (Bickmore & Cassell, 2004; Campbell, Grimshaw, & Green, 2009; Woolf et al., 2009, are implemented to promote positive emotions, it would be difficult to provide just-in-time support corresponding to the detected changes in emotions.

These issues are related to the *situatedness* of emotions, meaning that emotions are reciprocally and dynamically linked to cognitive and motivational processes in a specific, social-cultural context (Op't Eynde et al., 2006; Pekrun, 2006). Emotions should be studied within learning and performance contexts (Pekrun, 2006; Schutz et al., 2006). Therefore, the multilevel approach including several dimensions of analysis for personal, interpersonal, community-level, interactive, socially situated appraisal processes should be employed to fully understand and support learners' emotional experience in learning and performance contexts (Op't Eynde & Turner, 2006; Pekrun, 2006).

Conclusion

This chapter discussed the impact and process of emotions, design possibilities for optimizing emotional experience in learning and performance, and measurement instruments, technologies, and issues. Foundations for creating theory-based interventions and evaluation programs have been presented for instructional design and research on emotion and emotion regulation. Further research should continue to develop a design framework for cultivating learners' positive emotions and thereby motivation to learn and perform better. Also, a multi-method approach (Meyer & Turner, 2002; Pekrun, 2006) using not only self-report instruments and emotion-detecting technologies but also other data collection methods, such as discourse analysis, interviews, observations, interaction analysis, etc., should be considered to minimize limitations in emotion measurement. In addition, in order to test the effects of interventions developed for promoting or reducing certain discrete emotions, interventions should be implemented in the contexts where targeted emotions are present. There have been numerous studies where emotion-evoking stimuli were used, such as movie clips, images, and so on (e.g., Coan & Allen, 2007; DeSteno, Petty, Rucker, Wegener, & Braverman, 2004; Lepper, 1970). However, emotional responses can be different person to person and it is likely unethical to induce intense frustration, anxiety, hopelessness, anger, etc. (e.g., Lepper, 1970; Scheirer et al., 2002). Last, reframing motivation research that considers emotions in the realm of educational communications and technology is necessary (Meyer & Turner, 2002, 2006; Turner & Patrick, 2008).

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7 Instructional Design Models

Robert Maribe Branch and Theodore J. Kopcha

Abstract

This chapter presents information about the role of models used for instructional design. While heuristics provide broad references for approaching instructional design, specific applications of procedures necessary to actually develop teaching and learning materials require more defined models. The purpose here is to promote a better understanding about the appropriate utilization of instructional design models. Instruction is posited here as including both teaching and learning, and that teaching and learning are inextricably connected with regard to the construction of knowledge and skills. Since the first appearance of instructional design models in the 1960s there has been an ever-increasing number of models published in both the instructional technology and other education literature based on the assumptions that instruction includes both teaching and learning. While there are hundreds of instructional design models, there have been only a few major distinctions among them, until recently. Still, instructional design models provide conceptual tools to visualize, direct, and manage processes for creating high-quality teaching and learning materials. The proper selection of instructional design models assists us in appropriately matching the right process with the right situation. Thus, instructional design models serve as a valuable source for matching the right creative process to the right design situation as well as an effective framework for conducting instructional design research.

Keywords

Educational technology • Teaching • Learning • Instruction • Instructional design • Design models

Introduction

This chapter presents information about the role of models used for instructional design. Instructional design is a system of procedures for developing education and training curricula in a consistent and reliable fashion (Branch & Merrill, 2011). Instructional design is intended to be an iterative process of planning outcomes, selecting effective strategies for teaching and learning, choosing relevant technologies, identifying educational media, and measuring performance. Instructional design focuses on human learning by deliberately arranging sets of external events based on educational and training contexts (Gagné, Wager, Golas, & Keller, 2005). An instructional design process works best when it is matched to a corresponding context. However, educational contexts are often complex and feature complex issues related to teaching and learning. Therefore, effective instructional design models need to be sensitive to different

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educational contexts and be responsive to complex teaching and learning situations.

Instructional design is also known as instructional development. The specific term *instructional development* appears to have its origins in a project conducted at Michigan State University from 1961 to 1965 and defined as a systematic process for improving instruction Gustafson and Branch (2002). The final report entitled "Instructional Systems Development: A Demonstration and Evaluation Project" (Barson, 1967) is available as ERIC document ED 020673. The Barson (1967) model is one of the few models ever subjected to evaluation in different situations at a variety of institutions. According to Gustafson and Branch, the Barson project also produced a set of heuristics for instructional developers. These heuristics provided the basis for much of the early research on the instructional design process and also served as a general guide for developers in higher education.

While heuristics provide broad references for approaching instructional design, specific applications of procedures necessary to actually develop teaching and learning materials require more defined models. Markle (1964, 1978) produced models that applied the systematic approach to delivering programmed instruction, which successfully featured the tryout and revision process, although Markle did not use the specific term *instructional design*. Several attempts have been made to define instructional design and derive a standard set of meanings for various terms (Association for Educational Communications and Technology, 1977; Ely, 1973, 1983; Januszewski & Molenda, 2008; Seels & Richey, 1994), but the results have only been recently adopted or consistently used in the literature and in practice. Seels and Richey use the term instructional systems design (ISD) and defined it as "an organized procedure that includes the steps of analyzing, designing, developing, implementing, and evaluating instruction" (p. 31). The Seels and Richey definition is similar to that of the Association for Educational Communications and Technology (1977) committee's definition of instructional development:

> A systematic approach to the design, production, evaluation, and utilization of complete systems of instruction, including all appropriate components and a management pattern for using them; (p. 172).

Consistent to both definitions is that the overall instructional design and development process includes activities associated with preparing lesson plans and determining moment-to-moment instructional strategies, sequencing, motivational elements, and learner actions. Thus, the terms instructional design and instructional development have been used interchangeably and often considered synonymous. A complete discussion about the possible differences and other nuances of each term is beyond the scope of this chapter. However, the position taken here is that instructional design is different from instructional development. Design refers to the comprehensive process from beginning to end, while development specifically refers to creation activities within the overall design process. Hence, the term instructional design will be used herein for the sake of clarity.

Some Assumptions

The purpose of this chapter is to promote a better understanding about the appropriate utilization of instructional design models. Both long-time practitioners and those new to the field as well should benefit from a greater awareness about the variety of models used to portray the instructional design process. The role of instructional design models is based on three assumptions: (1) instruction includes both teaching and learning, (2) education encompasses macro-learning activities, and (3) instruction focuses on micro-learning activities.

Instruction includes both teaching and learning because teaching and learning are inextricably connected with regard to the construction of knowledge and skills. Teaching is the action performed by the person or the technology that facilitates the presentation of content and the exchange of knowledge and skills. Teaching is an attempt to organize external events for the purpose of constructing knowledge and skills. The assumption is that instruction deals with learning that is intentional (Tennyson, 1997) rather than unintentional. Unintentional learning results from everyday natural occurrences. While unintentional learning can happen in a variety of ways, such as through conversations, observations, impressions, and any unintended stimuli that occur within a context, intentional learning fosters immediate information flow, authentic experiences, and a sense of community. Intentional learning is characterized by goal-oriented strategies rather than incident-oriented strategies. The goal-oriented nature of intentional learning promotes self-regulatedness in students. Figure 7.1 summarizes some of the main differences between unintentional learning and intentional learning. Thus, focusing on intentional learning provides an opportunity for a student to be reflective, yet purposeful during periods where they are constructing knowledge, during instruction.

Unintentional	Intentional
1. Unplanned	1. Planned
2. Existential	2. Directed
3. Incidental	3. Guided
4. Accidental	4. Purposeful
5. Opportunistic	5. Defined Teacher-Student Roles
6. Informal	6. Formal

Fig. 7.1 Unintentional learning compared to intentional learning

Learning is a personal and covert cognitive activity, which is idiosyncratic to an individual. Individuals who construct knowledge and skills accomplish learning. Education encompasses macro-learning activities and refers to the activities occurring outside the classroom that directly influence the context in which intentional learning occurs. Factors that influence an educational context consider such things as human resources, technology resources, financial resources, infrastructure, and curriculum that support formal and informal learning opportunities. Instruction focuses on micro-learning activities concerned with the specific actions between the teacher and the students on a daily basis, where the intention is on achieving a defined and agreed-upon outcome. Instructional strategies are the overt means by which knowledge, skills, and procedures are constructed during intentional learning. Instructional design models vary in the amount of attention each devotes to considering macro factors (educational) related to teaching and learning, and micro factors (instructional) related to teaching and learning. Thereby, a need arose for a comparison framework by which instructional design models could be reviewed.

Since the first appearance of instructional design models in the 1960s there has been an ever-increasing number of models published in both the instructional technology and other education literature based on the assumptions that instruction includes both teaching and learning, education encompasses micro-learning activities, and instruction focuses on micro-learning activities. However, a clear need has emerged during the same time period for a way to properly utilize contextualized models to support intentional learning. This chapter presents the role of instructional design models and a taxonomy for classifying instructional design models, and describes a framework for conducting instructional design research.

The Role of Models in Instructional Design

Models conceptualize representations of reality. A model typically is a simple representation of more complex forms, processes, and functions of physical phenomena or ideas. Models by necessity simplify reality because the reality often is too complex to portray and because much of that complexity is unique to specific situations. Thus, models generally seek to identify what is generic and applicable across multiple contexts. Seel (1997) identifies three different types of instructional design models (theoretical/conceptual, organization, and planning-and-prognosis) and would label instructional design models as organization models that can be used as general prescriptions for instructional planning.

One of the most influential instructional design model builders was Silvern (1965) in the 1950s and 1960s. Silvern's work with the military and aerospace industry resulted in an extremely complex and detailed instructional design model with multiple variations that drew heavily on general systems theory. Silvern's instructional design model is rarely used today, but it remains an excellent original resource for those willing to wade through Silvern's sometime obscure writing. Students of the instructional design process easily observe Silvern's influence on the content of contemporary instructional design models.

A model developed by Hamreus (1968), while at the Teaching Research Division of the Oregon State System of Higher Education, is another classic instructional design model. One of Hamreus' significant contributions to the instructional design process was to present *maxi* and *mini* versions of his model. Hamreus' *two-size* approach to instructional design was based on the belief that there is a need for a simple model to communicate with clients and a more detailed operational version for those working on the project. Hamreus' process provided the basic structure for the Instructional Development Institute (IDI) model (National Special Media Institutes, 1971). Hamreus' model was extensively reviewed by Twelker (1972). The IDI model received extremely wide distribution and was among the best known in the United States in the 1970s and 1980s.

During the same period, instructional design scholars began reviewing the growing plethora of instructional design models to ascertain any fundamental tenets of the instructional design process. Stamas (1972) reviewed 23 models to determine whether or not each included a list of components he felt were part of the ID process. Andrews and Goodson (1980) reviewed 40 instructional design models and similar to Stamas, Andrews and Goodson developed a matrix of instructional design elements and analyzed the models for their inclusion of those elements. Salisbury (1990) reviewed a number of instructional design models from major textbooks in the field to determine the degree to which they contained specific references to a range of general systems theory concepts. Salisbury concluded that most models contained few specific references to those general systems concepts contained in his matrix. Edmonds, Branch, and Mukherjee (1994) presented the results of a review of instructional design models as a way to address their proliferation over the previous decade. Edmonds et al. concluded that an instructional design model is understood better when it is classified by its context and by the level of application for a specific context.

Such reviews of instructional design models provide a sampling of the array of processes dedicated to the systematic design of instruction. Generally, the overall instructional design process as originally conceived has changed very little, even though additional learning theories and delivery tools have emerged. The last few years have seen a shift in thinking about how instructional design can be practiced. Thus, the role of instructional design models in generating effective teaching and learning materials is ever more important.

Instructional design models now convey the guiding principles for analyzing, producing, and revising learning environments. Instructional design models either old or new should accommodate contemporary and emerging theories about planned learning and the broad array of contexts in which instructional design is being applied. Philosophical orientation and theoretical perspective frame the concepts upon which instructional design models are constructed. The more compatible the theory and philosophy are to the context in which a model is to be applied, the greater the potential that the original intent of the model will be achieved. Reiser (2001) noted "although the specific combination of procedures often varies from one instructional design model to the next, most of the models include design, development, implementation and evaluation of instructional procedures and materials intended to solve those problems" (p. 58). There are many different and inconsistent uses of terminology to describe the comprehensive process we call instructional design, but the position here is that all instructional design processes consist of at least five major activities:

1. Analysis of the setting and learner needs
2. Design of a set of specifications for an effective, efficient, and relevant learner environment
3. Development of all learner and management materials
4. Implementation of instructional strategies
5. Evaluation of the results of the development both formatively and summatively

The addition of detail related to specific applications has led to the creation of many different instructional design models. Conceptual tools and operational tools assist in identifying those contexts within which an instructional design model might be utilized.

Instructional Design Models as Conceptual Tools

Models help us describe relationships between entities, and prescribed actions among and between entities. The instructional design process is both descriptive and prescriptive. It is descriptive because it shows relationships, illustrates what happens during a process, is interactive, explains, and provides if–then relationships, and models can be conceived from displays of the processes. The instructional design process is prescriptive because it guides, assigns methods, generates strategies, is goal oriented, is active, and applies to a variety of procedures.

Instructional design models visually communicate their associated processes to stakeholders by illustrating the procedures that make it possible to produce teaching and learning materials. Instructional design models provide communication

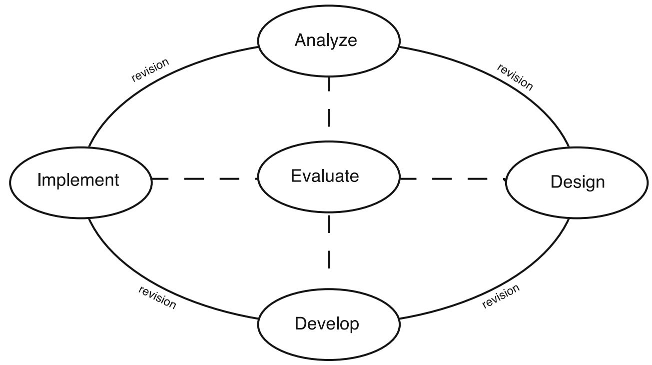

Fig. 7.2 Conceptual core elements of instructional design

tools for determining appropriate outcomes, collecting data, analyzing data, generating learning strategies, selecting or constructing media, conducting assessment, and implementing and revising the results. Figure 7.2 shows a conceptual relationship among the core elements of the instructional design process. The five core elements, Analyze, Design, Develop, Implement, and Evaluate (ADDIE), inform each other as development takes place and revision continues through the completion of the instructional design process.

The five core elements, typically referred to as ADDIE, should be regarded as a generic instructional design concept and not a model. ADDIE provides a useful tool for measuring whether a model is inclusive of the entire instructional design process or only one or more of its essential elements. Conceptual tools assist in identifying the contexts within which an instructional design model might be utilized. In fact, the quantity and quality of tools accompanying a model become significant criteria for selecting one for a specific context.

The instructional design process can be conceived as a single linear process or as a set of concurrent and recursive procedures. Rectilinear portrayals typically build from the ADDIE concept by bringing greater depth to key aspects of the design process. They are often used to teach novice designers the design process because they are simple, generic, and applicable across many different contexts. Critics of instructional design models sometimes interpret them as stifling, passive, lockstep, and simple because of the visual elements used to compose the corresponding model (Branch, 1997). This is partially due to the portrayal of the design process as rectilinear rows of boxes connected by straight lines with one-way arrows and one or more feedback (revision) lines that are parallel to other straight lines (Fig. 7.3). The visuals associated with rectilinear portrayals of instructional design models often do not acknowledge the actual complexities associated with authentic instructional design practice. Bichelmeyer, Boling, and Gibbons (2006) have criticized the use of rectilinear models for failing to provide novice designers with a portrayal of the design process that reflects

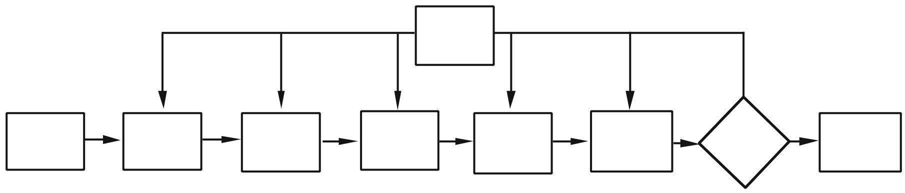

Fig. 7.3 Rectilinear portrayal of the instructional design process

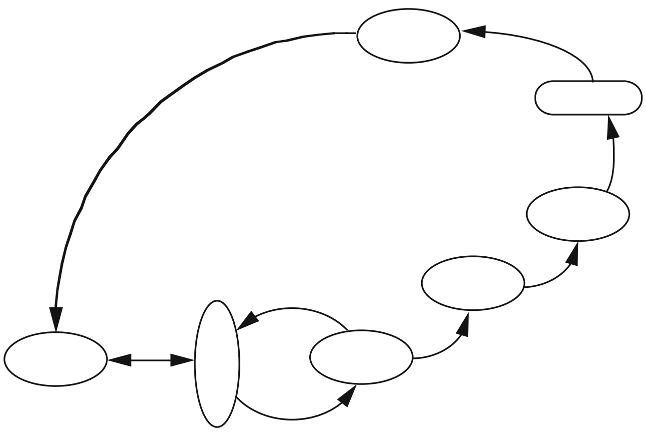

Fig. 7.4 Curvilinear portrayal of the instructional design process

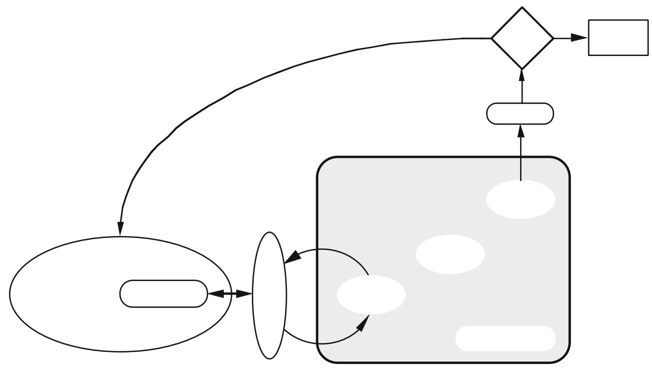

Fig. 7.5 Nested portrayal of the instructional design process

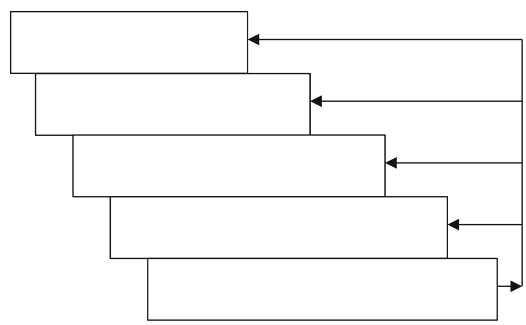

Fig. 7.6 Concurrent portrayal of the instructional design process

the manner in which designers in the field engage in instructional design.

Curvilinear portrayals of instructional design models attempt to acknowledge the complex reality upon which the instructional design is often practiced (Fig. 7.4). These are different than rectilinear models in that they are composed of various shapes (e.g., ovals, rounded rectangles, etc.) that are connected by curved lines or two-way arrows. The curved lines, arrows, and sequence of shapes attempt to represent the cyclic nature of design, where information gained at later steps in the design process can lead to revisions in earlier steps. Such models are helpful in portraying design situations where analysis cannot be completed before development and, as a result, early field trials will be treated as an opportunity to gain critical design information. However, even here, there remains an implied sequence, at least among the core elements.

Nested and concurrent portrayals of the design process tend to acknowledge the nonlinearity that is inherent within the design process. Unlike rectilinear and curvilinear portrayals, nested and concurrent portrayals present specific design elements as smaller shapes within larger shapes or as overlapping shapes. In this way, these models convey the idea that certain aspects of the design process may occur at the same time rather than in a neat, orderly sequence. The nesting and overlapping of shapes in these models is an attempt to better portray the simultaneous iterations that characterize the way instructional design is commonly practiced (Rowland, 1992; Visscher-Voerman, 1999).

Figure 7.5 portrays a nested portrayal, which contains a combination of rectilinear and curvilinear modeling as an attempt to accurately conceive the true practice of instructional design. In a real design situation, this might represent a designer who begins developing instructional goals and objectives as part of conducting the initial analysis in an effort to improve the efficiency and efficacy of the design process. Embedding the design of instructional goals and objectives within the analysis phase allows the designer to prototype and assess the clarity and accuracy of those goals and objectives at an early, critical stage.

As greater utilization of various forms of prototyping has become common in instructional design, two main forms of rapid prototyping have emerged. Some recent models have adopted a concurrent portrayal of the design process (Fig. 7.6) and a spiral design (Fig. 7.7) to indicate the recursive and highly iterative nature of the instructional design process.

The concurrent portrayal presents the design phases as a series of overlapping rectangles. This portrayal is particularly useful in situations where design must occur rapidly and key design phases must occur simultaneously or in near succession.

Much of the work using a recursive approach draws on an original model from computer software development that was created by Boehm (1988). One example of a highly iterative instructional design model is Dorsey, Goodrum, and Schwen (1997). A second form of rapid prototyping model emphasizes early development of a simple and incomplete prototype that then *evolves* into a complete design as the client and developers become clearer on what the problem is and the type of solution desired (Stokes & Richey, 2000; Tripp & Bichelmeyer, 1990). Both forms of prototyping are particularly useful in situations of high uncertainty as to client expectations or when a highly creative solution is desired. Another important instructional design concept is the Layers of Necessity (Wedman & Tessmer, 1991) that has since been refined and extended as the Contextual Instructional Design model (Tessmer & Wedman, 1995). Tessmer and Wedman conveyed the importance of context when selecting the processes and procedures for an instructional design project. Therefore, instructional design is most effective when practiced within context.

While the conceptual display of the core elements and procedures of the instructional design process are helpful, there remains a need to indicate *how to practice* particular elements of the instructional design process within specific contexts. The selection of an appropriate model for an instructional design context may in part depend on the need to reflect the degree of linearity or concurrency planned for the duration of the project. An instructional design model should contain enough detail about the process to establish operational guidelines for managing the people, places, and things that will interact with each other, and to estimate the resources required to complete a project. Given the variety of concepts upon which an instructional design process can be modeled, future instructional design research should consider the role of context during the selection or modification of an instructional design model.

Fig. 7.7 Recursive portrayal of the instructional design process

Instructional Design Models as Operational Tools

While models provide the conceptual reference, they also provide the framework for selecting or constructing the operational tools needed to apply the model. Tools such as PERT charts, nominal group techniques, task analysis diagrams, lesson plan templates, worksheets for generating objectives, and production schedule templates operationalize the instructional design process. Some instructional design models include highly prescriptive information about how to develop the companion tools or provide most of the tools necessary to apply the process. Other instructional design models only provide a conceptual diagram without any operational tools or directions for constructing companion tools necessary for their application. The Interservices Procedures for Instructional Systems Development model (Branson, 1975) is an example of a highly prescriptive instructional design model with a comprehensive set of companion operational tools. The Dick, Carey, and Carey (2005) model is moderately prescriptive and contains an array of companion operational tools. Describe tools that can be used with different instructional design models for those models having few or no accompanying tools. Effective instructional design models directly or indirectly specify products, such as timelines, samples of work, and periodic endorsements by appropriate supervisory personnel with other pertinent deliverables.

ADDIE describes a generic instructional design paradigm. Figure 7.8 presents a version of the ADDIE paradigm.

	Analyze	Design	Develop	Implement	Evaluate
Concept	Identify the probable causes for a performance gap.	Verify the desired performances, and appropriate testing methods.	Generate and validate the learning resources.	Prepare the learning environment, and engage the students.	Assess the quality of the instructional products and processes, both before and after implementation.

Fig. 7.8 A version of the ADDIE paradigm

	Analyze	Design	Develop	Implement	Evaluate
Common Procedures	1. Validate the performance gap 2. Determine instructional goals 3. Confirm the intended audience 4. Identify required resources 5. Determine potential delivery systems (including cost estimate) 6. Compose a project management plan	7. Conduct a task inventory 8. Compose performance objectives 9. Generate testing strategies 10. Calculate return on investment	11. Generate content 12. Select or develop supporting media 13. Develop guidance for the student 14. Develop guidance for the teacher 15. Conduct formative revisions 16. Conduct a Pilot Test	17. Prepare the teacher 18. Prepare the student	19. Determine evaluation criteria 20. Select evaluation tools 21. Conduct evaluations
	Analysis Summary	*Design Brief*	*Learning Resources*	*Implementation Strategy*	*Evaluation Plan*

Fig. 7.9 Common ADDIE procedures

Branch (2009) highlights some of the common procedures and main deliverables associated with the ADDIE paradigm (see Fig. 7.9).

Instructional designers are creating many tools for use by themselves and other designers as well as tools to support teachers or subject matter experts in doing their own development. Goodyear (1997) and van den Akker, Branch, Gustafson, Nieveen, and Plomp (1999) provide several descriptions of some such tools and how they are being used. Conceptual and operational tools assist in identifying the contexts within which an instructional design model might be utilized. In fact, the quantity and quality of tools accompanying a model become significant criteria for selecting one for a specific setting. However, specific procedures for planning, conducting, and managing the instructional design process can be implemented with operational tools that may or may not be identified as part of the instructional design model.

The Proper Selection of Instructional Design Models

Instructional design is practiced in a variety of settings, leading to the creation of many different models. A taxonomy of instructional design models can help clarify each model's underlying assumptions and identify the conditions under which each model might be most appropriately applied. Although the number of models published far exceeds the number of unique environments in which they are applied, there are several substantive differences among instructional design models. Thus, there is some value in creating a classification taxonomy dedicated to instructional design models. A taxonomy also helps to organize the extensive literature on this topic and perhaps to assist instructional designers in selecting a model that is best matched to a given set of circumstances. Gustafson (1981) created such a taxonomy. Gustafson's schema contains three categories into which instructional design models could be placed: classroom, product, and system. Gustafson's classification factors focused on:

1. Typical output in terms of amount of instruction prepared
2. Resources committed to the development effort
3. Whether it is a team or an individual effort
4. Expected ID skill and experience of the individual or the team
5. Whether most instructional materials will be selected from existing sources or represent original design and production
6. Amount of preliminary (front-end) analysis conducted
7. Anticipated technological complexity of the development and delivery environments
8. Amount of tryout and revision conducted
9. Amount of dissemination and follow-up occurring after development

Visscher-Voerman (1999) created different classification schemas for instructional design models and processes based on extensive data collections related to how instructional designers actually performed during instructional design projects, and created a four-category classification framework. Visscher-Voerman's four categories were instrumental, communicative, pragmatic, and artistic. Visscher-Voerman's intent was to characterize the underlying philosophy and values of each approach to instructional design, rather than the context. Visscher-Voerman and Gustafson (2004) used a

Taxonomy		
Delivery Format	Online	Synchronous = any place, but same time
		Asynchronous = any place and any time
	Face-to-Face	Same place and same time
	Blended	Any combination of Online & Face -to-Face
Selected Characteristics	1. Opportunity for Analysis	None, Limited, Unlimited
	2. Opportunity for Formative Evaluation / Assess Objectives	None, Limited, Unlimited
	3. Level of ID Expertise required	Novice, Intermediate, Expert
	4. Planned Course Length	Hours, Days, Weeks, Months, Years
	5. Level of Human Resources Needed	Individual, Small Group, Large Team
	6. Amount of Technology Resources Needed	Less Than Average, Average, More Than Average
	7. Degree of Distribution	Local, throughout the system, beyond the system
	8. Need for Usability Testing throughout Development	Low, Moderate, High
	9. Nature of Objectives and Content	Stable, Changes Infrequently, Changes Frequently

Fig. 7.10 A taxonomy for instructional design models

development research approach to reconstruct the actual practices of professional designers in an attempt to determine the reasons that designers did or did not use a particular instructional design paradigm. The results of the Visscher-Voerman and Gustafson study indicated that most designers in the study's sample followed the instrumental paradigm, and none followed the artistic paradigm; nevertheless, a conceptual framework emerged consisting of the following four design paradigms:

1. Instrumental paradigm: planning-by-objectives
2. Communicative paradigm: communication to reach consensus
3. Pragmatic paradigm: interactive and repeated tryout and revision
4. Artistic paradigm: creation of products based on connoisseurship (p. 76)

Cennamo and Kalk (2005) suggest, "full-scale, systematic instructional design and development efforts are in order in at least four situations:

1. When the content is stable enough to warrant the time and costs
2. When the potential audience is large enough to warrant the time and costs
3. When communication among a team of designers and developers is required
4. When it is important to make sure that the instruction works before it's used." (p. 12)

Dills and Romiszowski (1997) published a comprehensive collection of alternative instructional design paradigms that continue to influence the field today. However, after many years of little change in the underlying structure of the instructional design process and its accompanying models, there are new trends in learning, design, and technology that require an evolution of instructional design models.

Gustafson and Branch (2002) examined the following nine characteristics of each: (1) typical output in terms of amount of instruction prepared; (2) resources committed to the development effort; (3) whether it is a team or an individual effort; (4) expected ID skill and experience of the individual or the team; (5) whether most instructional materials will be selected from existing sources or represent original design and production; (6) amount of preliminary (front-end) analysis conducted; (7) anticipated technological complexity of the development and delivery environments; (8) amount of tryout and revision conducted; and (9) amount of dissemination and follow-up occurring after development. Figure 7.10 presents a revision to the selected characteristics section of Gustafson's (1981) taxonomy, and intends to represent contemporary instructional delivery formats. The revised taxonomy will retain the original three categories: (1) individual classroom instruction, (2) products for implementation by users other than the developers, or (3) larger and more complex instructional systems directed at an organization's problems or goals. Consider the following additions to the taxonomy above:

- Nature of the situation
- Prevailing type of knowledge
- Intended audience

- Nature of the course in terms of the curriculum, such as experiential
- Degree of flexibility inherent in the ID model

The taxonomy is intended to help designers consider the characteristics of a design situation and decide which model or aspects of specific models may be more or less appropriate based on those characteristics. For example, situations where opportunity for formative evaluation is low or where user feedback is needed on a frequent basis may benefit from employing elements of concurrent or recursive models to acquire critical user feedback throughout development rather than after it. Similarly, designers may benefit from incorporating the evaluative elements of rectilinear models in situations where the content is somewhat stable or the intended audience is large in size. By considering the characteristics noted in the taxonomy, designers might make more informed decisions about the models they employ and the reasons for doing so.

Instructional Design Research

While there are hundreds of instructional design models, until recently, there have been only a few major distinctions among them. Many of the models are simply restatements of earlier models by other authors, often using somewhat different terminology. The typical journal article simply describes the major steps in the instructional design model and perhaps how they are to be performed. Books on the topic provide extensive guidance on how to apply the models and some computer-based tools are beginning to appear. However, in almost all instances, the authors assume that their models are worthwhile, but evidence to substantiate their positions was unavailable. Ertmer and Quinn (2006) provide a useful compilation of general case studies intended to support instructional design knowledge, which has proven a valuable asset to the field of instructional design. Still, there is a disturbingly small volume of literature describing any testing of instructional design models. While instructional design models have been applied to many situations over the decades, a rigorous evaluation during the implementation of those instructional design models rarely included collecting empirical evidence about the model's effectiveness. A case study of a development project is presented along with the instructional design model in some instances, but even such low level of validation is less than desired for a healthy scholarly community or a community of practice, such as that related to instructional design theory and practice.

Instructional design models need to be subjected to rigorous validation. Such validation would require precise description of the elements of the model followed by systematic data collection concerning their application and the impact of the resulting instruction. The investigator would also need to be alert to possible discrepant or negative data. Repeated trials under such conditions would, if the model had validity, result in a set of specifications regarding the conditions under which the model was valid. Very few of the instructional design models currently available in the literature have been subjected to such rigorous scrutiny.

Rarely are instructional design models tested in the sense of rigorous assessment of their application and the resulting instruction against either predetermined criteria or competitive means of developing instruction using some other defined process. Rather, instructional design models with wide distribution and acceptance gained their credibility by being found useful by practitioners, who frequently adapt and modify them to match specific conditions. Richey (2005); Van den Akker, Gravemeijer, McKenney, and Nieveen (2006); and Richey and Klein (2007) offer relevant ideas and appropriate insights into instructional design model validation research.

Conclusion

There will continue to be an interest in instructional design models; however, the level of specificity at which they are applied will change over time. People who intend to utilize instructional design models may be well served to investigate the instructional design competencies required to successfully implement an instructional development model, such as those promoted by the International Board of Standards for Training, Performance and Instruction (Richey, Fields, and Foxon, 2000).

New trends in learning are clearly being influenced by contemporary theories in educational psychology as they concentrate on moving from teacher-centered approaches to student-centered approaches. The concept of instruction design promoted here is intended to facilitate active, multi-functional, inspirational, situated approaches to intentional learning. The presumption is that intentional learning involves multiple, concurrent interactions among people, places, and things, situated within a context, during a period of time. New trends in technology reflect improved digital delivery tools. Advances in technology increase our ability to create more interactive and engaging learning environments, such as beginning to think about the instructional design process that includes performance support systems, information management systems, and concurrent engineering.

Instructional design models provide conceptual tools to visualize, direct, and manage processes for creating high-quality teaching and learning materials. The proper selection of instructional design models assists us in appropriately matching the right process with the right situation. Finally, instructional design models serve as a valuable source for conducting instructional design research.

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The Impact of Technology and Theory on Instructional Design Since 2000

8

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Abstract

The impact of shifting epistemologies in the field of instructional design during the last century has had a major impact on how we design instruction. The goal of this chapter is to provide an overview of important shifts in ideas about what knowledge is, how it can be produced or constructed, and what it has meant for instructional design in the last decade. We discuss how technology has influenced instructor, learner, and designer beliefs about knowledge, instruction, and learning. Furthermore, we look at the changing landscape of theory and research that supports and questions these perspectives, and the implications it has on instructional practices.

Keywords

Conceptual age learning • Multiuser virtual environment • Epistemology

Introduction

Systematized models and theories of instruction can be traced as far back to pre-Socratic times of the Elder Sophists. Early educators such as Comenius, Pestalozzi, Herbart, and Montessori developed their own instructional models (Saettler, 1990; Jonassen, 1996). Since the early twentieth century, instructional design has moved through four stages, each being built on the previous one and each of them being characterized by a specific focus, theoretical assumptions, and practical implications (Winn, 2002). According to Winn (2002), the Four Ages of Educational Technology are the Age of Instructional Design, the Age of Message Design, the Age of Simulation, and the Age of Learning Environments. We will discuss how the four ages were guided by different philosophical assumptions that shaped how we design instruction, implement learning, and determine assessment.

For the purposes of this chapter, we define instructional technology according to Seels and Richey (1994) as "the theory and practice of design, development, utilization, management and evaluation of processes and resources for learning" (p. 1). While almost two decades old, this characterization manages to provide a succinct description of the field, without excluding the innovations that have come since that time. Winn proposed that current instructional design research should focus on learning environments that integrate technological innovations. Some of these include (1) artificial learning environments, (2) communication tools used to foster social interaction, (3) distributed cognition in the form of communities of practice, and (4) integrated or "complete systems" (Winn, 2002, p. 343). These technologies include high-level graphic representations of users in three-dimensional learning environments, synchronous and asynchronous communication tools, and Web-based instructional materials for guiding students to research and other learning materials.

This focus on learning environments fits well in the US public schools today. In these environments, there is call for

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shifting toward a new paradigm for learning. This is one that takes advantage of advances in technology that have been made for more than a decade. We argue that instructional design has entered a fifth age, the Age of Conceptual Learning, which was predicted nearly two decades prior:

> Technology will play central roles in teaching, assessment, and keeping track of learner progress…computer-based simulations will be excellent tools for modeling the real-world, authentic tasks and for maximizing active involvement and construction of learning. Multimedia systems will integrate computers and interactive video. (Reigeluth & Garfinkle, 1994, p. 67)

Such advances that were once viewed as a part of the future, are now at the forefront of many technology integration efforts in both K-12 and higher education settings. However, much past and current research focuses on whether learning improves, as measured by standardized tests, from the use of particular technologies. This is as opposed to studies that examine how the use of technology can transform learning environments to address higher order thinking skills and teach advanced concepts (Christensen, 2002; Guzman & Nussbaum, 2009; Zhao, Pugh, Sheldon, & Byers, 2002). Topics such as how a technology-supported learning environment increases student critical thinking ability, creativity, organizational ability, or research skills are now being explored. However, much research remains focused on teacher perceptions of technology integration rather than teaching high-level skills with technology as tool rather than as central facet of instruction (Gorder, 2008; Makki & Makki, 2012; Yanchar & Gabbitas, 2011). Throughout the chapter, we discuss how new research findings affect the state of instructional design today. In the next sections, we examine how the four ages of educational technology have led to the Age of Conceptual Learning.

Age of Instructional Design

In this section, we present the four ages of instructional design as distinct from one another in terms of theoretical frameworks, foci, and methods. While this is a necessary oversimplification to delineate the unique characteristics associated with each age, the four ages chronologically overlap as one paradigm begins to take hold as another recedes. This is not to say that vestiges of older paradigms do not continue to exist in daily practice. Many instructional designers today first learn rudimentary instructional design methods from older paradigms to gain prerequisite knowledge regarding how to design from different perspectives, as clients may desire one or another. Further, one must understand the rules of a prior paradigm before one is qualified to break them. Knowing where we have been as a field is important as we seek the future of design.

The Age of Instructional Design, which focused mainly on content creation, was based on behaviorist and cognitivist theories of learning. Learning was perceived as simply a change in behavior or cognitive structure or both with instruction designed to effectively transfer knowledge to the learner. This age was heavily influenced by the curriculum reform movement of the 1950s and specifically Tyler's (1949) linear model of instruction (Jonassen, 1996; Saettler, 1990). This included the mechanisms of scientific management emphasis and focused on both standardization and increasing learning efficiency through content and task analysis. The instructional model follows the sequence of input–process–output and its goal is to construct a comprehensive plan of instruction. Such designs presume that optimal conditions for learning primarily depend on defined learning process goals. As such, analyzing the goals of education is expected to allow instructional designers to devise methods for the achievement of these goals (Mager, 1997; Smith & Ragan, 2005). Through content and task analysis, the designer and teacher identify specific prerequisites and skills needed and select the tasks the learner should complete to achieve the specific learning outcomes (Saettler, 1990; Jonassen, 1996; Vrasidas, 2000). The approach leads to emphasis on content structure and analysis techniques and to the presentation of information (Dijkstra, 2005).

Several instructional models and learning taxonomies have followed this approach and each has made significant contributions. These have included theoretical frameworks provided by Gagné and Merrill (1990), Piaget (1972), Bruner (1990), Bloom (1984), and Ausubel (1978) among others (Cennamo & Kalk, 2005). The combination of behavioral and cognitive theories of learning gave rise to the systems approach of instructional design, which was an effort to design a complete program to meet specific needs and objectives (Reigeluth, 1999). Technology was perceived as a means to boost performance and support programmed instruction representing mastery learning, drill and practice, and convergent tutorial programs (Jonassen, 1996). Task analysis was the main method for determining content organization and instruction was to be planned, designed, evaluated, and revised (Winn, 2002).

Age of Message Design

The Age of Message Design emphasized instructional format rather than instructional content. In this era, the instructional designer and the learner had greater control over learning material than in the instructor-directed paradigm that preceded it and students with different skills and abilities were recognized to learn differently from different instructional treatments (Cronbach & Snow, 1977). During this time, pedagogical foundations emphasized how an environment was designed and its particular learning affordances were made available in conjunction with an underlying psychological model. The challenge for instructional designers working in the design of instruction has been to regulate philosophically informed principles, take advantage of technological capabilities, and to look beyond "the assumption that the format of the message alone determines the level of encoding in memory" (Jonassen, 1996, p. 317).

The basis for learning in this model is what John Dewey (1943) identified nearly a century ago as the greatest educational resource—the natural impulses to inquire or to find out things; to use language and thereby to enter into the social world; to build or make things; and to express one's feelings and ideas. Dewey saw these impulses rather than traditional discipline as the foundation for curriculum, to be nurtured for lifelong learning. The focus shifts from the features of hardware or software and instead to the user or the learner, which serves as the starting point for instructional design. Instruction centers on understanding and meaning making, with a focus on the analysis of learning processes, in particular on the way technology alters environments for thinking, communication, and action. The interactive, multimedia capabilities of the computer (i.e., sound and graphics) account for individual learning differences, individual aptitude, and learner preferences. Hence, the term "message design" evolves with both the media and the learner. Flexibility of technology provides designer and learner greater control over the learning process.

The social constructivist paradigm. Social constructivists assert, "knowledge is individually and socially constructed by learners based on their interpretations of their experiences in the world" (Jonassen, 1999, p. 217). Drawing upon foundations of situated cognition (Brown, Collins, & Duguid, 1989), context is critical in influencing how information is processed, negotiated, and used, as well as how understanding evolves. Lesson content and heuristics for performance are seen as best embedded or situated within an authentic task. As such, learning activities are interpreted by each learner rather than only an external agent such as an instructor (Brown & Palincsar, 1989). Technology and other instructional aids scaffold performance, making complex tasks more manageable without simplifying the task itself (Glaser, 1990; Vygotsky, 1978).

The goal is to cultivate the learners' thinking and knowledge construction skills. Learning becomes an act of critical and creative thinking. Accompanying instructional design principles include:

- Embedding learning in complex real-world problems
- Providing rich and flexible learning environments with goals and objectives set by the learner
- Including continuous assessment embedded in the instruction
- Detailing an evaluation which gives feedback to both learner and teacher

Multiple perspectives and social negotiation are integral parts of learning (Jonassen, 1992) in this paradigm. The overarching goal is to encourage manipulation rather than simple acquisition, and to root the learning process in concrete experiences.

Age of Simulation

As the Age of Message Design faded, the Age of Simulation emerged in response to the wide availability of technologies that allowed for the development of digital models that students could directly experience, which encouraged interaction that is learner centered. We adopt Saunders' (1987) definition of simulation in that they are "a working representation of reality … [that] may be an abstracted, simplified, or accelerated model of process" (p. 9). These tools nurture individual learning and understanding, rather than teach explicitly (Olson, 1988). Dewey (1933, 1938) perceived schools as settings in which students received life apprenticeships. Thus, interest in environments that immerse individuals in authentic, reality reflecting learning experiences, where the meaning of knowledge and skills are realistically embedded, has been long standing.

Advances in technology (e.g., Internet, increased computing power) and software innovations (i.e., *synchronous/asynchronous*, *multimedia development*, *production tools*, *simulation software*) have changed the nature and breadth of learning experiences and the instructional professional's capacity to support the learners. These technologies have greatly advanced our ability to deliver instruction in different formats and in different ways. Learning systems of enormous power and sophistication have been developed to represent evolving notions of partnerships among learners, their experience, discourse, and knowledge (Hannafin & Land, 1997).

Age of Learning Environments

Winn (2002) stated that the next paradigm shift in the field would be the Age of Learning Environments. This was an expected product of the shift from the design of instruction to the design of learning environments with learning being more dependent on the learner. Such environments cognitively and/or physically situate content and skills within complex, adaptive educational scaffolding spaces both face to face and online. From an instructional design perspective, we argue that the advances made during the Age of Learning Environments were crucial in paving the way for the current Age of Conceptual Learning. Winn's argument has been borne out with a transformation of learning environments in the last from face-to-face classrooms to online, distance-delivered courses now ubiquitous across the United States and the world.

Keefe and Jenkins (2000) categorized learning environments into three distinct periods: traditional, transitional, and interactive. Traditional learning environments were "based on nineteenth-century factory models, scientific management, the behavioral research of Thorndike and Skinner, and the learning hierarchies of Gagné and Bloom" (p. 6). According to Keefe and Jenkins, transitional learning environments came about as attempts to improve the behaviorist classrooms by emphasizing individualized instructions and group-based mastery. They go on to note that, during this period, several benchmarks were used to measure school effectiveness including test scores, attendance, completion rate, and school ratings. However, the authors contended "the movement failed to move schools toward authentic and reflective environments that the new century seems to demand (p. 10)." As a result of this failure, Keefe and Jenkins further argued that a third period called the interactive learning environments emerged to meet the needs of the next generation of learners.

Keefe and Jenkins (2000) also stated that the purpose of interactive learning environments is "to involve students and teachers in a total learning experience. Who and what define(s) a total learning environment? We argue that the definitions are different for different learners" (p. 12). To wit, Winn (2002) stated "learning environments can either be entirely natural, or they can be artificial, existing only through the agency of technology" (p. 335).

There are two reasons why artificial learning environments were proposed as beneficial by Winn. First, he asserted that artificial learning environments help people avoid the dangers associated with learning in the natural environment. Flight stimulation and army combat training come to mind as examples where the artificial learning environment provides an alternative to the real ones and have been used to train both pilots and soldiers (Nieborg, 2005; Schneider, Carley, & Moon, 2005). Secondly, Winn proposed using artificial learning environments such as digital simulations to show a child the concept of friction through a rolling virtual ball or may provide interactive demonstrations of Newton's Laws of Motion.

Interactive learning environments have been at the forefront of many research agendas including projects such as *River City* led by Chris Dede, *Quest Atlantis* under the direction of Sasha Barab, and other emerging projects funded by the National Science Foundation. Additionally, the National Institutes of Health have long funded research into the use of virtual environments to help treat psychological and addiction disorders (Anderson, Zimand, Schmertz, & Ferrer, 2007; Bordnick, Copp, Brooks, Ferrer, & Logue, 2004; Bordnick, Copp, Traylor, Walton, & Ferrer, 2009; Bordnick et al., 2008). Researchers have also explored the use of Second Life, a 3D virtual world in education, finding some benefits to learning from providing learners with advanced models with which they can interact (Brown, Gordon, & Hobbs, 2008; Derrington & Homewood, 2008). Bares, Zettlemoyer, and Lester (1998) proposed that 3D learning environments enable "learners to participate in immersive experiences" that help them "develop a deep, *experiential* understanding of highly complex biological, electronic, or mechanical systems" (p. 76–77).

Dawn of a New Age: The Age of Conceptual Learning

Winn (2002) reminds us that:

> as our technologies become more able to bring information, learning materials, even learning environments to whenever people to be, the argument can be made that we no longer need to remember what we need to know; we can simply call it up and display it when it is needed. Whether this trend spills over into the world of education to any great extent is unclear. If it does, then the impact on traditional curricula will be tremendous. (p. 348)

In a similar vein, Pink (2006) argued that we are moving from the Information Age to the Conceptual Age. He goes on to add that the future belongs to a new breed of empathizers, pattern recognizers, and meaning makers. Today, one of the biggest criticisms of instructional design is that instruction created from older paradigms does not prepare students for the real world. Many of us are still held fast in the era of traditional or transitional learning environments.

As we shift to a new Age of Conceptual Learning, a determination must be made of what a learning environment that includes these characteristics should look like. Spector (2010) suggested the shift as a reconceptualization of learning rather than the reinvention of learning itself. Current research often focuses on systemic change of school learning environments themselves, as well as the use of instructional technology to develop or expand alternative learning environments. This is instead of exploring how technology and curriculum can be aligned to merge the needs of the Industrial Age or the Information Age paradigms with what is currently available. However, a number of questions remain regarding the emerging concepts of what constitutes a comprehensive learning environment and how contemporary technologies and/or technology-supported learning environments and their complementary instructional methodologies may be used to support them.

In the context of this chapter, technology-supported learning environments are those that employ tools such as computers, distance learning equipment, Internet resources, or other comparable hardware or software in order to improve student understanding.

This notion is comparable to Winn's (2002) concept of an artificial learning environment or Grabinger's (1996) notion of a rich environment for active learning (REAL). The use of such environments is increasingly prevalent as the availability of technology in K-12 schools increases through access to online forums, educational games and simulations, and integrated digital learning environments (Squire, 2008). In the next section, we examine several trends that emerged last decade and how they have redefined instructional practices today.

Major Development: The Learning Sciences

An important development in the aughts was the establishment of the learning sciences. As with other paradigms, the learning sciences drew some inspiration from both the previous decade and fields outside of education such as cognitive science, psychology, neuroscience, computer science, engineering, and linguistics. Soon after, the Cognition and Technology Group at Vanderbilt (1990, 1993, 1994) experimented with situated cognition and anchored instruction at Vanderbilt with Jasper Woodbury and laser disc-delivered instruction. Ideas such as situating learning in context (Barab et al., 2007) and anchoring learning within narrative and ill-structured problems (Jonassen & Hernandez-Serrano, 2002) have supported later developments such as learning games (Kafai, Quintero, & Feldon, 2010; Squire, 2006), advanced forms of problem-based instruction to support science learning (Kolodner, 2002; Walker & Shelton, 2008), and multiple forms of literacy (Steinkuehler, 2007, 2008; Warren, Barab, & Dondlinger, 2008). In 1999 and 2000, the National Research Council released *How People Learn* and its companion text *How People Learn*: *Bridging Research and Practice*, which combined to outline not only the theoretical model of the learning sciences but also how the model would be implemented in classrooms and its efficacy researched.

Instructional Design from 2000 to 2010

During this period, several learning environments have been of special interest. These include computer-assisted language learning (CALL) environments, mobile learning, multiuser virtual environments, and games and simulations designed to support learning concepts and or practicing science, mathematics, and language arts skills. Each of these foci responds to the changing needs of our schools such as the large increase of non-English-speaking students at every grade level, the recent shift in the needs of businesses from Industrial Age skills to Information Age skills, and the increase in student computer knowledge and experience with new technologies.

Table 8.1 Affordances of technology-supported learning environments

General	PBL	IBL
Frees teacher to act as facilitator (Grabinger, 1996; Hewitt, 2004)	Allows for authentic, embedded assessments and rapid feedback (Grabinger, 1996)	Allows for customized teacher and environmental feedback to address learner needs (Grabinger, 1996)
Allows for learner-control of instruction (Winn, 2002)	Has propensity for strengthening fledgling communities resolved around common practice (Wenger, McDermott, & Snyder, 2002)	Allows for embedding of simulations to practice dangerous techniques with feedback (Winn, 2002)
Allows rapid customization to learner needs (Hannafin & Hannafin, 1995)	Allows for peer feedback (M. Hannafin, Hannafin, Hooper, Rieber, & Kini, 1996)	Allows for self-directed learning using situational role-play and team-building games (Winn, 2002)
Motivational for students (Hannafin et al., 1996; Prensky, 2001)	Allows for active learning through interaction with peers to solve authentic problems (Grabinger, 1996)	Allows access to large databases to support individual and group knowledge building (Hewitt, 2004)

The use of virtual/digital environments is increasingly prevalent as the availability of technology in K-12 schools increases through online forums, educational games, simulations, and integrated digital learning environments. This is especially true in theoretical frames stemming from social constructivism such as inquiry-based learning (IBL) and problem-based learning (PBL). IBL has commonly been employed to challenge students to experiment with the world and find answers to perplexing questions rooted in science. The latter, PBL, involves learners in interacting with ill-structured problems with no single answer to construct their own knowledge and solutions. These solutions are constructed in small groups through communication and inquiry with the instructor serving as facilitator of learning rather than provider of fixed knowledge. Research-supported benefits of technology-enhanced learning environments are presented in Table 8.1.

At present, there is an emerging focus on using K-12 students in studies using digital learning environments. This primarily stems from research showing students in grade school are strongly motivated by the visual and self-regulated learning elements of digital learning environments (Foster, 2008; Tuzun, 2004), impacts on student empathy for social and other complex systems (Brush & Saye, 2003; Gee, 2004), and that they can provide strong visual models through graphical representation (Englert, Manalo, & Zhao, 2004), simulation (Aldrich, 2003; Baylor & Kim, 2005), and animated pedagogical agents (Baylor, 1999, 2002, 2005; Baylor & Kim, 2005) within designed digital learning environments that are complemented by rich face-to-face learning interactions facilitated by knowledgeable teachers (Barab et al., 2007; Warren, Dondlinger, Stein, & Barab, 2009; Warren et al., 2008).

Also during the last decade, we have witnessed the transformation of clunky cell phones into elegant smart phones. These small but powerful devices are minicomputers that are fundamentally redefining teaching and learning. Mobile learning allows us to embrace the anytime–anywhere learning model worthy alternatives to help educators, administrators, and researchers achieve the nation's vision for the twenty-first-century model of wired schools.

As developers flood the educational market with technology products, researchers must separate those that have little or no educational value from those with research-supported uses in K-12 classrooms. Spector (2010) reminded us "technology is not what learning is all about" (p. 30). This makes our research role larger than simple academic inquiry and places the researcher in a position as a shield against potentially harmful or ineffective technologies. As such, we need research-driven data to help us sieve through technologies that help advance the field and technologies that are simply available.

Game-Based Learning

Over the last few years, one major area that has emerged in education for design, development, and research is in the realm of digital games and simulations. In 2009, the Entertainment Software Association (ESA) estimated that the US computer and video game software sales generated $10.5 billion (Entertainment Software Association, 2011). Between 2005 and 2009, the industry grew at an annual rate of more than 10 %.

According to De Freitas (2006), there are four types of game-based learning: (1) educational games, (2) online games, (3) serious games, and (4) simulations. For the purpose of this chapter, games for learning are "applications using characteristics of video and computer games to create engaging and immersive learning experiences for delivering specified learning goals, outcomes, and experiences" (De Freitas, 2006, p. 3).

Beginning with such seminal games as *Math Blaster*, *Lemonade Stand*, and *Oregon Trail* in the early 1980s, the educational gaming or *edutainment* market has become massive (Slagle, 2004). Since then, digital products by companies such as *Leap Frog* have become best sellers, despite a lack of research to support their use (Dondlinger, 2007; Hays, 2005). Without such research, companies that sell products and digital learning environments may make unsupported claims regarding the educational benefits of their edutainment products.

Recently, researchers have begun exploring foundational questions about learning through interaction with digital gaming environments themselves, as well as through interactions with other participants in massively multiplayer online games (Squire, 2006, 2008; Squire & Steinkuehler, 2005; Steinkuehler, 2004). Gee (2004) believes that for games to be educational, three principles in design must be included empowered learners, problem solving, and understanding. Educational games must encourage learners to be active participants in their learning, be flexible in meeting the needs of the learners, and create a sense of identity for them.

The complexity of the digital environment, as well as the intensity of communication use to solve problems and meet objectives in video games such as Blizzard's *World of WarCraft* and NCSoft's *Lineage* series, provides a rich environment for qualitative inquiry, using such methods as computer-mediated discourse analysis (CMDA) (Herring, 2004), interviews with players, and observer participation. In a Kaiser Foundation study (2008), 97 % of the teens said that they have played games on the computer, the Internet, gaming devices, or TV; further, over half of these teenagers stated that they play games on a daily basis. This study also noted that for teens, games offer a social experience for them whether it is face to face or online.

Researchers are now examining whether gaming is educational for students (De Freitas & Oliver, 2006; Mikropoulos & Natsis, 2011; Squire, 2006). Questions such as why, when, and how learning is taking place in a digital gaming environment, the depth of cognition engaged in by learners, the social nature of learning, and player motivation for learning have implications for the design of future technology-supported learning environments.

Emerging research methods and questions. While important because of the promise of student interactivity, autonomy, motivation, and modeling potentials (Prensky, 2001; Salen & Zimmerman, 2004; Winn, 2002), the limitations of games and simulations as platforms for K-12 learning must be explored. Additionally, research regarding the educational value of console and computer games and simulations is still uncertain. The field has yet to face extensive, systematic research, so serious questions remain (Bowers, 2000; Warren & Lin, 2012). Current research has started to explore a number of important research questions such as:

1. What organizational structures in a K-12 setting represent the greatest challenge to introducing new kinds of learning environments such as those based on games and simulations?
2. Once a limitation is identified, how have successful systems been chosen and how have they implemented a systemic change process that overcame this obstacle?

3. At what point does their use begin to interfere with the larger educational, affective, and disciplinary goals of K-12 schools? Are there harmful side effects to their use in the classroom to attention span, level of independent thought, or motivation to learn without the extrinsic reinforcement of the game or simulation? Are the instructional goals and affordances of a game at cross-purposes with those in a state curriculum?
4. Are learning environments that take advantage of several computer technology affordances concurrently, such as communication tools or the ability to embed audio and video, more successful at engaging students in learning than traditional, non-digital learning environments as Gee (2003), Squire (2006, 2008), and others suggest?

This last question focuses primarily on the use of integrated, digital learning environments. Such online spaces have been built based on research on the use of games and simulations, forums, web logs, and online scaffolding as instructional tools (Barab, Warren, & Ingram-Goble, 2008; Barab et al., 2009; Warren & Jones, 2008). The combination of several different technology tools to take advantage of the learning affordances of each in an attempt to build an immersive learning environment is a next step in the use of technology to support education. It would move beyond the use of isolated technology tools and create a thematically unified experience for learners.

One attempt to create such a situation at the K-12 school level was *Quest Atlantis* (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Barab et al., 2009). This digital learning environment was designed to improve elementary school students' understanding of science through IBL methods in which students develop solutions to difficult, persistent environmental problems. Research studies with *Quest Atlantis* indicated improvement of student motivation and a reduction in gender differences communicated in the game environment (Barab et al., 2005; Group, 2004). New designs, coupled with stringent research, will help determine whether such complex learning environments have other benefits to learning and allow the development of guidelines for future designs.

In addition to quantitative methods, the researchers at Quest Atlantis also employed qualitative methods to describe the experiences of the learners in the learning environment. This included data collection and analysis tools such as interview, CMDA (Herring, 2004), critical ethnographic analyses (Carspecken, 1996), and case studies (Robson, 2002) in order to identify those learning experiences in the environment that make the most impact. In addition, multiple observations, teacher interviews, and document analysis were also used in order to gain additional data regarding (1) student attitudes toward using the digital learning environment, (2) student motivations for completing schoolwork in the space, and (3) teachers' multiple means of scaffolding or otherwise aiding student learning either in the classroom or in the digital environment.

Further research may result in findings that support the development of engaging educational games and simulations. Research completed at the end of the decade has already provided some guidelines for the appropriate design and use of games and simulations in or as learning environments (Dondlinger & Warren, 2009; Warren & Dondlinger, 2008; Warren, Dondlinger et al., 2009; Warren & Lin, 2012; Warren, Stein, Dondlinger, & Barab, 2009). Without such research, a number of products with problematic content or instructional methods may make their way into classrooms, resulting in reduced student learning, disciplinary problems, or other unforeseen consequences. Further, it is important that researchers make known their successful, and even unsuccessful (Baker, 2008), attempts at making games and simulations for learning so that others may replicate or improve upon those instructional designs.

Computer-Assisted Language Learning Environments

CALL is a theory of language learning that focuses on using the audio-visual, tactile, and interaction affordances of computers to improve student acquisition of second and foreign languages (Egbert & Hanson-Smith, 1999; O'Bryan & Hegelheimer, 2007). While many of these products been standalone CD-ROM-based computer programs, teachers increasingly use online learning environments to improve language learning (Bacherman, 2007; Edasaw & Kabata, 2007; Vilmi, 1999; Wimberly, 2007). One of the most common online learning environments used to support language learners in the early to mid-2000s was *Tapped In* (http://www.tappedin.org). This technology was used in English-as-a-second-language (ESL) and English-as-a-foreign-language (EFL) classrooms to allow primary language speakers and secondary language speakers to meet synchronously. During their interactions, second language speakers could clarify questions about idiom, grammar, and spelling rules, as well as discuss cultural issues relevant to learning a foreign language from a peer. Inquiry in this area is under way, but is mainly conducted by researchers in fields lacking knowledge of message design, media design, or production that would generate studies that are more valid. Of notable exception is the work of Boling and Soo (1999) in the area of CALL software design. Their chapter provides an excellent example of what our field can contribute to the study of CALL environments.

Emerging research methods and questions. Because of the use of online forums, research in the area of CALL has focused on the use of these spaces to increase student understandings of foreign culture, foreign language idiomatic use, and as a means to practice textual exchanges with native language speakers (Bacherman, 2007; Edasaw & Kabata, 2007; Kirkley, 2004; O'Bryan & Hegelheimer, 2007; Wimberly, 2007). Possible research questions include the following:

1. How does a technology-supported CALL learning environment impact the learning experience of nonnative learners as they work to improve their fluency in a foreign language, as mediated by a digital learning environment?
2. How is learning impacted when native language speakers act as peer tutors, modelers of appropriate idiom and general language use, or instructors regarding their local culture for nonnative speakers?

Research methods such as CMDA (Herring, 2004) may be useful for examining learning in such a setting. CMDA methods are used to analyze online textual interactions among learners to help identify critical periods of learning. This is especially helpful when using instant messaging, e-mail, and electronic forums as part of CALL. Quasi-experimental studies using pre- and posttests to measure changes in language fluency stemming from intervention using a CALL environment should also generate important findings regarding their effectiveness. These research methods should be valuable for measuring gains regardless of whether the learning environment consists of daily classroom use of software programs or online learning environments such as *Tapped In*.

Online environments used to support ESL and EFL learning such as electronic forums and video games such as *Where in the World is Carmen San Diego*? have been used since the 1980s to explore other conceptions of a learning environment in order to understand a foreign culture (Egbert & Hanson-Smith, 1999). This view of learning conceives of learners as central participants in the generation and sharing of knowledge in a supportive learning environment.

Conclusions

While the Age of Learning Environments has opened up new possibilities, there remain challenges and limitations faced during the era that still must be overcome. Among them: (a) K-16 are systems prone to technological fads (Cuban, 2001; Lee, 2009); (b) there remains a lack of research supporting instructor choice of appropriate emerging technologies; and (c) some instructors and administrators still resist new technologies as classroom tools (Cuban, 1988; Cuban, Kirkpatrick, & Peck, 2001).

Where is instructional design going next? What major developments of the last decade in the fields of technology, education, epistemology, and cognitive science will come together to create the next stage in our development? We believe that mobile computing is the next frontier in the field of instructional design. For far too long, we have relied on instructional design models of the past to prepare learners for the Age of Conceptual Learning. Today, learning is personal, portable, and unpredictable. As we leap from an industrial society to a knowledge society in a single generation, learning means greater flexibility, accessibility, immediacy, interaction, and collaboration. These changes have significant ripple effects on education and instructional design. Pink (2006) reminds us that early adopters may do extremely well but the rest may miss out and fall behind.

For instructional designers, this means asking what we can do *through* technology instead of what can we do *with* the technology? The answer may be deceptively simple. The Age of Conceptual Learning is about harnessing the power of the mind rather than the machines. This would require generating new ideas rather than acquiring inert knowledge and, importantly, designing instruction to teach conceptual thinking rather than only concrete facts to be repeated on a standardized assessment. It is an age when students will learn to see computers as tools that help them see and create their own bright future.

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The Technological Pedagogical Content Knowledge Framework

9

Matthew J. Koehler, Punya Mishra, Kristen Kereluik, Tae Seob Shin, and Charles R. Graham

Abstract

In this chapter, we introduce a framework, called technological pedagogical content knowledge (or TPACK for short), that describes the kinds of knowledge needed by a teacher for effective technology integration. The TPACK framework emphasizes how the connections among teachers' understanding of content, pedagogy, and technology interact with one another to produce effective teaching. Even as a relatively new framework, the TPACK framework has significantly influenced theory, research, and practice in teacher education and teacher professional development. In this chapter, we describe the theoretical underpinnings of the framework, and explain the relationship between TPACK and related constructs in the educational technology literature. We outline the various approaches teacher educators have used to develop TPACK in pre- and in-service teachers, and the theoretical and practical issues that these professional development efforts have illuminated. We then review the widely varying approaches to measuring TPACK, with an emphasis on the interaction between form and function of the assessment, and resulting reliability and validity outcomes for the various approaches. We conclude with a summary of the key theoretical, pedagogical, and methodological issues related to TPACK, and suggest future directions for researchers, practitioners, and teacher educators.

Keywords

TPACK • Professional development • Teacher knowledge • Technology integration

Introduction

The increasingly ubiquitous availability of digital and networked tools has the potential to fundamentally transform the teaching and learning process. Research on the instructional uses of technology, however, has revealed that teachers often lack the knowledge to successfully integrate technology in their teaching and their attempts tend to be limited in scope, variety, and depth. Thus, technology is used more as "efficiency aids and extension devices" (McCormick & Scrimshaw, 2001, p. 31) rather than as tools that can "transform the nature of a subject at the most fundamental level" (p. 47).

One way in which researchers have tried to better understand how teachers may better use technology in their classrooms has focused on the kinds of knowledge that teachers require

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in order to use technology more effectively. Shulman (1986) proposed that effective teaching requires a special type of knowledge, pedagogical content knowledge (or PCK), that represents "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8). The central idea of PCK is that learning to teach a particular subject matter requires not only understanding the content itself but also developing appropriate instructional strategies and skills that are appropriate for learners.

Mishra and Koehler's (2006) formulation of the technological, pedagogical, and content knowledge (TPACK) framework extended Shulman's (1986) characterization of teacher knowledge to explicitly consider the role that knowledge about technology can play in effective teaching. Specifically, three major knowledge components form the foundation of the TPACK framework as follows:

- *Content knowledge* (*CK*) refers to any subject-matter knowledge that a teacher is responsible for teaching.
- *Pedagogical knowledge* (*PK*) refers to teacher knowledge about a variety of instructional practices, strategies, and methods to promote students' learning.
- *Technology knowledge* (*TK*) refers to teacher knowledge about traditional and new technologies that can be integrated into curriculum.

Four components in the TPACK framework, address how these three bodies of knowledge interact, constrain, and afford each other as follows:

- *Technological Content Knowledge* (*TCK*) refers to knowledge of the reciprocal relationship between technology and content. Disciplinary knowledge is often defined and constrained by technologies and their representational and functional capabilities.
- *Pedagogical Content Knowledge* (*PCK*) is to Shulman's (1986) notion of "an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8).
- *Technological Pedagogical Knowledge* (*TCK*) refers to an understanding of technology can constrain and afford specific pedagogical practices.
- *Technological Pedagogical Content Knowledge* (*TPACK*) refers to knowledge about the complex relations among technology, pedagogy, and content that enable teachers to develop appropriate and context-specific teaching strategies.

The TPACK framework suggests that teachers need to have deep understandings of each of the above components of knowledge in order to orchestrate and coordinate technology, pedagogy, and content into teaching. Most importantly, TPACK is an emergent form of knowledge that goes beyond knowledge of content, pedagogy, and technology taken individually but rather exists in a dynamic transactional relationship (Bruce, 1997; Dewey & Bentley, 1949; Rosenblatt, 1978) between the three components (Koehler & Mishra, 2008; Mishra & Koehler, 2006). An important part of the TPACK framework is that TPACK does not exist in a vacuum but rather is grounded and situated in specific contexts as represented by the outer dotted circle in the TPACK diagram.

Relationship Between TPACK and Similar Constructs

The TPACK framework is not the only framework developed to understand and explain teachers' use of technology. Though these alternative approaches may employ slightly different labels they are in broad agreement that the advent of new technologies requires teachers to possess knowledge that connects the affordances (and constraints) of these new technologies to the transformation of content and pedagogy. Our focus on the TPACK framework (as opposed to the others) in this review is that amongst the similar and related approaches, the TPACK framework has received the most traction in research and in professional development approaches, as evidenced by over 600 journal articles about TPACK.

Similar frameworks have been developed both independently and directly out of the TPACK framework, most based upon Shulman's (1986) model of Pedagogical Content Knowledge Similar frameworks include (but are not limited to): *ICT-Related Pedagogical Content Knowledge* (ICT-Related PCK); *Knowledge of Educational Technology*; *Technological Content Knowledge*; *Electronic Pedagogical Content Knowledge* (ePCK); and *Technological Pedagogical Content Knowledge-Web* (TPCK-W) (Angeli & Valanides, 2005; Franklin, 2004; Lee & Tsai, 2010; Margerum-Lays & Marx, 2003; Rhonton & Shane, 2006; Slough & Connell, 2006). Each of these alternative approaches are briefly defined below, highlighting significant departures from the TPACK framework.

ICT-Related PCK

ICT-Related PCK is an instructional systems design model based on Shulman's (1986), and Cochran, Deruiter, and King's (1993) conceptualization of PCK defined as an integrated understanding of four components: pedagogy, subject matter content, student characteristics, and the environmental context for learning. Specifically According to Angeli and Valanides (2005), ICT-Related PCK comprises the body of knowledge educators must possess to teach with ICT, and consists of a combination of five components of teachers' knowledge: pedagogical, subject area, students, environmental context, and ICT. ICT-Related PCK is defined as knowing how to: (a) Identify topics to be taught with ICT; (b) Identify

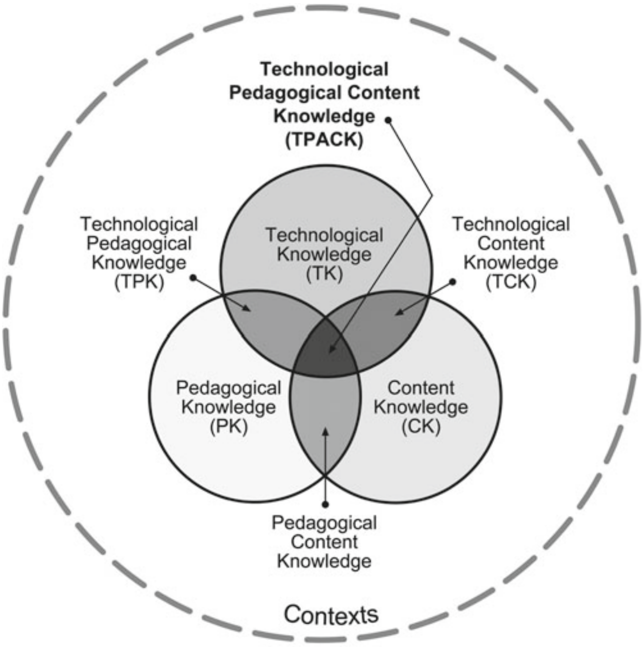

Fig. 9.1 The technological pedagogical content knowledge framework

representations for transforming content; (c) Identify teaching strategies that were difficult with traditional technology; (d) Select ICT tools to support content and teaching strategies; and (e) Infuse ICT activities in classrooms.

ICT-Related PCK differs from TPACK in that it conceptualizes the integration of technology into teaching as happening within the realm of PCK, and requiring additional types of knowledge within PCK. Whereas the TPACK framework considers technology knowledge as its own body of knowledge (Fig. 9.1), it should interact with other bodies of knowledge (CK, PK, and PCK) to form new types of knowledge (TCK, TPK, and TPCK).

Knowledge of Educational Technology

Knowledge of Educational Technology (Margerum-Lays & Marx, 2003) views teachers' understanding of educational technology through the lens of Shulman's (1986) conceptualization of teacher knowledge—content knowledge, pedagogical knowledge, and pedagogical content knowledge. Knowledge of Educational Technology is different from the TPACK framework, in that the TPACK framework emphasizes the interactions between content, pedagogy, and technology—treating technology knowledge as separate but interacting with all other forms of teacher knowledge. In contrast, Knowledge of Educational Technology treats the integrated understanding of teaching with technology as understandable, for the most part, using the Shulman's existing framework of teacher knowledge. Specifically, teachers' knowledge of educational technology can be understood as three components: Content Knowledge of Educational Technology, Pedagogical Knowledge of Educational Technology, and Pedagogical Content Knowledge of Educational Technology.

Technological Content Knowledge

Technological Content Knowledge is a theoretical framework defined by an emphasis on the "total intersection" between technology and content (Slough & Connell, 2006). Slough and Connell use the analogy of lenses, one each for technology and content through which teaching and learning can be viewed, as such the two components, technology and content become one. Additionally, according to Slough and Connell the lenses serve to "magnify" teaching and learning providing a more focused approach and collaborative professional development process. Slough and Connell offer the example of computer-generated visualizations, as the total overlap of technology and content, offering a new way building scientific understanding. The Technological Content Knowledge framework differs from the TPACK framework in that the TPACK framework conceptualizes technology as a realm of knowledge separate from content or pedagogy and focuses on the areas of overlap between the three realms of necessary knowledge.

Electronic Pedagogical Content Knowledge

Electronic Pedagogical Content Knowledge (ePCK) consists of knowledge that teachers must possess in order to successfully integrate technology into their classrooms (Franklin, 2004; Irving, 2006). ePCK is not a framework necessarily but a specific type of teacher knowledge that exists alongside knowledge of content, pedagogy, and curriculum. This type of knowledge is distinctly different from basic technical knowledge and linked to teacher efficacy, a necessary component of technology integration (Becker, 2000; Dawson, 1998). Teachers who possess ePCK are able to develop and implement a curriculum that includes methods and strategies for integrating technology in content areas in an effort to maximize student learning. Electronic Pedagogical Content Knowledge differs from the TPACK framework as ePCK emphasizes pedagogical practices specific to educational technology rather than conceptualizing technology as a distinct realm of knowledge.

Technological Pedagogical Content Knowledge-Web

Technological Pedagogical Content Knowledge-Web (TPCK-W) consists of knowledge of TPACK components content and pedagogy, and in place of general technology, the World Wide Web (Lee & Tsai, 2010). TPCK-W is identified as an extension of both Shulman's (1986) original framework and Mishra and Koehler's (2006) TPACK framework. This framework was specifically developed in response to the generality of technology in the TPACK framework and attempts to elaborate and clarify the more advanced knowledge necessary to teaching specifically on the Web. The new Web component includes knowledge regarding general uses of the Web, specific Web tools, and advanced use of the Web. An example of TPCK-W is being able to select proper (to desired content and pedagogy) existing Web-based courses to assist teaching.

To summarize, although these alternative approaches employ different labels, they are in broad agreement that the advent of new technologies requires teachers to develop new forms of knowledge that connect the affordances (and constraints) of these new technologies to the transformation of content and pedagogy. Early research on TPACK focused on establishing and developing the underlying conceptual framework (Koehler & Mishra, 2005a, 2005b; Mishra & Koehler, 2006). As the TPACK framework has been increasingly adopted, research has turned to measuring TPACK as well as to test the effectiveness of various TPACK-based interventions (Graham, Tripp, & Wentworth, 2009; Guzey & Roehrig, 2009).

Research on Measuring TPACK

A wide range of instruments have been developed to assess pre- and in-service teachers' use and understanding of TPACK (Koehler, Shin, & Mishra, 2012). Using a specific set of inclusion criteria, Koehler, Shin, & Mishra (2012) identified a total of 66 research publications that implemented TPACK measures after reviewing a total of 303 TPACK-related articles that were published in journals, conference proceedings, dissertations, and conference presentations. They found that 141 instruments, which included 31 self-report measures, 20 open-ended questionnaires, 31 performance assessments, 30 interviews, and 29 observations, were used across those studies to assess participants' understanding of TPACK. The following section briefly reviews each of the five types of instruments and provide some concrete examples (see Koehler et al., 2011 for a more detailed analysis of these different instruments).

Self-Report Measures

A total of 31 self-report measures have been developed and utilized, most commonly for pre- or in-service teachers (29 of 31). Typical self-report measures take the form of asking participants to numerically rate their agreement with statements regarding technology and teaching. For instance, the Survey of Preservice Teachers' Knowledge of Teaching and Technology consists of 47 self-report items that assess pre-service teachers' knowledge of 7 subscales of TPACK (Schmidt et al., 2009).

Open-Ended Questionnaires

A total of 20 TPACK instruments utilized open-ended questionnaires, all with pre- or in-service teachers. Typical TPACK open-ended questionnaires contain items that ask teachers to write about their overall experience in an educational technology course or professional development program that are designed to promote pre- or in-service teachers' TPACK. For instance, So and Kim (2009) used a prompt such as "what do you see as the main strength and weakness of integrating ICT tools into your PBL lesson?" in their research. The authors then coded pre-service teachers' responses focusing on their representations of content knowledge with relation to pedagogical and technological aspects of the course.

Performance Assessments

Performance assessments are intended to directly evaluate participants' TPACK by examining their performance on tasks that are designed to represent authentic teaching tasks or scenarios. There are 31 known TPACK instruments that utilize performance assessments, most of which are designed for use with pre- or in-service teachers. Performance assessments take many forms; for instance, some ask participants to create artifacts such as lesson plans, portfolios, or reflective journals (Graham et al., 2009; Harris, Grandgenett, & Hofer, 2010; Kereluik, Casperson, & Akcaoglu, 2010; Suharwoto, 2006). Other types of performance assessments ask participants to respond to a teaching scenario that involves complex problem solving (Curaoglu, Bu, Dickey, Kim, & Cakir, 2010; Graham, Borup, & Smith, 2012).

Interviews

As of June 2010 there were 30 known TPACK interview assessments. Interviews typically include a pre-determined set of questions and are typically recorded for later transcription, analysis, and coding. A vast majority of interviews were conducted with pre or in-service teachers. For examples, to examine changes in pre-service teachers' TPACK, Ozgun-Koca (2009) interviewed those teachers and asked them about the advantages/disadvantages of calculator usage and the effects on the teaching and learning process and environment.

Observations

Observations are intended to directly observe participants' TPACK at a given time point and to track the development of their TPACK over time. Observations were typically conducted either in classrooms or during a professional development session. There are 29 known studies that utilized observation, and a vast majority of the observations were conducted on pre- or in-service teachers. Observations, like interviews, were typically recorded for later analysis. For example, in Suharwoto's study (2006) researchers videotaped all the courses taught by internship teachers to see how they implemented technology in their own teaching. Once the observations were completed, researchers analyzed the transcript of the observation by following the coding scheme that was grounded in the TPACK framework.

Issues of Reliability and Validity in Measuring TPACK

Koehler et al. (2011) found that of the 141 TPACK instruments used as assessment tools, most were done so without any evidence of reliability or validity. Approximately 69 % of the studies included in their analysis did not present any evidence of reliability. Over 90 % of them failed to establish the validity of the measures that were used in their research. As research in TPACK becomes more empirical, it becomes more important that researchers scrutinize the measurement properties of TPACK instruments. The critical issue of "does my instrument accurately capture my participants' levels of understanding in TPACK?" needs to be addressed first as it is essential for good research (Kelly, 2010; Koehler et al., 2011).

Researchers who develop TPACK survey instruments, however, have devoted attention to the reliability and validity properties of TPACK measurement. Specifically, TPACK survey research has allowed researchers to further address the following issues about the measurement of TPACK: Internal consistency, test–retest reliability, and discriminant and convergent validity.

Internal consistency of TPACK surveys. Across several different TPACK survey instruments, researchers have found high levels of internal consistency (a form of reliability), indicating that the items of the TPACK survey correctly focus on the individual factors comprising TPACK. For example, Schmidt et al. (2009) created a 47 Likert item survey designed to measure each of the seven components of TPACK. One hundred and twenty-four preservice teachers completed the survey and showed significant growth in all seven TPACK areas, with the largest growth in their TK, TCK, and TPACK. Schmidt et al. (2009) report good to excellent internal consistency (using Cronbach's alpha between 0.75 and 0.92) for each of the seven constructs.

Similarly, Archambault and Crippen (2009) developed a survey of 24 statements to measure teachers' knowledge with a national sample of 596K-12 online teachers. These teachers assessed their own knowledge (PK/CK/TK/TCK = 12 items, PCK/TPK/TPACK = 12 items) using a 5-point Likert scale. They established the instrument's internal consistency (using Cronbach's alpha) to be 0.70 to 0.91 for each of the seven constructs. Sahin's (2011) TPACK survey also finds internal consistency ranging between 0.88 and 0.93 for the seven constructs of TPACK.

Test–retest reliability. To date, the only TPACK survey to study test–retest reliability is Sahin (2011), reporting test–retest reliability ranging from 0.79 to 0.86 on each of the seven constructs of TPACK. The time between the two measurement periods was not reported.

Discriminant and convergent validity. Discriminant validity tests the extent to which a concept is not highly correlated with other measures of theoretically different concepts. In the Schmidt et al. (2009), Archambault and Crippen (2009), and the Sahin (2011) studies, discriminant validity was addressed through exploratory factor analysis, finding support for each of the seven factors in each study. Additionally, the Sahin (2011) study measured the correlation between the seven TPACK subscales and external variables including the grades achieved in various types of teacher education courses (content courses, pedagogical courses, technology, courses, etc.).

The flip side of the coin to discriminant validity is convergent validity—the extent to which two measures agree (correlate) when they are both theoretically related. Sahin found high degrees of convergent validity, finding that scores on Pedagogical Knowledge (PK), for example, correlated significantly with grades achieved in pedagogical courses. Sahin also concluded that there was evidence of discriminant validity because PK did not correlate with grades in content courses or technology courses. Sahin (2011) found similar results for each tpack subscale and course grade pairing, consistent with a high degree of discriminant validity (when the measure and the grade in a course shouldn't correlate) and convergent validity (when the measure and the grade in a course should correlate).

Survey studies have also shown, however, significant correlations between the seven constructs of TPACK. For example, Schmidt et al. (2009) wrote:

> With respect to correlations between subscales, coefficients varied from 0.02 (social studies and math content knowledge) to 0.71 (TPK and TPACK). TPACK was significantly correlated with eight subscales at the 0.001 level and with social studies content knowledge (SSCK) at the 0.05 level. The highest correlations were between TPACK and TPK ($r = 0.71$), TPACK and TCK ($r = 0.49$), and TPACK and PCK ($r = 0.49$). (p. 135)

Similarly, Archambault and Crippen (2009) noted "correlations between pedagogy and content knowledge responses were high (0.690) as were those between pedagogical content and content (0.713) and pedagogical content and pedagogy (0.782)" (p. 318). Similar high degrees of correlation exists across studies, although which of the seven subscales of TPACK are most strongly correlated differs from study to study.

The high degree of correlation between the subscales of TPACK raise questions about the extent to which the components of TPACK are, in fact, separate components. Archambault and Crippen conclude, for example, that "We are concerned, however, that this distinction between content knowledge and pedagogic content knowledge introduces an unnecessary and untenable complication into the conceptual framework on which the research is based…" (p. 318).

Correlation between the subcales, per se, is not problematic in the TPACK framework. For example, theoretically TPK and TPACK should relate (and therefore correlate) to one another (see Fig. 9.1). TPACK, in part, derives from an understanding of TPK. To what extent the components of TPACK should correlate, however, is a question for further research. Answers to such questions have important implications for how TPACK should be measured, as well as what researchers are actually measuring when they administer TPACK instruments.

Models for Developing TPACK

The development of TPACK is clearly an important area of research due to its significant implications for teacher education and teacher professional development. Research to date, however, has not identified an ideal developmental sequence for developing TPACK in teachers, though many have raised the issue (Brush & Saye, 2009; Graham, 2011; Holmes, 2009; Niess, 2008).

There are some unique challenges in developing TPACK within the pre-service teacher population. Pre-service teacher candidates, for example, typically begin with minimal levels of all the TPACK constructs, meaning there is not a natural knowledge base upon which to build. In-service professional development programs, on the other hand, can usually depend on participants having a certain level of pedagogical content knowledge, and increasingly, as technologies become more ubiquitous and easy to use, technology knowledge, that they can use as a starting place for developing TPACK.

Several professional development approaches can be found in the literature for helping pre-service and in-service teachers develop TPACK. It should be noted that there is some overlap in the different approaches. In the sections below, we broadly characterize these approaches into three broad categories (Fig. 9.2). We also try to provide a key example of what these efforts look like in practice.

From PCK to TPACK

In this approach, technology is introduced as a way to support and enhance the strategies already being used in the classroom. For in-service teacher training this is a natural approach because it builds on teachers' years of teaching experience. Researchers have found, however, that this approach also has its limitations because in-service teachers bring prior beliefs that actually limit their vision and willingness to try new technology-supported strategies (Niess, van Zee, & Gillow-Wiles, 2010). In this approach, a teacher who first develops PCK through methods courses and experiences that don't involve the use of technology. Then later, the teacher learns how technology might be used to enhance and build upon the strategies they are already familiar with.

An example of the PCK to TPACK approach in practice is the use of activity types (Harris & Hofer, 2009; Harris, Mishra, & Koehler, 2009). In this approach, learning is driven content focused pedagogies called *activity types*, a shorthand for that which is "most essential about the structure of a

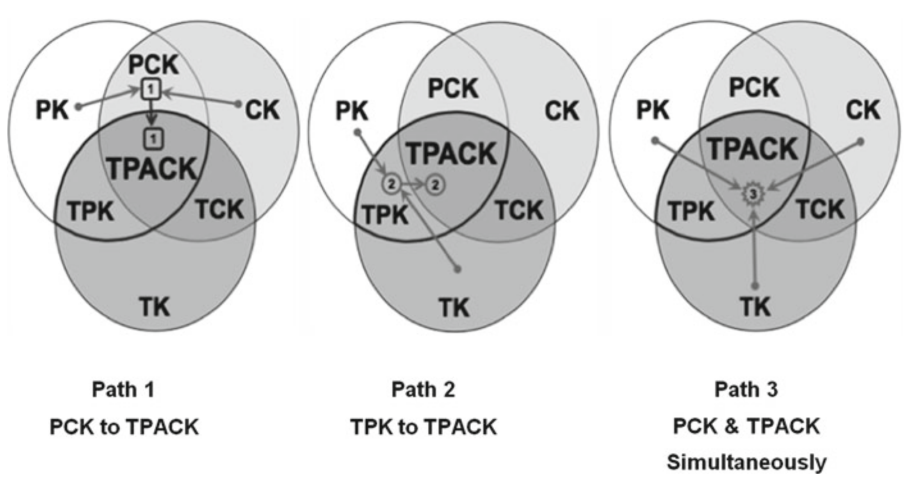

Fig. 9.2 Three paths to developing TPACK

particular kind of learning action as it relates to what students do when engaged in that particular learning-related activity." Examples of activity types include "group discussion," "role play," and "field trip" (Harris & Hofer, 2009; p. 101).

In this approach, activity types are seen as content-specific. The activity types for social studies teaching, for example, might be different than those used for mathematics teaching. Using activity types, teachers first focus on learning goals, and based upon pedagogical decisions, teachers then select appropriate activity types for a given learning experience, formulate assessment plans, and select tools (including technology) that will best help students benefit from the learning experience.

A recent study looking at the use of an instructional intervention using an activity types approach for in-service teacher professional development found that teachers' decisions around educational technology use became more deliberate and judicious and their use of learning activities and technologies became more "conscious, strategic, and varied" (Harris & Hofer, 2011, p. 211).

Other notable examples of the PCK to TPACK pathway include the use of dynamic spreadsheets for teaching mathematical reasoning and problem solving (Niess et al., 2010), the use of geospatial technologies to facilitate science inquiry (Trautmann & MaKinster, 2010) or teaching geography (Doering, Veletsianos, Scharber, & Miller, 2009), and the use of moviemaking to create digital documentaries to promote historical thinking among students (Hofer & Swan, 2006).

From TPK to TPACK

An approach prevalent in my teacher preparation programs is going from TPK to TPACK. The typical example of this approach involves a pre-service candidate who has had not yet taken content-specific methods courses when he/she is required to take a prerequisite technology integration course. These courses are typically taught by an instructional technologist with either limited expertise in all subject areas, or an explicit goal to broadly cover technology that spans all content areas. Because the candidate does not already know pedagogical strategies specific to teaching science, mathematics, language arts, social studies, or other subject areas, the technology integration courses tend to focus on how technology can support teacher productivity and general pedagogical strategies. For example, candidates may learn how to use Web 2.0 technologies to increase active learning or technologies for communicating with parents and students, but that learning isn't directly connected content-specific methods such as guided inquiry in science or balanced literacy in language arts. It is only later when the candidate takes methods courses and has field experiences that she can start to integrate her TPK with PCK to develop TPACK. Thus, the first step in this path is to develop TK and TPK in these early course experiences. As candidates take methods courses specific to their content specialty, their knowledge of TPK should expand into TPACK, and they should incorporate their knowledge into their disciplinary understandings.

This approach is the "default approach" in most institutions of higher learning. Technology is relegated to a few courses and teachers are left to take those lessons and apply them to their own content areas.

A more sophisticated example of the TPK to TPACK pathway is an approach called *Technology Mapping* (Angeli and Valanides, 2009). As "an empirically-based approach for understanding and promoting a situative orientation toward the development of ICT–TPCK" (p. 160), the technology mapping approach emphasizes mapping or connecting the properties of technological tools with the ability to transform content representations and/or support student-centered pedagogies. Examples of ways that tools can transform content include making representations visual, multimodal, or interactive. So, a tool like Google Earth transforms a static visual geographic representation into one that the learner can interact with. Similarly, the affordances of a tool may facilitate or make difficult certain pedagogies. For example, Google Earth could facilitate a virtual field trip in a way that a whiteboard cannot. Angeli and Valanides (2009) conducted a study to investigate the effectiveness of the technology mapping approach for developing TPACK with over two hundred pre-service teachers. They found statistically significant improvements in students' performance on design tasks towards the end of the semester as compared to the beginning of the semester.

Developing PCK and TPACK Simultaneously

A third pathway to TPACK is to try and develop PCK and TPACK simultaneously. In a pre-service context this means replacing the educational technology course, as we know it, with a systematic integration of technology-supported strategies into the methods courses and field experiences. For example, a program following this approach might not have a technology integration course at all but rather require that each of the content-specific methods courses teach candidates how to use technology for teaching within the discipline. Thus, candidates would be developing their PCK and their TPACK simultaneously.

One challenge of this approach is the cognitive load that students experience when they are simultaneously trying to develop their pedagogical, content, and technological knowledge. Brush and Saye (2009) comment on this, "Many times, pre-service teachers are simultaneously learning content, technology, and pedagogy—as well as learning the craft of teaching—which can prove overwhelming to individuals just entering the teaching profession" (p. 47).

An example of this approach in practice is the *Learning Technology by Design* approach (Koehler & Mishra, 2005a, 2005b). In this approach, teachers develop TPACK by them working in teams to design solutions to ill-structured, real-world problems of teaching and learning over an extended period of time. Instead of directly teaching technologies to teachers, teachers' learning is driven by the design-problem and a consideration of different technologies that may contribute to the final design solution. Because real problems of practice require designers to integrate content, pedagogy, and technology, learners necessarily engage with actively integrating these types of knowledge as they work on a solution.

Others have also explicitly used design as a vehicle for helping teachers to develop TPACK (Angeli & Valanides, 2005; Lambert & Sanchez, 2007; So & Kim, 2009; Valanides & Angeli, 2008). The *Learning Technology by Design* approach, however, is the only approach of these that uses the simultaneous development TPACK and PCK pathway.

Research that looked at the effectiveness of the learning by design approach found that participants on design teams significantly developed knowledge in each of the seven components of TPACK (Koehler & Mishra, 2005b), and that design team conversations increasingly demonstrated higher forms of integrated understanding, in the form of PCK, TPK, TCK, and TPACK (Koehler, Mishra, & Yahya, 2007).

Developing TPACK in the Content Areas

A central theme of TPACK development is that this kind of knowledge is situated in a content-specific context rather than a more general context. This section outlines three aspects of TPACK development that are woven throughout the TPACK research.

Teaching Strategies/Methods

One distinction between TPACK and traditional technology integration efforts is a focus on content-specific pedagogies as opposed to general pedagogies. The TPACK literature is full of examples, predominantly in social studies, math, and science. Many of the activity types identified by Judi Harris (see http://activitytypes.wmwikis.net/) are content-specific activities that are found in one content domain but not others (Harris & Hofer, 2009). Bull, Hammond, and Ferster (2008) focus on the strategy of historical investigations for social studies teachers and show how Web 2.0 tools can support that strategy. Other examples in social studies include using technology to support empathetic role-paying or historical think-alouds (Brush & Saye, 2009), using geospatial technologies to develop a "sense of place" (Doering & Veletsianos, 2007), and the use of primary sources to develop historical thinking (Swan & Locascio, 2008). In math and science, examples include using technology like spreadsheets to analyze real data in the science inquiry process (Niess et al., 2010) and the use of technology to support different phases of scientific problem-solving inquiry in biology classrooms (Toth, 2009).

Knowledge of Learners

Content-specific understandings of learners is a focus of the PCK literature, but it has not been a strong focus in the TPACK literature, even though several TPACK measurement instruments have questions related to content-specific learner understandings (Cox & Graham, 2009; Graham, Borup, & Smith, 2012; Mouza & Wong, 2009; Schmidt et al., 2009). Knowledge of learners' content-specific understandings is an implicit part of both the technology mapping (Angeli & Valanides, 2009) and activity structures (Harris & Hofer, 2009) approaches to teaching TPACK. However, more research could be done on specifically how technology supports teachers in identifying learner content-specific understandings and not just how it is used to address misconceptions or difficult concepts.

Content Representations

Many researchers have noted that the properties of a particular technology support teaching specific content, and that technological tools can transform representations in ways that afford some conceptual understandings better than others to students (Angeli & Valanides, 2009; Bull et al., 2008; Valanides & Angeli, 2008). McCrory's research on representations in science teaching (McCrory, 2008; McCrory, Putnam, & Jansen, 2008), for example, demonstrates how technological affordance can be useful to (1) speed up the time of natural events, (2) organize large bodies of data, and (3) record data that would normally be hard to gather.

The need to attend to context is by no means restricted to TPACK research—These three themes have also been identified as central in the existing PCK literature base (Lee & Luft, 2008; van Driel, Verloop, & de Vos, 1998). The further development of an understanding of the contexts in which TPACK is developed is an important dimension of future TPACK related research.

Conclusions

Clearly the TPACK framework since its introduction in 2006 has had significant impact on both theory and practice in educational technology. In conclusion we point to both what the framework has achieved as well as point to some key limitations and directions for future work.

The single biggest contribution of the TPACK framework has been in the area of teacher education and teacher professional development (Koehler, 2012; Mishra, & Wolf, et al., 2012). Research has indicated that most pre-service and in-service professional development of teachers often fail to "support and develop educators identities as fluent users of advanced technology" (US Department of Education, 2010, p. 45). The TPACK framework argues that programs that emphasize the development of knowledge and skills in these three areas in an isolated manner are doomed to fail. Thus, effective teacher educational and professional development needs to craft systematic, long-term educational experiences where the participants can engage fruitfully in all three of these knowledge bases in an integrated manner.

One of the significant limitations of the TPACK framework is that it is neutral with respect to the broader goals of education. For instance, the TPACK framework does not speak to what kinds of content need to be covered and how it is to be taught. As many scholars have pointed out the new millennium requires a great level of focus on higher order thinking skills, collaboration and creativity (see Mishra & Kereluik, 2011 for a review). A beginning in this direction has been made through an argument for the role of TPACK in developing twenty-first Century trans-disciplinary skills (Mishra, Koehler, & Henriksen, 2011).

Finally, though there has been a flowering of research on TPACK and its measurement, the review indicates that there is still much to be done—particularly in the area of measuring how TPACK works in different disciplinary contexts. The quality of research has also been patchy, and there is a clear need for better-designed studies and instruments.

Concerns, however, go beyond merely research designs and instrumentation. A key aspect of the TPACK framework has to do with teacher autonomy and seeing teachers as designers, particularly with technologies that change at a very rapid pace (Koehler & Mishra, 2008; Mishra, Koehler, & Kereluik, 2009). This open-endedness and rapid rate of change have implications for the kinds of research we do since it is challenging to develop instruments when the final goals are creative products that often cannot be specified in advance, or when the tools inherent to the pedagogy and content keep changing. This means that we need to newer methodologies and ways of capturing and analyzing phenomena that respect this open-endedness and creativity even while being sensitive to statistical variability and experimental biases. Norman (2010) recently made a similar argument new research paradigms for the design sciences as well. Thus, though we applaud the effort that has gone into extant instruments and measures for TPACK we also argue that we need to be looking beyond existing methodologies to develop newer techniques and approaches that recognize the pragmatic, applied and creative goals of teaching with technology.

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Ethics of Educational Technology

10

Stephanie L. Moore and James B. Ellsworth

Abstract

While ethics has been an under-researched area in educational technology, it is receiving current recognition as a critical focus for inquiry and development. In this chapter, we review the contribution of ethics as part of the history of professionalization of the field, the development of a code of ethics for the profession, and contemporary ethics issues like cultural competence, intellectual property, accessibility and universal design, critical theory in educational technology, system ethics, and social responsibility of professionals. In addition, this chapter presents major theoretical and philosophical models for ethics that pertain specifically to technology in educational systems along with implications of research from other fields exploring the integration of ethics into policy, standards, and higher education curricula. Existing research on ethics in educational technology programs suggests a very low level of integration in such domains at present; findings from a survey of the curricular landscape and implications for future research and development are discussed along with consideration of ethics as a foundational component not only to professional standards, practices, and leadership, but also to education policy, as we highlight the role of faculty and graduate programs, practicing professionals, and scholarly associations in shaping future directions and research in this emerging domain.

Keywords

Professional ethics • Ethics as design • Ethics across the curriculum • Social responsibility • Conative domain

Introduction

> "*Neither stability nor change have any intrinsic value. The worth of stability is in the goodness it preserves, while the worth of change is in the goodness it brings about.*"
>
> (Don Ely, 1976, p. 151)

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We must start any conversation on ethics within the discipline of educational technology by underscoring how dramatically understudied this topic has been—and by suggesting that much of this owes to our legacy of viewing ethics as the domain of philosophy rather than action. Yet ethics, properly conceived, are about more than abstract pondering; they are the foundation of the exemplary standards of performance we expect of professionals (Dean, 1993) and thus the necessary precursor to any valid and effective planning and design (Moore, 2010, in press).

Unfortunately, while calls for a more systematic treatment of ethics in our field are increasing, educational technologists today have little to turn to as a robust, well-defined discourse within our own literature. This chapter examines priorities for addressing this gap through development of

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models (including instructional design, instructional systems design, and evaluation frameworks), proposing a synergistic relationship between ethics and research: one that suggests how we can look to the history of the field and the research represented in this very volume as informing professional ethics for the field. Based on this, we advance a framework and research agenda for deepening our discourse and understanding in the ethical domain.

This is only a beginning. If we succeed in our call to action, then this chapter looks dramatically different in future editions, as rigorous investigations of the relationship between our models and theories and the societal impact of our practice become habitual and intertwined through the discourse of our profession.

A Brief History of Ethics in Educational Technology

Attention to the ethics of technology, in general, is a relatively recent phenomenon. Although "techne" has been a part of the human condition since antiquity, it was long considered too worldly for philosophical consideration, and since ethics were the domain of the philosophical, technology and ethics rarely met in discourse over the centuries, even though their narratives are tightly entwined (Scharff & Dusek, 2003). Until the last 100 years or so, when thought was given to technology at all, it was generally assumed to be an inherent good. Under this Positivist paradigm, because technology was viewed as the derivative of science—and science claimed the objective high ground—its products and outputs inherited those same claims to objective virtue. Today, though, we live in a world where a century of unintended consequences—and of their greater transparency to public scrutiny—has recast this faith as naïve. Scanning the popular literature, it might almost appear that the default narrative of technology today is one in which it is inherently bad. These two storylines do daily battle in the headlines: one side is boldly proclaiming "the Internet promises to democratize the world," and the other is whispering "the Internet promises to expose our children to pedophiles."

In between these rival claims is a chasm—one created and widened by our legacy of neglecting any meaningful deliberation on the ethics of technology; it is this chasm that our discipline and many others are seeking to bridge today. Davis (1999) details what he calls the "ethics boom" across disciplines. Thanks to national scandals, technological advances, or poor professional performance, a host of disciplines began to build ethics into college curricula and map ethics-related standards for professional practice.

During this time, the military profession returned to wrestling with the ethical obligations of leadership in war, after civil-military tensions came to a head when President Truman fired General Douglas MacArthur in Korea, and when soldiers under an inexperienced lieutenant massacred Vietnamese civilians at My Lai. Medicine was also among the first to integrate ethics into the curriculm by attempting to define what constituted "practical ethics" or "applied ethics," according to Davis (1999), as physicians confronted increasingly difficult decisions due to technological advances that pitted expensive devices that treated the most ill patients against (for example) building a clinic to serve more people with less serious ailments. Medical faculty worked with faculty in philosophy to develop a new approach to integration of ethics into the curriculum that emphasized ethics as practice or part of a decision making process. The legal profession has faced national scandals like Watergate, which led states to start mandating ethics courses in law programs, and they similarly started developing "practical ethics" as part of the curriculum. Soon after, engineering and science disciplines began to follow suit, following their own scandals ranging from bribery (kickbacks paid by civil engineers to receive preferential treatment in contracts, which ultimately forced the resignation of Vice President Spiro Agnew), to discovery of falsified testing records for airbrakes supplied by B.F. Goodrich for the Air Forice's A7D plane, to the Ford Pinto's exploding gas tank and poorly designed cargo doors on DC-10 aircraft. Similarly, social science disciplines faced an extensive history of cases of mistreatment, deception, abuse, debilitation, or even death of human subjects during research spanning several centuries and occuring in numerous countries. In 1948, the Nuremberg Code was the first international document to establish ethical boundaries for research in social and medical sciences, establishing core principles and practices such as informed consent. Then the boom really took off, as business, accounting, nursing, journalism, financial analysis, public administration, and even dentistry followed suit.

Yet one glaring and curious void in Davis' history of ethics in higher education curricula is the profession of education itself (in general, and educational technology specifically). Although he discusses research ethics extensively, his primary focus is on their application in medical or social science fields like sociology and psychology. Based on Davis' logic, however, that disciplines integrate ethics based on responses to public scrutiny, the time appears at hand for education disciplines to explore ethics beyond just research ethics. *A Nation At Risk* and *No Child Left Behind* reflect increasing national scrutiny of educational systems and teacher preparation, calling into question the value that we add to—or subtract from—our learning systems and society in general. Critics of educational technology such as Cuban (1986, 2003) and Healy (1990, 1999) offer pointed indictments underscoring a perceived failure of technology to contribute anything worthwhile to teaching and learning, challenging our relevance and therefore our *raison d'etre*. A policy brief from WestEd (2002) poses the question directly:

> Investments in education technology can pose major dilemmas for policymakers. Most agree that in today's world, technology is not a frill but an important part of any modern curriculum. Equally clear, however, is its expense.... Over the last decade, K-12 spending on technology in the United States tripled, now totaling more than $6 billion. Given these realities, policymakers at state and local levels are asking the predictable question: Does this level of spending on technology make a difference in student learning? (p. 1)

This question of "worthwhileness" was raised in several early foundational pieces of the field. Texts republished as "classics" by founding figures in Ely and Plomp (1996)—such as Finn (1996a, original published 1962, 1996b, original published 1953), Davies (1996, original published 1978), and Kaufman (1996, original published 1977; see also Kaufman, Corrigan, & Johnson, 1969)—explicitly focused awareness on ethics for the profession, calling for a professional code of ethics, reflection on the ethical nature of educational technology, and development of assessment models that evaluated societal level impact of educational technology as a profession. According to Davies (1996), while technology and creativity expanded the range of choices available to educators, they also "made it more difficult to foresee the full consequences of the choices made and the actions taken" (p. 15). He states:

> Technology, contrary to popular belief, is not necessarily confined to the *means* by which educators realize their ends. Technology also raises anew questions about the nature of the ends themselves. It forces us to reflect on the morality of what we are about, by its very insistence on defensible choices. … Unfortunately, the deep satisfaction, sense of creativity, and feelings of accomplishment that can be expressed in the *doing* of educational technology are too often preferred to the related, but very different, pleasures of *contemplating* educational technology. Yet contemplation and responsibility go hand in hand, one without the other is meaningless (sic, pp. 15–16).

Emphasizing the importance of a results orientation, Kaufman (1996, reprinted from 1977, 2000) provides a practical way of discussing results (or ends) and societal benefit by framing this discussion in terms of assessment. Kaufman outlines the explicit relationship between what educational technologists do and the ultimate impact of such work on society:

> The simple truth is that what the schools do and what the schools accomplish is of concern to those who depend upon the schools, those who pay the bills and those who pass the legislation. We are not in a vacuum, and our results are seen and judged by those outside of the school—those who are external to it.… This external referent should be the starting place for functional and useful educational planning, design, implementation, and evaluation—if education does not allow learners to live better and contribute better, it probably is not worth doing, and will probably ending up being attacked and decimated by taxpayers and legislators (1996, p. 112).

From Kaufman's perspective, school is not an end but rather a means to an end, for education is ultimately judged by graduates' ability to survive and positively contribute to society. If that is the real end of our efforts, our practices should begin by assessing the "gaps between current outcomes and required or desired outcomes based on external survival and contribution" (p. 112). Thus, according to Kaufman, the practice of educational technology should first begin by determining and justifying what the ultimate *desirable* impacts of our actions are on society and using that as a guide for the design process. Kaufman has developed this over the years into a full framework for assessment that he calls "Mega" (2000), which may very well prove to be a guiding framework for applied ethics in the field given its focus on societal impact. This framework is explored later in the review; here we note that as the field was developing, Kaufman made explicit this question of social responsibility—of the profession's ultimate impact on society—as something that its practitioners must answer to if educational technology was to be a viable, respected profession.

Reinforcing this focus on results, Finn (1996a, original published 1962) asserted that technology is not a collection of gadgets, hardware and instrumentation, but is instead "a way of thinking about certain classes of problems and their solutions" (p. 48). Finn argued that the questions of "what is desirable and why" should be subjects of continual contemplation by the profession. In fact, it was Finn who, in seeking to define the educational technology profession, laid out six traits that characterize any profession, and included ethics among these (1996b, reprinted from 1953):

1. An intellectual technique
2. An application of that technique to the practical affairs of man
3. A period of long training necessary before entering into the profession
4. An association of members of the profession into a closely knit group with a high quality of communication between members
5. A series of standards and a statement of ethics which is enforced
6. An organized body of intellectual theory constantly expanding research

Since Finn's initial advocacy for a professional code of ethics (1953), educational technology's associations have reliably addressed ethics within our profession in this manner. The Division of Audio Visual Instruction (DAVI) of the National Education Association did formalize a code of ethics (Hitchens, 1970; National Education Association, 1975), and this was carried over by the Association for Educational

Communications and Technology (AECT) through the Committee on Professional Ethics. That committee was formally charged with conducting an annual review of the code and adjusting it over the years, and continues to do so today (see Welliver, 2001). Ethics have also been preserved in formal definitions of the field among its essential characteristics. In the 1977 definition reprinted in the opening chapter of Ely and Plomp's *Classic Writings on Instructional Technology* (1996), the authors outline 16 parts, including two reflecting ethics:

> 9. Educational technology has an association and professional communications. There is at least one professional association directly concerned with educational technology—the Association for Educational Communications and Technology. *In addition to facilitating communication among members through its annual convention and three periodic publications*, ***it serves to develop and implement the standards and ethics***, ***leadership***, ***and training and certification characteristics of the profession***. (p. 13, emphasis ours)
>
> 11. Educational technology operates within the larger context of society. It advocates being a concerned profession—concerned about the uses to which its techniques and applications are being put. Further, as a profession, it has taken stands in favor of intellectual freedom, in favor of affirmative action, against stereotyping in materials, and in favor of enlisting technology in support of humane and life-fulfilling ends. (p. 13)

The 1994 Seels and Richey definition still included Finn's fifth criterion, but only a page and a half was devoted to how ethics have been addressed since Finn's original publication. The authors recognized that issues like copyright, fair use, and equity were becoming increasingly important. Still, the lack of depth they accorded this topic, and the contemporaneous dearth of citable research or applied work on ethics reveals that this particular "defining characteristic" has gone relatively unexamined for decades.

Despite this prolonged period where educational technology's code of ethics may have risked falling victim to Finn's warning that codes can become mere window dressing, later in the very year that definition was published (1994), a discussion began on the ethic of "social responsibility" that would revitalize one of the codes and suggest a means of making ethics actionable. Based on discussions at the 1994 AECT convention, an entire issue of *Educational Technology* was devoted to the topic of the ethics of the profession. Authors in that edition tackled the topic from a variety of critical theory perspectives including postmodernism and feminism.

Whereas the focus of ethics in educational technology had previously been the individual's behavior and correction where necessary, it was now expanding to include a sense of a professional "social" responsibility. The eleventh part of the 1977 definition that stated "Educational technology operates within the larger context of society" (fully quoted above) had become a formal topic in the literature. Yeaman, Koetting, and Nichols (1994) brought the notion of social responsibility to the fore as they introduced the special issue of *Educational Technology*. Their emphasis was "not on the ethical behavior of individuals, which seems to be the domain of the existing professional codes of ethics, but on the ethical position of educational technology in society" (p. 5). For the authors, social responsibility is an awareness of culture with its intrinsic values and interests and a commitment to basic human rights (p. 10). Social responsibility within educational technology seeks to understand how the profession relates to society, culture, politics, gender, and science and technology in general (Yeaman et al., 1994, p. 10). The authors close with a remark on what is lacking in our field's emphasis on "how to" research and presentations: "there is definitely nothing wrong with liking and advocating educational technology. It is good to find better ways of doing things. Nevertheless, it is important that better should include the qualities of being ethical and more humanizing" (p. 12). This led to changes to AECT's code of ethics to reflect an emphasis on the profession's social responsibility (Yeaman, 2004). Contemporaneously, other associations like the International Society for Performance Improvement (ISPI) began a similar shift in the emphasis of their codes and competencies (Watkins, Leigh, & Kaufman, 2000).

Most of this seminal discussion, however, remained philosophical, approaching the topic through a critical theory lens. With little of it linking results to professional practices, an evidentiary basis for prescribing how one would actually go about addressing ethical outcomes in one's work remained elusive. In one key exception, practitioners in the Human Performance Technology domain of the field have developed a professional certification, the Certified Performance Technologist (C.P.T.), which seeks to address this gap. In moving from a focus on code to one on competencies, the ISPI certification process has started to shift the emphasis of professional ethics to an empirical basis defined by desirable, demonstrable results that can be used to evaluate performance. Furthermore, in addition to competencies related to analysis, design, development, implementation, and evaluation (ADDIE), key authors in this domain have repeatedly called for the inclusion of assessment—which Kaufman (2000) argues is essential to ensuring socially responsible decisions—and ethics in the competencies for certification (Dean, 1999; Guerra, 2001; Stolovitch, Keeps, & Rodrigue, 1999).

The Current State of Affairs: Ethics Across the Curriculum and the Literature

Unfortunately, for a profession that prides itself on its grounding in research and evidence-based theory, educational technologists have very little to guide us, either in

Table 10.1 Count for articles on ethics across educational technology journals

Journal	Number of articles on ethics as of 2011[a]
Educational Technology Research & Development (ETR&D)	39 (since 1950) 4 with ethics as the primary topic; remaining have ethics as a subtopic[b] (1.5 % of articles based on 2,501 total articles since 1950 have some mention of ethics) Of what we deem to be the substantive research and theory in the field, 98.5 % doesn't even mention ethics
TechTrends	111 (since 1980)[c] (4.8 % of articles—based on 2,307 total articles—since 1980 have some mention of ethics)
Instructional Science	12 (since 1970)[d] (1.2 % of articles based on 958 total articles since 1970 have some mention of ethics)
Contemporary Issues in Technology & Teacher Education	52 (since 1997)
International Journal of Educational Telecommunications	9 (since 1997)
Journal of Interactive Learning Research	19 (since 1997)
International Journal on E-Learning	37 (since 1997)

[a]"Ethics" was defined broadly in this search, including articles on ethics, social responsibility, accessibility, copyright, and cultural considerations. No articles specific to research ethics turned up in this search, probably owing to the fact this is a much more general topic affecting many disciplines and therefore appearing in research methodology journals

[b]A majority of these articles focused on application of educational technology in non-US settings. In articles where "ethics" or "social responsibility" were explicitly in the title, the article's focus was still on cultural considerations, suggesting that this is the current predominant conception of ethics in the field. In every instance except one (Lin, 2007), ethics was mentioned as a "need" or a gap but not the actual topic of investigation

[c]An initial search yields 176 articles in *TechTrends*; however, the 111 reported exclude convention reports, calls for proposals, "Datebook" entries, and "Editor's Notes." Of those 111, 11 (10 %) are Paul Welliver's "Ethics Today" series from 1990 to 1995. Twelve are Andrew Yeaman's contributions to that series, and another seven from his 2004 "Professional Ethics" series (17 % of the total articles)

[d]Technically, all articles with any mention of ethics in *Instructional Science* appeared from 1999 onward; no such articles appeared in this journal prior to that year. Further, none of these articles focused on ethics as a primary topic; rather, all gave passing mention to ethics in their discussion of other matters. These trends in treatment are also representative of the remaining journals

considering the ethics of our own practice or in the preparation of our students for contemplating their own. A recent study by Moore (2005, 2009) surveyed faculty and graduate curricula in educational technology programs in the USA and Canada using Kaufman's "Mega" framework mentioned earlier. The survey asked faculty to indicate which dimensions of social responsibility the field currently adds value to and which dimensions it *should be* adding value to that it presently does not. Moore's study also reviewed vision and mission statements for degree and certificate programs in the USA and Canada, as well as curricula (represented by course offerings), to assess the presence of ethics as a subject of study and the degree to which ethics are formally integrated into professional preparation.

Faculty responses to the survey painted a telling story of the current collective disposition towards social responsibility, both as a topic within a course or curriculum and as a guiding ethical framework for the profession. While Kaufman's framework did validate as a comprehensive social responsibility construct (Moore, 2005), of its 13 elements, faculty believed 12 applied rarely or never to their current professional practices. Survey responses did suggest faculty believed that the field should do better in a few of the areas, but even there, ratings of relevance and commitment were relatively low. In short, the findings suggested—and open comments on the survey supported—that faculty in the educational technology field do not perceive a connection between societal level outcomes and what they do or should focus on as scholars in the profession.

Moore concluded, based on these findings as well as implications from her curriculum analysis, that educational technology professionals simply do not have a well-developed schema for considering social responsibility, differentiating between its various elements, or identifying those for which our profession shares responsibility. Her curriculum review of 67 educational technology programs found only 1 in 5 offering any courses reflecting an explicit consideration of ethics, fewer than 1 in 10 declaring ethics among the program's stated objectives, and fewer than 1 in 15 including ethical practice in its vision—even when "ethics" was as broadly defined as possible.

Finally, a current analysis of the educational technology literature reinforces the sense that professional ethics are rarely on our collective mind. In conducting this search, we defined "ethics" as the topic of an article broadly, to include articles on ethics, social responsibility, accessibility, copyright, and cultural considerations—and, based on this definition, counted related articles in the primary research and applied journals in the domain. Table 10.1 summarizes these counts along with notes on each to better assist in interpreting nuances within the articles and data.

Together, such findings begin to paint a troubling picture. It seems clear that, despite the contributions of prominent authors on the topic, such as Yeaman, Nichols, and others noted above, systematic consideration of the ethics of our professional practice has not diffused throughout educational technology's research, design models, or curricula. What's more, this scant literature's focus on cultural sensitivities and on legal themes like intellectual property, accessibility, and content filtering—issues similar to (or possibly orthogonal to) but not properly part of ethics itself—is typical of constructs around which a collective and individual schema has yet to form (Anderson, 1977; Ormrod, 1999), reflecting the work still to be done in this area.

From Current Themes to Promising Frameworks

This chapter aims to chart some promising pathways toward such a schema, while illustrating how educational technology professionals can reconceptualize existing ethics themes to incorporate a greater focus on measurable results (in accordance with principles long-embraced in other domains of educational practice, such as change facilitation and technology integration and human performance technology). First, we consider a few of the examples noted above, where the lack of a common ethics schema has often led our consideration of ethical issues to veer off into discussion of legal mandates or regulatory compliance.

Intellectual Property and Open Content

Discussions of intellectual property "ethics" in educational technology have most often centered on issues like copyright (law), work-for-hire (law), and similar considerations, where "what is right"—while it may perhaps be obscure to the participants—is grounded in statute or regulation. While important, and while one hopes that laws enshrine practices that are ethical, the ability to conceive of an unethical law—or an illegal act that is nevertheless an ethical obligation—makes it clear that the two constructs are distinct. Losing sight of this distinction can obscure other aspects of intellectual property in our professional practice, however, which are more properly the domain of ethics. Consider one common scenario: a graduate student "co-authors" a presentation at a major conference with a prominent faculty member. The student does virtually all the work, with the senior scholar contributing little more than his name. Yet without that name, a presentation by the unpublished grad student would probably not have been accepted for such an important venue. Who owns the intellectual property? Can the faculty member ethically claim principal authorship to increase the student's likelihood of acceptance?

Another ethical issue related to intellectual property is found in the burgeoning discussion of open content. Open content advocates such as Wiley (2010) argue that society's interests are maximized when intellectual property is shared freely, with proper attribution, for noncommercial purposes. Ironically, this notion of a public interest in the free and open exchange of ideas was the *genesis* of modern copyright law (Ferguson, 2012). It is of special interest in this chapter's context to note that the subtitle of the United States Copyright Act of 1790 was "an Act for the encouragement of learning." And yet, once we set about trying to resolve an issue of ethics using the blunt instrument of law, "over time, the power of the market transformed this principle beyond recognition" (Ferguson, 2012). In short, open content represents an attempt to reclaim a public good that has actually been *subverted* by the legal framework created to protect it, because we have virtually abdicated our reponsibility to oversee that framework within the domain of ethics.

Other frameworks are possible; that is, in fact, the point. Our ethical obligations do not center on "finding the right answer," but rather on *achieving a desirable outcome*—in this case, creating a rich "primordial soup" in which ideas and innovation can flourish, by balancing incentives for content creators with a vibrant public domain in which their creations are accessible to all to drive the next cycle of innovation. Further research is required to measure the contribution of Open Content to this end and to identify and similarly validate other possible frameworks for wrestling with the ethics of intellectual property. Still, Open Content exemplifies the ethical *approach*, by finding its touchstone in this purpose rather than in law and compliance—which are, by definition, means and not ends.

Accessibility and Universal Design

Accessibility and Universal Design have their early roots in the idea of "barrier free design" that emerged in the 1950s across Europe, Japan, and the USA. Like intellectual property, accessibility is among the more common topics associated with the concept of professional ethics in the current literature that exists on ethics in educational technology journals specifically, as noted above. Yet, once again, much of this discussion tends to gravitate toward legal issues—like Americans with Disabilities Act (ADA) compliance—or conflates the term with other concepts (like "having access" to a computer). The literature defines accessibility as the ability of a person with a disability to use an environment—including digital environments—as effectively as people who do not have disabilities (Slatin & Rush, 2003). Clearly—whether we consider children born with congenital disabilities yet active minds, accomplished adults developing a natural disability later in life, or service members wounded in combat—making learning environments accessible to all is an area where educational technologists must play a crucial role if individuals and the society of which they are a part are to benefit. While accessibility can seem a purely technical issue, with emphasis on hardware or software accommodations, such details are better understood as manifestations of design choices and cognitive principles that enable or inhibit socially desirable objectives.

Here, too, we have largely ceded an ethical issue to the domain of law—and here too, this has produced unintended consequences that have undermined the social good being sought. The first time most designers encounter accessibility is when they are told, on the job, that a module or course must be Section 508 compliant. In 1998, Section 508 was added as an amendment to the Rehabilitation Act of 1973, extending the requirement for accessibility of *physical* environments (e.g., buildings and transportation) to cover electronic and information technologies. Unfortunately, legislation by definition promotes a compliance orientation—emphasizing strict adherence to the requirements of the statute, over actually ensuring equal access. For example, in one learning management system, the live collaboration environment is not accessible during the actual meetings, but the recordings from these meetings are made accessible afterwards with subtitles and transcripts from chat windows. While meeting the technical and legal standards of Section 508, this still clearly excludes learners with disabilities *from the main instructional strategy* of live collaboration, relegating them to observers of—rather than participants in—the learning process. Such unintended consequences are consistent with research that suggests compliance-oriented training fails to produce actual changes in behavior or performance, compared to values-oriented training supported and modeled by leadership (Dean, 1993; Harrington, 1991; Trevino, 1987, 1992; Weaver, 1999).

In contrast, in a discussion article on accessibility from an outcomes perspective, Roberts (2003) showed how technical solutions can be informed by the learning sciences to yield *cognitive* access to information and environments. Roberts states that cognitive accessibility is

> the super layer of strategies and methods that help any learner or user understand or cognitively integrate the interface and content. Every user accessing an environment should have the same understanding of how the interface operates and the meaning of any content regardless of form or media. Cognitive accessibility accounts for message and information design behind everything on a website, for example, from an entire interface design down to a specific graphic to ensure those same messages are conveyed through multiple avenues for users accessing the site in different ways. (p. 2)

She describes techniques developed to improve Web site navigation for blind or visually impaired users based on cognitive load theory that improved efficiency of user navigation and allowed users to spend more time on content integration rather than navigation. This sort of technique requires a mindset that goes beyond compliance: one focused on achieving the desired outcomes, for learners both with and without disabilities, through our design choices. To date, however, we have little to no research examining accessibility in light of learning sciences research, or viewing accessibility of digital environments as a cognition question; future research might productively examine the role of design theories or principles in developing learning environments that are truly accessible to all.

A promising approach in recent literature, called "universal design for learning" (UDL) defines the goal more broadly than accessibility. UDL is a design disposition adapted from the more generic principles of "universal design," a term coined by US architect Ron Mace asserting that the design of products, environments and communication should focus on making them usable by all people *to the greatest extent possible* (Fletcher, 2002; Mace, Hardie, & Plaice, 1991). Universal design was adopted as a guiding principle in other design-oriented fields by the World Design Congress in 1987 and has become policy in corporations like Microsoft and Pacific Bell and international organizations such as the United Nations. In recent years, this concept has been imported into education, principally by Rose and Meyer, who assert that "barriers to learning are not, in fact, inherent in the capacities of learners, but instead arise in learners' interactions with inflexible educational materials and methods" (2002, p. vi).

Moore describes UDL as a way of thinking about the design of learning environments that "takes diversity of the learner population into account from the start and builds features into the learning materials, environment, and system that allow a broad set of learners to access the learning (both the content and the instructional strategies) and accomplish learning goals" (2007). This begins to connect UDL to specific Instructional Systems Design (ISD) processes such as definition of learner characteristics, articulation of learning objectives, and message and materials design. UDL encourages a plural definition of learners, with ripple effects throughout other design decisions like clarification of objectives to emphasize learning results rather than means of assessment, selection of appropriate instructional strategies, and development of flexible learning materials. This hypothesized relationship between a broader precept of design for accessible learning and elements of our ISD models suggests another path of ethics research, shaping what we as a profession consider socially responsible design practices.

Access and the Digital Divide

Access, which is distinct from accessibility, has traditionally been defined as physical availability of computer equipment and software and, later, networks—without which it was assumed that society's "digital have-nots" would be shut out from modern citizenship and prosperity, creating a "digital divide." This simplistic understanding of sociotechnical systems assumed that everything else required for computers' effective educational use was already present in the classroom, as it was for blackboards and textbooks. Warschauer (2003)—in one of the definitive texts on the topic—notes that "digital divide" as a construct appears to be waning, as research calls into question not "access," but "access to what," and whether what learners are accessing is worthwhile. This is a fundamental issue of our profession, as poor design or implementation choices *can* perpetuate social inequalities or even deepen existing ones. The challenge then becomes defining what constitutes a gap in *results* and designing contextually appropriate solutions that close those gaps.

An artifact-based "digital divide" construct proved especially vulnerable to hijacking by the obvious commercial interest of technology providers in selling their products, when it met the traditional legalistic approach. In the 1980s and early 1990s, a legislative and budgetary agenda emerged to get "technology" and connectivity into schools—often with little discernable effect. Yet the relevance of rethinking access is not limited to the "hard technology" aspects of our profession. The mere presence of an educational program of *any* sort does not ensure, and therefore should not assume, positive societal impact. Rather, any societal benefit from educational endeavors is *purposeful*, resulting from intentional objectives that drive their design and align them *toward* that outcome, from the system level down to specific projects and programs.

This is not just the case in developed nations. In its review of the role of education in fragile states (defined as states that are in conflict or crisis), the Inter-Agency Network for Education in Emergencies, as part of a commissioned study for the World Bank, explains how education—depending on how it is implemented—can mitigate *or contribute to* fragility. Employing a scale describing education's impact on fragility—ranging from actively reinforcing or perpetuating it, through inadvertently favoring it, to mitigating against it—INEE's analyses show both the complexity and the criticality of determining impact. For example, in Afghanistan, schools are often attacked by insurgents, owing both to their use as polling places and to education's role in empowering women. Building physical schools can therefore inadvertently *increase* fragility by consuming resources *and* inviting lethal attacks on the community's children and best-educated adults. Radio-based distance education was employed to remove this paradox, enabling safer schooling and measurably reducing fragility (INEE, 2011).

In other settings the learning materials themselves may promote social divides. In Bosnia and Herzegovina, INEE documented biased curricula, textbooks and teacher training that were designed to maintain ethnic and language divisions. These biases reproduced patterns of inequality that ultimately determined outcomes and employment opportunities for students on an ethnically differentiated basis, increasing fragility. Armed with these results, however, the country appears to be reducing these impacts, through more national governance and intentional designs to promote social cohesion (INEE, 2011).

Such examples reveal a layer of design considerations we may not normally confront: how do our designs work with—or *against*—other parts of the educational system to affect learning; how could our choices increase or decrease participants' safety; to exactly what are we providing access—and is that contributing to desirable outcomes, or maintaining *undesirable* ones like social inequalities? These questions challenge us to clarify the actual needs and objectives we pursue—and highlight that *learning* outcomes are not the only results of instructional designs, but rather a subset of the ethical considerations that should inform the design process.

Security and Privacy

Outside conflict-affected nations like those mentioned in the preceding section, safety issues like privacy invasion and identity theft, cyberbullies and sexual predators tend to take center stage—and educational technologists have important roles to play in shaping the design of learning environments that both leverage the capabilities and resources of the Internet for inquiry, problem solving, and growth *and* protect the security of learners of all ages.

Once again, though, our primary response to these challenges has often sought to substitute law for ethics. Legislation has been passed making cyberbullying a crime, in response to widely reported incidents that have even led to fatalities. Inappropriate access to and use of student records has been addressed through the Family Educational Rights and Privacy Act (FERPA). Societal concern over access to age-inappropriate content or exposure of students to exploitation and abuse—sexual or commercial—via the Internet led to passage of the Children's Internet Protection Act (CIPA) and the Children's Online Privacy Protection Act (COPPA) in the opening years of the century. Ethics research and literature in the educational technology field frequently points to the importance of such laws in society's attempt "to balance the safety of children and the rights of adults," and to "balance freedom of speech with freedom from unethical uses of information" (Yeaman, Eastmond, & Napper, 2008, pp. 312–313).

While the serious crimes such laws target ensure them a place in any future strategy, a purely legalistic approach continues to present the shortfalls noted throughout this chapter. Laws against cyberbullying leave unaddressed the ethical responsibilities of educators (including instructional designers) in providing learning environments resistant to the conditions allowing such dynamics to develop in the first place. The requirements of FERPA, while providing important safeguards for student privacy, are also in some instances preventing instructor access to *their own students*' performance data, and obstructing cooperative research studies involving researchers and students from multiple institutions. Statutes like CIPA and COPPA tend to focus on content filters and other (frequently ineffective) technological "solutions," potentially sacrificing attention to the human and social issues and challenges underlying inappropriate content and risky behaviors online—or to the lessons and critical thinking that are more appropriately the domain of ethics, which could *continue* to protect students after they've graduated into adult life.

Cross-Cultural Competence

A large portion of the literature that does mention ethics focuses on cultural considerations. International collaborations and the introduction of technologies and technological systems into different cultures require additional attention to cultural differences that can affect every part of the instructional design cycle.

The relationship between cultural competence and moral reasoning is perhaps more established than other ethics topics. Endicott, Bock, and Narvaez (2003) examined the relationship between moral reasoning and intercultural sensitivity, finding a strong relationship between participant scores on scales of intercultural development (Intercultural Development Inventory, or IDI) and moral judgment (Defining Issues Test, or DIT) corresponding to participants' depth of multicultural experiences. They offer a cognitive framing of the relationship between moral and intercultural development as an increase in sociocognitive flexibility, which they hypothesize is largely facilitated by multicultural experiences. Hammer, Bennett, and Wiseman (2003) developed the IDI to measure "intercultural sensitivity," hypothesizing that sensitivity is associated with exercising competence. They distinguish "intercultural sensitivity"—which they define as the ability to discriminate and experience relevant cultural differences—from "intercultural competence"—a performance-oriented construct they define as the ability to think and act in interculturally appropriate ways. While the IDI measures five categories of an individual's intercultural sensitivity, as of yet it has not been used to determine whether scores on this inventory predict culturally sensitive behaviors—behaviors that, as the authors articulate them, are worth noting as strongly similar to Mega level outcomes as identified by Kaufman (2000) in our own field (e.g., "lower levels of prejudice and discrimination" and "decreased conflict and/or violence toward people from different cultures" from Hammer et al., 2003, p. 441).

Hammer et al. (2003) suggest that the IDI is "useful for purposes of assessing training needs, guiding interventions for individual and group development of intercultural competence, contributing to personnel selection, and evaluation programs" (p. 441)—language that again should sound very familiar and that suggests ways in which we can begin to translate an abstract concept like "cultural sensitivity" into a performance expectation for professionals and therefore a professional competency addressed through programs and further studied through research. Other disciplines are already integrating this approach into the development of professional practitioners. The US military, increasingly finding itself cast in international humanitarian relief, infrastructure development, and security coorperation roles around the world, is devoting substantial resources and emphasis to cultural competence as a training and performance outcome, although much remains to be done (Alrich, 2008). In academic circles, other disciplines are increasingly emphasizing global awareness. For example, one of the major program outcomes for accreditation in engineering is development of students' ability to "understand the impact of solutions in a global and societal context" (ABET, 2009). Using Bloom's taxonomy, researchers in engineering education have defined learning and performance objectives to support the development of more courses on global and societal impact in more programs around the country (Besterfield-Sacre et al., 2000). This is beginning to show up in engineering both in the curriculum as well as in engineering education journals (Downey et al., 2006; Jesiek, Borrego, & Beddoes, 2010; Moore, May, & Wold, 2012).

A shift towards a definition of "cultural competence" as a professional competency affords our own discipline several opportunities through this framework: an expanded definition of applied professional ethics and framework for discussing existing research in international education as a component of our professional ethics complexion, an existing framework for defining and measuring cultural sensitivity, opportunity to extend existing literature by defining and measuring cultural competence in learning and performance terms to examine the predictive ability of cultural sensitivity measures, a framework for developing courses within programs, and a framework for evaluating graduates of programs as well as projects and project outcomes.

Social Responsibility

Social responsibility is also one of the primary themes identified in what literature exists on ethics, but it is most rightly treated as the overarching concept that authors are converging on—and rather emphatically—as the most appropriate construct for moving discussion (and therefore research, design, and development) beyond codes that focus on individual behavior to a description of the profession's position within society with pervasive influence on practice and research. Ethics have traditionally focused on the individual (an emphasis reflected in the normative ethics research tradition based on cognitive constructs of ethics, such as Kohlberg's theory of moral development, 1969), but the emphasis is shifting to systemic (i.e., global and societal) impact of technological designs and systems (Barbour, 1993; Kaufman, 2000; Moore, 2010; Strijbos, 1998; Yeaman et al., 1994). In this section, we extend this emphasis on social responsibility by looking at the convergence point between four models that heretofore have not conversed with each

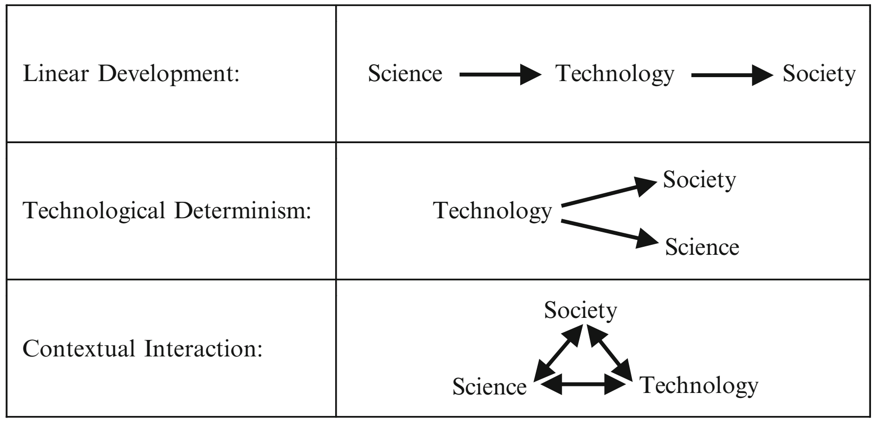

Fig. 10.1 Three views of the Interactions between Science, Technology, and Society (Barbour, 1993, p. 20)

other and the implications of this for future work: Barbour's model of ethics in a technological society, Whitbeck's notion of ethics as design, Kaufman's model for socially responsible planning and design, and Reeves' resurrection of the conative domain. Throughout, we suggest that we are not without a model for how to proceed from here, as we can take a page from the discipline of Science, Technology and Society (STS).

Barbour: Technology as Social Constructions—It Is What We Design It to Be

Barbour's work, *Ethics in an Age of Technology*, provides a strong foundation for a design disposition towards ethics beyond codes and regulations. Barbour examines three differing views of technology: technology is liberating (beneficial), technology is a threat (destructive), or technology is an instrument of power (design and use are defined by context). Based on these three views of technology, Barbour examines assumptions about the relationship between science, technology and society to lay out three different models for thinking about technology and its consequences, advocating for the third "contextualist" model (see Fig. 10.1).

Traditional models are either linear (technology develops out of science) or deterministic (technological requirements drive science and society) and represent what has historically been a dichotomous approach. Linear development models and rhetoric assume that all technological developments have their roots in scientific discoveries and therefore inherit the moral objectivity of the scientific tradition. Determinist models and rhetoric view technology as such a predominantly overarching force that it drives all aspects of society. Common to all variations of deterministic models is the implication that both human freedom and technological choice are limited (Barbour, 1993; Together these two positions also reflect the vast majority of rhetoric on technology: something to be embraced or something to be rejected as a polarized discussion with no real middle ground. The Internet will bring about democracy, or the Internet will expose children to pedophiles.

Barbour argues that instead, there are complex interactions between technology, science and society, where social goals and institutional interests are built into the technical designs we choose. He explains that the third model, with three bidirectional arrows, represents the complex interactions between science, technology, and society:

> Social and political forces affect the design as well as the uses of particular technologies. Technologies are not neutral because social goals and institutional interests are built into the technical designs that are chosen. Because there are choices, public policy decisions about technology play a larger role here than in other views. (p. 21)

Barbour states that many authors/theorists in this third group are still critical of most current technological features but maintain the optimistic belief that technology can be used for humane ends. Those humane ends would be brought about by political measures for more effective guidance within existing institutions or by changes in the economic and political systems themselves. For example, within educational technology, we could develop measures for ensuring decisions and designs are driven by a sense of social responsibility. In order to achieve such an end, Barbour calls for "greater public participation and a more democratic distribution of power in the decisions affecting technology" (1993, p. 16). Other authors such as Andrews (2006) echo this sentiment of engaged "technological citizenship" in which both technical experts and nontechnical experts work together on design and implementation decisions. Pinch and Bijker (1984), developers of the model of social construction of technology (SCOT), would take this a step further to assert that "relevant social groups" *do* influence how new technologies are developed, including input into and modifications of designs, and actively shape policies guiding implementation and diffusion. This is closely akin to the findings of stakeholder involvement in the change literature our field draws from extensively, providing a direct link between that body of research and ethical practices in educational technology. Participation of end users in every stage of technology development is not only a desirable approach for professionals but is a realistic representation of the social dynamics at play that influence how something develops, whether it is adopted, how and whether it is modified, and so forth.

The essence of this third position is that technical design cannot be meaningfully developed separate from human context. The impact on society and the change it brings about must be considered and *can* be considered. Instead of adopting a reactive position to technology, where we simply accept what is already given, society at large and members of technology professions can (and should) adopt a proactive stance to embed socially responsible values in technological designs (Barbour, 1993, pp. 22–23). To tie this to research in our field, what Barbour effectively argues for is a systemic view of technology that demands stakeholder participation in design and decisions. He lays out a design philosophy that focuses on social responsibility as the prime directive: "I believe that we should neither accept uncritically the past directions of technological development nor reject technology *in toto* but redirect it toward the realization of human and environmental values" (italics in original, 1993, p. 24).

Whitbeck: Ethics as Design

In other design-oriented disciplines, such as engineering, there is increasing recognition that the act of design is also one of developing solutions to meet societal challenges. For example, Whitbeck writes that solving moral problems "is not simply a matter of choosing the 'best' of several possible responses. It is also a matter of *devising* possible responses" (1996, p. 9, emphasis added). She explains that moral problems are practical challenges and bear many striking similarities to another class of practical problems—the design problem. Developing a response to an ethical problem requires one to take multiple considerations into account—and often there is some tension or conflict between these demands. Traditionally, a philosophical approach to ethics would conclude that these are irresolvable conflicts, so a person must "opt" for a solution. However, design processes tend to approach these competing demands as varying needs or constraints that can often be at least partially satisfied through a more considered design. Whitbeck notes, for substantive design problems, that "there is rarely, if ever, a uniquely correct solution or responses" but emphasizes that this is an entirely different claim than saying there are no right or wrong answers. Whereas the latter is an extreme expression of relativism in ethics, the former is a practical approach to ethics offered by design. While there may be no one correct solution or response, it *is* possible to devise—or design—a response or solution that effectively balances the competing requirements.

There are even broader examples in these other fields that can inform our evolving ethical discourse in educational technology. In the field of Science, Technology and Society the literature has long since moved past deterministic models of technology to focus on a design disposition to this question of the ethical consideration of technology: the ethics of any technology lie in our design decisions and our implementation processes. Humanity is not a victim of technology (nor are we necessarily the grand benefactor)—but rather the consequences of a given technology are a result of design and implementation choices. There is a complex interaction effect between technology and culture, one which STS authors term "mutual shaping" or "coshaping" (Neeley, 2010), in which technology simultaneously shapes and is shaped by the culture around it.

When we examine historical examples or look at cross-cultural comparisons, the pattern that really emerges is that technology has been shaped across history and cultures to reflect a culture's emphasis on desired ends. Carlson's seven-volume review of technology across world history paints the most compelling portrait of this design orientation (2005). Historical analyses and cross-culture comparisons of varying technologies and the ways they have developed, or did not develop, or were implemented demonstrate repeatedly that a deterministic narrative of technology is a false narrative—culture, context, and what Carlson calls the "prime directives" of different cultures dramatically influence what technologies are developed, how they are shaped, and how they are implemented.

Kaufman and Reeves: Planning, Design, and Conation

Within our own field we have some excellent building blocks already—but we are only likely to see them as such when we reframe ethics through the design lens. For example, in the area of needs assessment, planning, and evaluation, Kaufman's model for organizational performance presents a robust framework for planning and evaluating multiple levels of impact which includes societal impact. In Kaufman's (2000) model, societal impact is both the basis for planning (a process that starts there then plans "downward" into organizational outcomes, performance outcomes, inputs and processes) and the longitudinal measure of an organization's success (as results at each level align back from the inside out). He presents an operational definition of societal outcomes as well as a framework that assesses and employs societal needs as the basis for design, implementation, and evaluation—in short, one that not merely hopes, but *plans* for ethical outcomes.

Kaufman's model for planning starts with societal level outcomes, which he terms "Mega," and in which he details basic measures of societal impact:

- Zero pollution—no permanent destruction of our environment
- No deaths or permanent disabilities from what is delivered

Table 10.2 The organizational elements, the related results, and definitions used with permission from Kaufman (2000, 2006)

Name of the organizational element	Name of the level of planning and focus	Brief description
Outcomes	Mega	Results and their consequences for external clients and society
Outputs	Macro	The results an organization can or does deliver outside of itself
Products	Micro	The building-block results that are produced within the organization
Processes	Process	The ways, means, activities, procedures and methods used internally
Inputs	Input	The human, physical, and financial resources and organization can or does use

- No starvation and/or malnutrition resulting in incapacity
- No partner or spouse abuse resulting in incapacitating physical or psychological damage
- No disease or disabilities resulting in incapacity
- No substance abuse resulting in incapacity
- No murder, rape, crimes of violence, robbery, or destruction of property
- No war, riot, or terrorism, or civil unrest resulting in incapacity of individuals or groups
- No accidents resulting in incapacity
- Citizen positive quality of life

Kaufman argues that all organizations and all professions either add value to or subtract value from each of these dimensions. Responsible planning and design, thus, treats these as top-priority constraints that can be articulated as higher-order objectives to inform design or planning (Moore, Ellsworth, & Kaufman, 2008, 2011). These measures then also inform an evaluative framework for the societal impact of any given product or process (or Outputs, in Kaufman's model). In Table 10.2 summarizing his model, above, planning or design occurs from top to bottom (reflecting an approach that begins by defining external impact first and is next aligned downward); implementation then proceeds from bottom to top—with evaluation conducted at all levels. An example of this applied in educational institutions is provided by Guerra and Rodriguez (2005) as they followed the positive societal impacts across eleven years from a university that used Kaufman's model for their strategic planning process, with impacts including decreased poverty, decreased crime, and increased employment opportunities in the surrounding community.

Further, in recent years, Reeves has been emphasizing the importance of the little-discussed but highly relevant conative domain (2006, 2011). In the early twentieth century, the conative domain was a generally assumed equal, along with the cognitive and affective domains (McDougall, 1923), with roots stretching back to ancient times. However, from mid-twentieth century onward, it has all but disappeared from the psychology lexicon as cognition dominated learning research. From the Latin word "conation," the conative domain pertains to the act of striving and has to do with intention, will, and drive or desire. Kolbe (1990) provides a summary comparison of the three domains of the mind (Table 10.3).

Table 10.3 Comparison of cognitive, affective, and conative domains (adapted from Kolbe, 1990, emphasis ours)

Cognitive	Affective	Conative
To know	To feel	To act
Thinking	Feeling	Willing
Thought	Emotion	Volition
Epistemology	Esthetics	*Ethics*
Knowing	Caring	Doing

Reeves laments the complete absence of this domain today in research or practice in teaching, learning and assessment, noting its vitality to students' ability to perform in authentic and global contexts once they graduate (2006). For this chapter, we draw specific attention to "ethics" as part of the conative domain—in the same category as doing, acting, and volition. These are the very same definitions and descriptors often used to define design. Design is a goal-oriented activity that seeks not just to understand, but to produce and act upon a problem. This would imply that the very act of design itself is a manifestation of ethics, and conversely that the most accurate way to discuss ethics is not as contemplation, or knowing, or even as a code that requires a compliant response, but as a goal-oriented activity that requires us to engage sophisticated design processes—just as Whitbeck suggests and as Kaufman exemplifies.[1]

Conclusions

The implications of a design-oriented ethics framework for educational technology research are exciting. Ethics is transformed from the subject of compliance-oriented codes and abstract philosophy into one of action, of leadership of our profession as it seeks and creates its future. Rather than the relationship between ethics and research getting confined to the institutional review board, research becomes the primary informant for ethical practices of our profession, envisioned in a recent research article in *Educational Technology Research & Development*. Towards the end of a study on multimedia principles from Mayer and the "reversal effect" of redundancy for experts, its authors state,

[1] The Smithsonian exhibit "Why Design Now?" as part of their National Design Triennial features a host of examples across disciplines that further reflect this intersection of design and ethics. (McCarty, Lupton, McQuaid, & Smith, 2010)

> If educational technology is not adapted to the human cognitive system, we run the risk of introducing novel procedures that inhibit rather than facilitating (sic) learning. Providing learners with auditory or visual information, or a combination of both, can be highly beneficial but the circumstances in which a benefit is obtained depends on human cognitive factors. (Leslie, Low, Jin, & Sweller, 2012, p. 11)

The body of evidence reflected here in the *Handbook* is a distillation of the best we have to offer to the design of instructional technology products and systems that measurably benefit their users and the society they comprise. This suggests both that we have a firm foundation and broad discourse for deeper integration of ethics into our models and discourse and that we have new avenues of research available to extend this even further. Much of our research retains its primary focus on learning as our chief or only outcome. Yet our professional practices impact far more than learning outcomes; thus our body of research can, and should, expand to examine this full range. Other fields such as medicine, defense, business, and engineering actively discuss the societal implications of new technological developments, not with an eye towards rejecting innovation but rather as a way to actively and collectively make the complex design choices that shape technology towards worthy results.

Kuzma and Tanji (2010), in an extensive review of synthetic biology using a blend of historical and policy analysis, employed research to identify policy problems and lead public oversight, suggesting a continuum of evidence-based policy approaches: preventative, precautionary, permissive and promotion. Yet such analysis benefits not only external audiences like policymakers, but also informs the research and development of the technology. Similarly, Sparrow and Sparrow (2006) examine the implications of humanoid development and specific applications for such technology to eldercare, concluding from an ethical analysis that certain envisioned uses would be detrimental and other applications beneficial – and that the decision space to be navigated demands shaping from policy makers and technologists alike. It may be easy to dismiss these examples as coming from domains that can't assume the same "educational" benefit of our discipline, but consider the ancient wisdom of Quintillian (2006) in his "Institutes of Oratory" in which he lays out an entire system of schooling for young boys in ancient Greece. With the "techne" of writing long debated on an accept/reject basis (with Plato concluding it should be rejected!), Quintillian instead suggested that writing had both value and drawbacks – and therefore its integration into the educational system should be based on how to maximize the benefits and minimize the harm. The effective citizen required both the skill of oratory and the skills of critical reflection & refinement. Writing and revision developed cognitive flexibility and agility – yet the student could spend too much time trying to perfect a written piece, and had instead to cease writing, eventually, and leave his room to speak publicly. The use of each tool, each pedagogy, should be deliberately harnessed to a specified public good. This impacted not just what the young scholars learned in school, but also the type of leaders they grew into – and ultimately the direction of the society they led. It is this very sort of longitudinal perspective that our study and practice of ethics must encourage.

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Section II

Methods

Jan Elen and M.J. Bishop

At the core of scientific research are the methods. This second section of the *Handbook* is devoted to research methods with a focus on approaches that have, in previous editions of the Handbook (Jonassen, 2004; Jonassen, Harris, & Driscoll, 2001; Spector, Merrill, van Merriënboer, & Driscoll, 2008), attracted less attention or that have been evolving over the last several years. In contrast to the very first edition, for instance, attention on philosophical and experimental methods has shifted in this edition to more design research-based methods. This growing diversity of available research approaches in educational technology research is reflected in this section of the *Handbook*, which reviews the current research methodologies and—an interesting addition from our perspective—the tools that are used in order to support those methods as well.

The first chapter in this section is devoted to educational design research. McKenney and Reeves stress the ambition of educational design research to contribute to both practice and theory. The authors highlight the diversity of solutions that is paid attention to in educational design research. Challenges for educational design research such as finding a balance between information richness and efficiency or the need for more clear examples of impact are clearly outlined. The authors stress the need and potential for more close collaboration between researchers and practitioners in order to handle current issues in education.

The chapter on educational design research is followed by the chapter on design and development research. Through means of 11 recent publications, Richey and Klein illustrate the nature of design and development research. The authors stressed that this type of research is unique to the field of instructional design and technology. Two main categories are distinguished: those studies that focus on products and tools, and those that are oriented towards the study of design and development models. The authors nicely describe the research space of design and development research by specifying the problems addressed, the settings and participants involved, the research methodologies used, and the role of evaluation.

Two new chapters address research practices in educational technology research that did not get a lot of attention in previous editions of the *Handbook*. Karakus presents the potential of Activity Theory for educational technology research arguing that Activity Theory provides a productive framework to analyze and understand how tools within particular contexts work. The potential is illustrated by references to examples. As an extension, Activity Network Theory is presented as a framework to analyze interactions among multiple activity systems. While the Karakus chapter shows the impact on research methods of theoretical frameworks, Manfra and Bullock reveal the practical and theoretical consequences of a widely used research method: action research. They argue that action research fundamentally transforms the relationship between practitioners and researchers by putting practice at the core. This transformation may help to close the gap between theory and practice. Concrete examples of approaches in action research are discussed in view of extending action researchers' toolkits.

The educational technology research field used to be a field dominated by quantitative research. Today, an increasing number of researchers use qualitative methods in their efforts to get to an in-depth understanding and to generate relevant and broadly applicable principles. The more widespread use of qualitative research methods in a variety of disciplines has engendered the further development of these methods. As a complement to chapters in previous editions of the Handbook on qualitative research, the chapter by Mardis, Hoffman, and Rich presents a well-documented overview of recent trends. Demonstrating that qualitative research is far from an easy thing to do, the chapter nicely presents the various issues of design, method selection, and

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knowledge generation with concrete examples of how these were tackled in recent educational technology research.

While different aspects of formative evaluation methods have been discussed in previous *Handbook* editions, a chapter solely dedicated to program evaluation has been missing. The chapter on Program and Project Evaluation by Spector fills this gap by discussing and illustrating methods used in an effort to evaluate the entire process from needs assessment through design, development, deployment, and support. The author stresses that project and program evaluation are directed towards increasing the probability of successful technology integration. Program evaluation calls for a holistic approach in order to consider the multiple and interwoven factors that affect successful integration.

This section concludes with two new chapters on data analysis tools that should be very informative for researchers. While Knezek and Christensen discuss tools for quantitative research, Gilbert, Jackson, and di Gregorio do the same for qualitative data. By discussing the tools and research in which these tools are used, Knezek and Christensen show how such tools might contribute to improving data acquisition, making data analysis even more sophisticated. and enriching data exploration often through visualization. The ongoing evolutions and developments in these tools are stressed by these authors and for qualitative research confirmed by Gilbert, Jackson, and di Gregorio. In response to frequent questions from researchers on what tools to use, these latter authors distinguish between Qualitative Data Analysis Software to support qualitative research and tools that are especially interesting when gathering data and/or presenting results are at stake. Issues related to the use of these tools as well as the potential of Web 2.0 tools are discussed.

The variety of chapters in this section reveals the diversity of research methods used in educational technology research today. New research questions have given rise to the use of new methods that, in turn, have resulted in the more frequent use of a diversity of tools. The diversity in research methods reflects the diversity in research questions and theoretical orientations. Considering that disciplines are characterized by some methodological agreement, it must be noted that the field of educational technology is a discipline characterized not by methodological unity but by methodological diversity. Such diversity is a benefit as long as there is a shared agreement on methodological decision making, on how to decide what methods are most appropriate for what questions. Putting that agreement on paper might be the biggest challenge for a methods section in a possible fifth edition of the *Handbook*.

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Educational Design Research

11

Susan McKenney and Thomas C. Reeves

Abstract

Educational design research is a genre of research in which the iterative development of solutions to practical and complex educational problems provides the setting for scientific inquiry. The solutions can be educational products, processes, programs, or policies. Educational design research not only targets solving significant problems facing educational practitioners but at the same time seeks to discover new knowledge that can inform the work of others facing similar problems. Working systematically and simultaneously toward these dual goals is perhaps the most defining feature of educational design research. This chapter seeks to clarify the nature of educational design research by distinguishing it from other types of inquiry conducted in the field of educational communications and technology. Examples of design research conducted by different researchers working in the field of educational communications and technology are described. The chapter concludes with a discussion of several important issues facing educational design researchers as they pursue future work using this innovative research approach.

Keywords

Design research • Design-based research • Formative research • Design experiments

Introduction

Educational design research is a genre of research in which the iterative development of solutions to complex educational problems provides the setting for scientific inquiry. The solutions that result from educational design research can be educational products (e.g., a multiuser virtual world learning game), processes (e.g., a strategy for scaffolding student learning in online courses), programs (e.g., a series of workshops intended to help teachers develop more effective questioning strategies), or policies (e.g., year-round schooling). Educational design researchers attempt to solve significant real world problems while at the same time they seek to discover new knowledge that can inform the work of others facing similar problems. This chapter summarizes arguments and evidence presented by Barab and Squire (2004), Burkhardt (2009), Reeves (2011), Schoenfeld (2009), van den Akker, Gravemeijer, McKenney, and Nieveen (2006a), and others that educational design research is an innovative and exceptionally promising approach to improving the quality and impact of educational research in general, and educational communications and technology research in particular.

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Educational Design Research Origins

> *Design research is not defined by its methods but by the goals of those who pursue it. Design research is constituted within communities of practice that have certain characteristics of innovativeness, responsiveness to evidence, connectivity to basic science, and dedication to continual improvement.* Bereiter (2002) p. 321.

What has prompted scholars around the globe sharing the above-mentioned characteristics of "innovativeness, responsiveness to evidence, connectivity to basic science, and dedication to continual improvement" to come together in the pursuit of educational design research? At least two main motives can be identified. Interestingly, both perspectives have strong historical ties to educational psychology, and both perspectives are concerned with making a contribution to educational practice. The first motive is driven more by what society needs while the second has more to do with finding adequate methods to meet those needs.

First, stemming from the notion that scientific understanding should be used to solve or at least gain a better understanding of practical problems, the call for scientific inquiry to yield what Lagemann (2002) refers to as "usable knowledge" has been present for over a century. Although this focus on demonstrable impact may be ignored by some who recommend that educational researchers should emulate the methods of the so-called hard sciences (e.g., physics) that seek knowledge without expectation of practical application, the expectation for social science research to connect fundamental understanding with applied use dates back to Münsterberg (1899) and Dewey (1900), if not earlier. Both of these former American Psychological Association presidents expressed the need for a linking science, which would use empirical insights and theoretical advancements to inform problem-solving and improvement initiatives in practice. This call has been taken up gradually within the fields of education and psychology, for example in the work of Robert Glaser (1976) who laid out the elements of a psychology of instruction and called for a science of design in education. Donald Stokes (1997), an American political scientist, provided a fresh look at the goals of science and their relation to application to real world problems, in his highly acclaimed book titled, *Pasteur's Quadrant: Basic Science and Technological Innovation*. Stokes promoted more "use-inspired basic research" akin to the work of the French chemist and microbiologist, Louis Pasteur. He contrasted Pasteur's pragmatic research approach with that of the basic science goals of Danish physicist, Niels Bohr, and the applied research aims of the American inventor, Thomas A. Edison.

Second, educational researchers have been searching for adequate methods to yield the kinds of empirical insights and theoretical advancements that could be used to address real concerns in educational practice. Acknowledging the limitations of laboratory settings, the value of relinquishing control of variables in return for increased ecological validity of the findings has been gaining support over the last 30 years. In 1992, two landmark papers were published which are often credited with launching educational design research as a specific genre of scientific inquiry. Brown's (1992) article in the *Journal of the Learning Sciences* discussed tensions between laboratory studies of educational innovations and challenges inherent in integrating these innovations into real world classrooms as background to describing her own design experiments. That same year, Collins (1992) published a book chapter arguing that education should be viewed as a design science akin to aeronautics, as opposed on an analytical science similar to physics, emphasizing the fact that laboratory conditions could rarely approximate conditions in real classrooms.

By the turn of the millennium, support was increasing for innovative research approaches that might yield the kind of knowledge that can be put to use for the improvement of education. Advocates for these new approaches accepted that the kinds of knowledge needed would have to be constructed in the complex "laboratories" of everyday learning environments such as classrooms or online courses. The establishment of educational design research is growing steadily. This momentum became apparent through several special issues of highly respected journals, including *Educational Researcher* (2003, 31(1)), *Journal of the Learning Sciences* (2004, 13(1)), and *Educational Psychologist* (2004, 39(4)). Since then, several books have been written about educational design research. Books have focused on conceptualization (van den Akker et al., 2006a) methodological considerations (Kelly, Lesh, & Baek, 2008), and the details of conducting design studies (McKenney & Reeves, 2012) across educational fields. Related volumes have appeared specifically in the domains of literacy (Reinking & Bradley, 2008) and instructional design (Richey & Klein, 2007). In addition to special issues and books about educational design research, numerous reports of educational design research initiatives have been published in research journals such as *Instructional Science* (cf. Xie & Sharma, 2011), the *Journal of the Learning Sciences* (e.g., Schwarz & Asterhan, 2011), the *Journal of Research on Technology in Education* (e.g., Basham, Meyer, & Perry, 2010), and *Educational Technology Research and Development* (e.g., Reynolds & Caperton, 2011). In addition, doctoral dissertations using educational design research have been completed at multiple institutions such as the University of California, Berkeley (e.g., Brar, 2010), Unversity of Florida (e.g., Drexler, 2010), the University of Georgia (e.g., Oh, 2011), the Pennsylvania State University (e.g., Lee, 2009), and the University of Twente (e.g., Raval, 2010).

Today we see many sectors within education that seem to embrace educational design research, including: learning sciences, instructional design, curriculum development and teacher professional development. While educational design research is not inherently tied to any specific subject area, much of the work published so far has been related to science or mathematics, perhaps because more funding has been available for research related to STEM (science, technology, engineering, and mathematics) disciplines than for other areas (Kelly et al., 2008). However, educational design research is also being increasingly used in language and literacy research (Reinking & Bradley, 2008), as well as other disciplines. A wide variety is present across educational design study literature, a development that is partly accounted for by the methodological traditions within the various educational sectors, individual researcher preferences and the resources available for specific projects. In addition, variance across the twofold motives driving educational design research plays a large role in explaining the diversity of these kinds of studies. While pursuing both goals simultaneously remains a defining feature of educational design research, one goal may feature more prominently than the other. For example, relating more to the motive of improving practice, educational design research may be conducted primarily to:

- Solve a problem (e.g., increase the participation of women and other minorities in engineering and science careers),
- Put knowledge to innovative use (e.g., use the affordances of smart phones to enable mobile learning), and/or
- Increase robustness and systematic nature of design practices (e.g., establish a set of design principles for implementing inquiry-based learning in middle school science).

Or, relating more to the motive of enhancing the quality of research findings, educational design research may be conducted primarily to:

- Generate new knowledge (e.g., develop a theory of game-based learning),
- Generate different types of knowledge (e.g., enhance and extend knowledge related to professional development for scaffolding strategies for math teachers), and/or
- Increase the ecological validity of research-based knowledge (e.g., increase the likelihood that educational innovations will be used to transform educational practice).

Clarifying the Nature of Educational Design Research

What Is Educational Design Research?

While studies do differ in terms of which motives are more powerful determinants in shaping the inquiry, educational design research in general distinguishes itself from other forms of inquiry by attending to both solving problems by putting knowledge to use, and through that process, generating new knowledge. As stated elsewhere (McKenney & Reeves, 2012), educational design research is a genre of research in which the iterative development of solutions (e.g., educational products, processes, programs or policies) to practical and complex educational problems, provides the setting for scientific inquiry, and yields new knowledge that can inform the work of others. Working systematically and simultaneously toward these dual goals may be considered the most defining feature of educational design research.

Educational design research is not a methodology. It uses quantitative, qualitative and—probably most often—mixed methods to answer research questions. In so doing, educational design research is held to the same standards as other scientific work when it comes to providing transparency of the process and adequate warrants for the knowledge claims it yields (cf. Shavelson, Phillips, Towne, & Feuer, 2003). In addition to the knowledge generated, the value of educational design research is measured in terms of its ability to improve educational practice (Design-Based Research Collective, 2003).

How Does Educational Design Research Compare to Other Approaches?

While both are concerned with developing new knowledge and are connected to design processes, *educational design research* has commonalities but also differences from the instructional design focused *design and development research* described by Richey and Klein (2007, and in this volume). If considered as a Venn diagram, educational design research and design and development research would overlap in projects that are concerned with actively solving problems in educational practice (e.g., design and testing of software to help plan lessons). The area that would be unique to design and development research would be those projects that are concerned with developing tools or models to support education in the long run, but that do not function as educational interventions (e.g., retrospective analysis of how instructional designers carry out their tasks). Design research projects that would not overlap with design and development research would be those not specifically concerned with advancing the field of instructional design (e.g., design and testing of a learning sequence for early literacy).

Educational design research is also different from evaluation research (Clarke, 1999), although formative and summative evaluation methods are among the main vehicles used to study and fine-tune interventions in both cases. First, problem definition and solution design are rarely featured in evaluation research. Second, a key difference is that evaluation research is primarily concerned with evaluating and possibly improving the qualities of a particular intervention. The broader scientific orientation of generating usable knowledge (e.g., in the form of models to underpin design, theories about how teachers learn, descriptions of what engages learners, etc.)

is not as overtly present in evaluation research as in educational design research.

Educational design research also entails more than research-based educational design. They are both forms of scientific inquiry, and often, each values a rational approach. They both embrace systems thinking and are both shaped by iterative, data-driven processes to reach successive approximations of a desired intervention. However, research-based educational design focuses solely on intervention development, whereas design research strives explicitly to make a scientific contribution—of value to others outside the research/design setting—in addition to the intervention development. This has important implications for the entire process. Additional information on these differences is available in (McKenney & Reeves, 2012; Oh & Reeves, 2010). Similarly, action research (cf. Mills, 2002) also lacks the emphasis on finding the kind of robust public knowledge that is a hallmark of educational design research.

Distinguishing educational design research from other forms of inquiry in education is made more difficult because it has been referenced in the literature by a number of different terms such as "design-based research" (cf. Barab & Squire, 2004), "design experiments" (cf. Brown, 1992), "development research" (cf. van den Akker, 1999), "formative experiments" (cf. Reinking & Bradley, 2008), "formative research" (cf. Newman, 1990), and simply "design research" (cf. Kelly et al., 2008). There are subtle differences in how these terms are used by various researchers as delineated in McKenney and Reeves (2012). The term "educational design research" is used in this chapter and elsewhere (cf. Plomp & Nieveen, 2009; van den Akker, Gravemeijer, McKenney, & Nieveen, 2006b) because including the word "educational" in the term helps to avoid confusion with design research as used in other fields. For example, Laurel's (2003) book simply titled *Design Research* concerns the field of human computer interface design and industrial engineering rather than education.

Conducting Educational Design Research

Characteristics

Characteristics of educational design research have been offered in the literature (Kelly, 2003; Reinking & Bradley, 2008; van den Akker et al., 2006a; Wang & Hannafin, 2005). Common descriptors include: pragmatic, grounded, interventionist, iterative, collaborative, adaptive and theory-oriented. Educational design research is pragmatic because it is concerned with generating usable knowledge, and usable solutions to problems in practice. It is grounded because it uses theory, empirical findings and craft wisdom to guide the work. It is interventionist because it is undertaken to make a change in a particular educational context. Educational design research is iterative because it generally evolves through multiple cycles of design, development, testing, and revision. It is collaborative because it requires the expertise of multidisciplinary partnerships, including researchers and practitioners, but also often others (e.g., subject matter specialists, software programmers or facilitators). Educational design research is adaptive because the intervention design and sometimes also the research design are often modified in accordance with emerging insights. Finally, it is theory-oriented not only because it uses theory to ground design, but also because the design and development work is undertaken to contribute to a broader scientific understanding.

Process

There is no set process for conducting the "manifold enterprise" (Bell, 2004, p. 245) of educational design research. This approach to inquiry is rich with variation in terms of models and frameworks that describe, and in a few cases, guide the process. Across that variation, some similarities can be identified:

- Educational design research uses scientific knowledge (and to varying degrees, also other kinds of knowledge such as craft wisdom) to ground design work
- Educational design research produces scientific knowledge (and in some cases, also craft wisdom among the participants)
- Though the terminology and contents differ, three phases can be distinguished in educational design research: an analysis/orientation phase; a design/development phase; and an evaluation/retrospective phase; these are often revisited in the lifespan of a project
- Educational design research strives to develop both interventions in practice and reusable knowledge

Rich Variation

Thought-provoking differences in design research are also present. Some of the differences stem from the units of analysis, scope of implementation, nature of the subject areas addressed, or from the research domains and methodological traditions in which studies originate. As mentioned earlier, the relative emphasis on each motive (solution development, new knowledge or equally on both) can also wield strong influence on the design research process. But other differences stem from the concerns of those interpreting the concept and conducting the studies.

McKenney and Reeves (2012) surveyed models for educational design research and, in addition to highlighting similarities like those mentioned above, noted unique con-

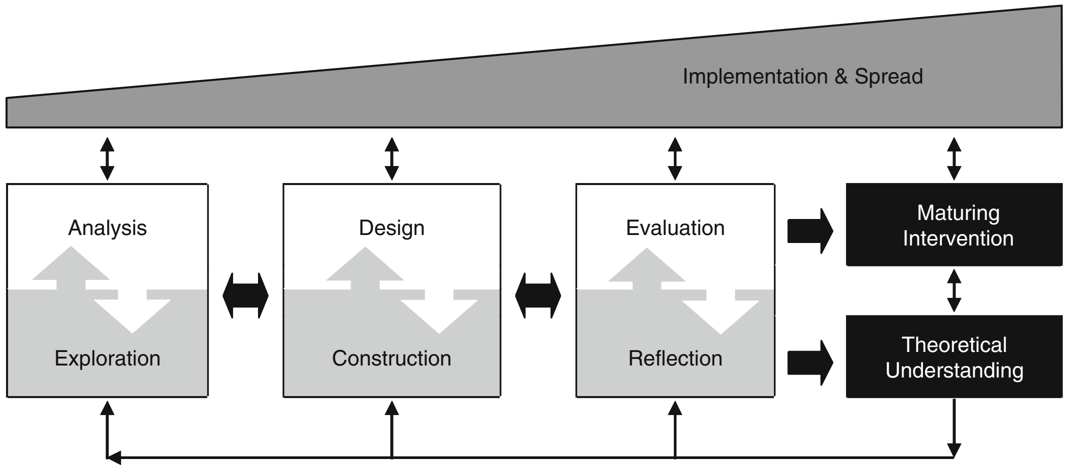

Fig. 11.1 Generic model for conducting educational design research (McKenney & Reeves, 2012)

tributions each one has to offer. The Osmotic Model, offered by Ejersbo et al. (2008), depicts the parallels of the design cycle and the research cycle. The authors point out that both cycles originate from the problem and would ideally run simultaneously, but state that this ideal is often not the case. Bannan-Ritland and Baek (2008) developed the Integrated Learning Design Framework, which depicts four main stages and across those, 14 steps, in a combined approach to research and development. Along with the process model, guiding questions for research and examples of applicable methods for each main phase are given. Reeves (2006) presented a minimalist model that highlights four main phases of design research: problem analysis; solution development; iterative refinement; and reflection to produce design principles. He compared these phases to the four phases of predictive research. In contrast to the aforementioned three models, McKenney, van den Akker, and Nieveen (2006) offered a model which is more conceptually oriented than process-oriented. This model depicts tenets guiding a research and development cycle, situated in a particular context, yielding three main outcomes: professional development of the participants; the designed intervention; and design principles.

In addition to these visual models, Gravemeijer and Cobb (2006) described important steps in the three main phases of their work: preparing for a design experiment; conducting a design experiment; and retrospective analysis. Based on a review of literature, Wang and Hannafin (2005) delineated and argued for nine principles of design-based research. Finally, Reinking and Bradley (2008) posed six questions as a guide for conducting formative experiments, relating to: pedagogical goals; classroom intervention; factors affecting the intervention; modifications to the intervention; unpredicted effects of the intervention; and changes in the instructional environment due to the intervention.

Based on their survey and analysis of existing models and frameworks for design research, McKenney and Reeves (2012) created a generic model for design research (see Fig. 11.1). Through this basic visualization, this model shows only the core elements of a flexible process that features the three main stages described earlier, taking place in interaction with practice and yielding the dual outputs of knowledge and intervention.

Scientific Outputs

Different terms have been used to describe the kinds of theoretical knowledge that are produced by educational design research (cf. Edelson, 2002; McKenney & Reeves, 2012; van Aken, 2004; van den Akker, 1999). Descriptive, substantive or declarative knowledge is generated to describe certain phenomena (e.g., what learner behaviors are triggered by certain prompts). Prescriptive or procedural knowledge is generated to help inform interventions in practice (e.g., how to facilitate learning through the strategic use of certain prompt types under certain circumstances). Some projects may develop a research agenda more attuned to one type of knowledge over another, though eventually attending to both types seems to be the case more often than not.

Different terms have been used in literature to describe the kind of integrated procedural and declarative knowledge that comes out of design research, but design principles is probably the most prevalent (cf. Kali, 2008; Kim & Hannafin, 2008; Mishra & Koehler, 2006; Quintana, Reiser, Davis, Krajcik, Fretz, Duncan et al., 2004; van den Akker, 1999). Bell, Hoadley, and Linn (2004) describe design-principles as:

> …an intermediate step between scientific findings, which must be generalized and replicable, and local experiences or examples that come up in practice. Because of the need to interpret design-principles, they are not as readily falsifiable as scientific laws. The principles are generated inductively from prior examples of success and are subject to refinement over time as others try to adapt them to their own experiences. (p. 83).

Table 11.1 Three examples demonstrating educational design research variation

	Thomas et al. (2009)	Klopfer and Squire (2008)	Oh (2011)
Problem	Middle school students were relatively unengaged in meaningful scientific inquiry	High school and college students were frequent users of handheld devices such as smart phones, but were not using them to learn	Graduate student collaboration in online learning course was superficial and unproductive
Main focus	Investigating the implementation of a technology-rich educational innovation in a public elementary school in the USA	Developing innovative applications for mobile computing for environmental science education	To optimize collaborative group work and student learning in an online higher education learning environment
Intervention developed	Quest Atlantis: a 3D multiplayer virtual environment	A series of games that can be played on handheld devices such as PDA and smart phones	"E-learning Evaluation" course based on authentic tasks for online delivery
Knowledge created	Theory of transformational play	Theoretical framework called "augmented reality educational gaming"	Multiple design principles and associated strategies to enhance group work in online courses
Research methods used	Observations Interviews Surveys Document analyses Three qualitative case studies	Observations Interviews Focus groups Discourse analysis Case studies Design narratives	Participant observations Questionnaires Interviews Three sequential case studies
Research scope	This design research initiative has been underway for more than a decade with substantial funding from NSF and other sources	The design research study has been underway since 2001 with initial funding from Microsoft and other sources	This study lasted 2 years with no direct funding
Primary practical contribution	As of 2010, Quest Atlantis had been used by 50,000 students in more than a dozen countries. atlantis.crlt.indiana.edu	The work started with this project is now part of the Games, Learning, and Society group at the University of Wisconsin where numerous learning games can be found. www.gameslearningsociety.org	An online course design for a graduate level course based around authentic tasks was developed with substantial support for group work. http://authenticlearning.info/AuthenticLearning/Home.html

On the other hand, van den Akker (1999) suggests that the knowledge encompassed in design principles can be conveyed through heuristic statements, such as, "If you want to design intervention X [for purpose/function Y in context Z]; then you are best advised to give that intervention the characteristics C1, C2, …, Cm [substantive emphasis]; and do that via procedures P1, P2, …, Pn [procedural emphasis]; because of theoretical arguments T1, T2, …, Tp; and empirical arguments E1, E2, … Eq." (p. 9). Complementing these perspectives on design principles, Linn and Eylon (2006) also describe design patterns, which illustrate promising instructional sequences, and may be guided or fine-tuned by design principles.

Practical Outputs

In educational design research, research and development are integrated to create educational interventions that address practical problems. In early stages, this involves analysis of the problem to be addressed. Using the findings from a needs and context analysis, together with a clarified problem statement, design work commences. Depending on the scope of the project, (re-)design work can last from several weeks to several years. Especially the revisions are fed by field investigations using a range of strategies and methods to study either the intervention itself (e.g., as a type of intervention for which guidelines or design frameworks are needed); or phenomena that are engendered by the interventions (e.g., learner reactions).

Examples

Different research reports are used here (Klopfer & Squire, 2008; Oh, 2011; Thomas, Barab, & Tuzun, 2009) to illustrate the variety of educational design research conducted within the field of educational communications and technology. One study (Thomas et al., 2009) was conducted by a research team led by Sasha Barab, one of the most highly respected senior professors in the field, with substantial funding from the National Science Foundation and other sources; one study was co-led by an at-the-time early career assistant professor, Kurt Squire, with start-up funding from Microsoft and other sources; and the last was carried out by a doctoral student, Eunjung Oh, working with one other doctoral student and a practitioner with no funding beyond a graduate teaching assistantship. For each one, the problem addressed, the primary focus of the research, the intervention that was developed, the theoretical contributions, the methods used, the scope of the intervention involved as well as its practical contribution are summarized in Table 11.1.

The three examples described here illustrate how different types of research reports are published as sub-components of larger educational design research projects. Published in the *Journal of Educational Computing Research*, Thomas et al. (2009) is one of a series of journal papers in which Barab and his colleagues have described their efforts to refine a theory of transformational play while at the same time seeking to develop advanced forms of interactive learning games. This paper summarizes the results of three qualitative studies focused on the challenges and successes involved in implementing Quest Atlantis, a 3D multiplayer virtual environment (MUVE), which serves as the primary vehicle for instantiating Barab's transformational play learning theory and for allowing it to be refined through iterative design-based research.

Published in the *Educational Technology Research and Development* Journal, Klopfer and Squire (2008) describe a multi-year project to enhance student learning related to environmental science through the development and refinement of learning games that are accessed with handheld devices such as PDAs and smart phones. In addition to developing an array of learning games, the project has sought to develop and refine a theoretical framework called "augmented reality educational gaming" that can be applied by other games designers. The paper provides considerable detail about the development of the learning games using a unique "design narrative" approach. This particular paper focuses on iterative design cycles based on five case studies conducted in real high school classrooms.

Oh (2011) reports the findings of a doctoral dissertation that pursued two primary goals: (1) optimizing collaborative group work in an online graduate level course focused on "E-Learning Evaluation," and (2) developing a refined model of group work in online courses and identifying design principles for supporting online collaborative group work among adult learners The dissertation provides a comprehensive portrayal of a 2-year design research project using what Boote and Beile (2005) called the "compilation of research articles" (p. 10) format for dissertations. The dissertation includes one published article, three submitted papers, one detailed methodology chapter, and one detailed results chapter. Oh (2011) documents how mixed methods were applied across several semester-length iterations of an online course to yield multiple distinct design principles for supporting group work by adults.

Addressing Inherent Challenges

Inspired by van den Akker's (1999) design research challenges, this section briefly touches on several important issues that often crop up in educational design research, how they may be attended to, and areas that require further consideration.

Information Richness and Efficiency: Seeking a Productive Balance

When conducting educational design research, it is necessary to address questions about appropriate tactics for increasing the information richness and efficiency of data collection procedures and instruments without being over-whelmed with data. Design researchers should not be driven by the misconception that "more is better." This notion is aptly conveyed by Dede (2004, p. 107) who noted in reference to a design study that "everything that moved within a 15-foot radius of the phenomenon was repeatedly interviewed, videotaped, surveyed and so-forth—this elephantine effort resulted in the birth of mouse-like insights in their contribution to educational knowledge."

Optimizing Processes: Stacking Smaller Studies Together

Other questions arise around the linkages among design, prototyping, implementation, data collection, processing, analysis, and re-design. Managing the process of communicating evaluation findings and subsequently utilizing them for improvement of interventions is difficult. Realistic timelines must be established with allowances for flexibility. Educational design research projects must inevitably be divided into smaller, more manageable chunks. These chunks and the smaller studies involved in them can function as "bricks" in a larger structure that forms both the evolving intervention and the refined knowledge. Emerging insights can be shared through shorter (e.g., article-sized) reports of smaller chunks, whereas books or other media might be more appropriate for sharing new knowledge derived from the whole of long-term efforts. Often, the interim (i.e., smaller chunk) reporting stands on its own and does not (need to) mention the larger study; also, interim reporting for an external audience can be a timely vehicle for fostering reflection among design research team members.

Measuring Impact: Powerful Examples Needed

Ultimately, educational design researchers must address questions regarding the most relevant indicators of quality, success and impact of the interventions and knowledge advances that result from their efforts. Burkhardt (2006) writes about what is needed to bring about greater acceptance of educational design research. He describes several Nobel Prize winners for design and development in other fields and concludes that educational design research candidates should be assessed on the basis of their: impact on practice; contribution to theory and/or knowledge; and improvement in either research and/or design methodology. While it is surely too early to be expecting Nobel Prizes for educational design researchers, this approach will only gain wide acceptance when it can be shown to make the much-needed gains in demonstrating the impact educational research (cf. Kaestle, 1993).

Generalizability: Toward Uptake and Use of New Knowledge

The main conceptual vehicle through which new knowledge is transferred outside of the research context, generalizability means different things to different researchers. All researchers must seek to identify promising approaches to enable uptake and use of research findings. Because educational design research takes place in natural settings where more variables are present than can be controlled for, the findings from these studies cannot yield immutable rules, easily transferred without consideration. But they can yield useful insights to inform the work of others (design work or otherwise). For example, when designs are tested in multiple settings and under varying conditions, or when design features are systematically varied under similar conditions, theory development can occur through analytic generalization. According to Yin (1989, p. 44), analytic generalization is a process through which "the investigator is striving to generalize a particular set of results to a broader theory" which can be of use to others. Alternatively, knowledge produced through design research can be shared and used through case-to-case generalization. Firestone (1993) refers to case-to-case generalization as the transfer of ideas that takes place when a person in one setting considers adopting an intervention, or its underlying propositions and frameworks in another setting. To do this, the knowledge producer is obligated to explicate how the specific instance studied compares to other instantiations of the phenomenon. In so doing, description of salient characteristics of both the intervention and the context in which it is enacted are essential. Clearly, when it comes to putting the knowledge of design research to use, the knowledge producer must portray the work well enough. This could mean, for example, adhering to Lincoln and Guba's (1985) criteria for naturalistic inquiry: credibility, transferability, dependability and confirmability (parallel to internal validity, external validity, reliability and objectivity, respectively). At the same time, knowledge consumers are obliged to critically assess the applicability of certain ideas for their own specific contexts.

On the Horizon

Educational design researchers and arguably all educational researchers must seek to balance rigor and relevance (Reeves, 2011). To find this balance, educational design researchers might do well to learn from sister fields. For example, engineering and product design tend to embrace creativity more than most educational researchers (e.g., Laurel, 2003). Another perspective can be found in appreciative inquiry in health care (e.g., Carter et al., 2007) that emphasizes design based on opportunity, as opposed to patching gaps uncovered by reductionist problem diagnostics.

Since the landmark design research articles in 1992, a growing appreciation for educational design research in a wide variety of contexts has been evident (Anderson & Shattuck, 2012). Gradually, the design research literature is beginning to show more consideration of factors that affect implementation. Instead of tossing innovations over the metaphorical walls of classrooms and online learning environments, educational design researchers are working hand in hand with practitioners to conduct design and research in ways that make substantive change possible. The importance of collaborative approaches and on-the-ground understanding of implementation issues, which were privileged topics of research in the 1970s (cf. Fullan & Pomfret, 1977; Hall, Wallace, & Dossett, 1973; Havelock, 1971) seem relatively new—but also quite dear—to many of those currently practicing design research. Some researchers emphasize this perspective by referring to their work as design-based implementation research (e.g., Penuel, Fishman, Cheng, & Sabelli, 2011). We embrace the surge of interest in these concerns, and express our hope for a renaissance of scholarship that brings researcher and practitioner expertise together to bear on substantial educational issues (McKenney & Reeves, 2013). Educational design research is one of several genres of inquiry that can lead the way in contributing to scientific understanding in the long term through its study of meaningful implementation in the here and now.

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Design and Development Research

12

Rita C. Richey and James D. Klein

Abstract

This chapter focuses on design and development research, a type of inquiry unique to the instructional design and technology field dedicated to the creation of new knowledge and the validation of existing practice. We first define this kind of research and provide an overview of its two main categories—research on products and tools and research on design and development models. Then, we concentrate on recent design and development research (DDR) by describing 11 studies published in the literature. The five product and tool studies reviewed include research on comprehensive development projects, studies of particular design and development phases, and research on tool development and use. The six model studies reviewed include research leading to new or enhanced ID models, model validation and model use research. Finally, we summarize this new work in terms of the problems it addresses, the settings and participants examined, the research methodologies employed used, and the role evaluation plays in these studies.

Keywords

Design and development research • Instructional and non-instructional products • Design and development tools • Instructional design models

The Empirical Nature of Design and Development

Design models often parallel the scientific problem solving processes. Thus, the practice of design and development is to a great extent empirical by nature. Therefore, it would reasonable to assume that design and development processes have robust empirical support. Yet historically there has been a scarcity of research on our models, products and tools. While there has been increased empirical work on design and development recently, we have been writing about and advocating this type of research for the past 15 years (Klein, 1997; Richey, 1997; Richey & Klein, 2005, 2007, 2008; Richey, Klein, & Nelson, 2004; Richey & Nelson, 1996).

This chapter is a continuation of our work. It examines design and development research (DDR) by providing an overview of its definition and scope. The major part of the chapter focuses on representatives of recent design and development research. Finally, we summarize this new work with special emphasis on the problems it addresses, the settings and participants examined, the research methodology used, and the role evaluation plays in these studies.

Design and Development Research: Rationale, Definition, and Scope

Opinions on the role of research on design and development often depend on one's own view of what it actually is. We take the position that design and development is a science,

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even though it is highly influenced by the creativity of the designer. We approach design and development (and in turn research on it) with the assumption that science and empiricism provide a more effective and reliable route to disciplinary integrity than depending on artistic tactics and craft-based solutions. As a science, design and development should be bound by understandings built upon replicated empirical research. Our models and procedures should be validated. The solutions to our problems should be supported by data. We believe that our field has not sufficiently employed empirical methods to facilitate our understanding of design and development processes. The need for research is especially critical with respect to the models and processes employed by designers and developers. Few models, design strategies, and tools employed in practice have been empirically tested and validated. This is the gap that design and development research seeks to address.

Design and development research is a type of inquiry unique to the Instructional Design and Technology (IDT) field that is dedicated to the creation of new knowledge and the validation of existing practice. We define DDR as "the systematic study of design, development and evaluation processes with the aim of establishing an empirical basis for the creation of instructional and non-instructional products and tools and new or enhanced models that govern their development" (Richey & Klein, 2008, p. 748). This definition aligns with recent suggestions that professionals in the IDT field facilitate learning and improve performance by creating, using and managing appropriate instructional and non-instructional interventions (Definition and Terminology Committee of the Association for Educational Communications & Technology, 2007; Reiser, 2012; Richey, Klein, & Tracey, 2011).

Design and development research covers a wide spectrum of activities and interests. It includes the study of the design and development process as a whole, of particular components of the process, or the impact of specific design and development efforts. Such research can involve a situation in which someone is studying the design and development work of others. It can also involve a situation in which someone is performing design and development activities and studying the process at the same time. In either case, there is a distinction between *doing* design and development and *studying* the processes.

Design and development research is an umbrella term for a wide range of studies that employ an assortment of traditional quantitative and qualitative research methods and strategies. Most design and development research, however, tends to rely more on qualitative strategies and deals with real-life projects, rather than with simulated or contrived projects. Many studies can be viewed as multi-method research.

Understanding the nature of this research is a matter of understanding the range of problems to which it can be applied. It is also a process of recognizing those research interests and endeavors that are *not* a part of this orientation. DDR does not encompass the following: instructional psychology or learning science studies; media delivery system comparisons or impact studies; message design studies; and research on the profession. While results from research in these areas impact design and development, the study of variables embedded in such topics does not constitute DDR.

Design and development research, as with all research endeavors, leads to knowledge production, a more complete understanding of the field, and the ability to make predictions. DDR reaches these goals through two main categories of research projects: (1) research on products and tools and (2) research on design and development models. We previously referred to these two categories of design and development research as Type 1 and Type 2 developmental studies (Richey, Klein, & Nelson, 2004). Others have referred to instructional product development studies as design-based research (Wang & Hannafin, 2005), systems-based evaluation (Driscoll, 1984), and formative research (Reigeluth & Frick, 1999; van den Akker, 1999).

Below we describe design and development research in detail and briefly examine 11 studies conducted since 2007 in this line of inquiry. In addition to being quite recent, these studies were selected to exemplify the major categories of DDR, the types of methodologies commonly employed, and the range of research settings examined. They also highlight studies conducted in a variety of locales around the world. We begin by discussing research on product and tools, followed by an examination of research on models.

Research on Products and Tools

The most straightforward type of DDR falls into the first category—research conducted during the design and development of a product or tool. Often, the entire design and development process (analysis–design–development–implementation–evaluation) is documented. In some cases, researchers concentrate only on one facet of design and development (e.g., needs assessment). Many recent studies focus on the design and development of technology-based products and tools.

Below, we discuss three classes of product and tool research. These include studies of (1) comprehensive design and development projects, (2) specific ID project phases, and (3) tool development and use. We review recent representative product and tool research in each of these categories.

Recent Comprehensive Design and Development Research

Studies of comprehensive design and development projects usually demonstrate the range of design principles available to practitioners. Frequently, the entire design and development process is studied and documented. The design processes used in a particular situation is described, analyzed, and a final product is evaluated. Consistent with predominant practice in the field, the procedures employed usually follow the tenets of instructional systems design (ISD), encompassing analysis through evaluation. This is the case in a research study by Visser, Plomp, Armiault, and Kuiper (2002) who describe the design and development of a product which addresses learner motivation in distance education programs. This work includes an initial pilot study, as well as a year-long try-out and evaluation of the product. A study by Sullivan, Ice, and Niedermeyer (2000) is also an example of comprehensive DDR that focuses on the impact of an instructional program. These researchers use field evaluation to test a comprehensive K-12 energy education curriculum that was the product of a design, development and implementation project on-going for 20 years. While few researchers have the opportunity to study an instructional program for such a long period of time, recent research continues to examine comprehensive design and development projects. Below we discuss two such projects.

Developing a Web 2.0 System for Community and Teacher Use

Research by Cifuentes, Sharp, Bulu, Benz, and Stough (2010) provides an example of a comprehensive product design study. The purpose of this 2-year study was to investigate "the design, development, implementation, and evaluation of an informational and instructional Web site in order to generate guidelines for instructional designers of read/write Web environments" (p. 378). The researchers implemented and documented the entire ISD process. Needs analysis was conducted on a practical problem—individuals with disabilities and their families have difficulty gaining access to information about support services. Findings pointed to the development of an online directory of resources using the capabilities of Web 2.0 technologies. Design decisions were based on theory including social constructivism, distributed cognition, and rapid prototyping. Formative evaluation occurred throughout product development. Participants included the design team, a variety of intended users in multiple locations, college students contributed resources to the Web site, as well as internal and external evaluators. The researchers provide context-specific findings related to problems and issues encountered, resources required, and product impact and use. They also give generalized recommendations for others designers of Web 2.0 solutions.

The Cifuentes et al. (2010) study is a good example of comprehensive product design research. The researchers identified and analyzed a real-world problem, used theory and formative evaluation to inform design and development decisions, meticulously documented these decisions, employed multiple research methods, considered issues such as researcher bias and instrument reliability, and collected data from several sources.

A Task-Centered, Peer-Interactive Course Redesign

A descriptive case study by Francom, Bybee, Wolfersberger, and Merrill (2009) provides another example of comprehensive design and development research focusing on a product. This study addresses the real-world problem of converting a passive, face-to-face college biology course to an online course that includes peer-interaction and task-centered instruction. The authors describe how the instructor selected content topics and "complex, authentic tasks that would require students to gain a sufficient knowledge of the subject area in order to complete the task" (p. 37). They also explain how the First Principles of Instruction (see Merrill, 2002) were used to redesign instructional activities and assessments. A formative evaluation was conducted during the first semester the course was offered; data included observations of the instructor, classroom activities, and online discussions, as well as a student survey measuring perceptions of the course and their learning. The authors offer a discussion of how these data were used to revise and improve the course.

While the work by Francom et al. (2009) does not provide the same level of detail as the Cifuentes et al. (2010) study, both are examples of comprehensive design and development research. They report on projects in which a researcher studies design and development while comprehensive ISD processes are used to produce a specific product.

Recent ID Phase Research

Not all DDR pertains to a comprehensive project. Instead, some researchers examine specific phases of an ID effort. These studies typically relate to data gathering phases of the ISD process (e.g., needs assessment, formative evaluation). For example, Klein, Martin, Tutty, and Su (2005) identify the optimal research competencies of graduate students by conducting a content review of course syllabi from several leading instructional design and technology programs and by administering a survey to faculty and students. In addition, Fischer, Savenye, and Sullivan (2002) conduct a formative evaluation of computer-based training on an online financial and purchasing system to verify the program's effectiveness and identify necessary revisions. Below, we discuss another design and development study that is representative of very recent research on a component of ID.

Formative Evaluation of a Learning Game

A recent study by Sahrir (2012) is an example of DDR on a specific phase of ID, namely, formative evaluation. This research investigates the development of an online vocabulary game for beginning Arabic language learners at a Malaysian university. The researcher employed a mixed-method approach to collect data on prototypes of the online learning game. Data sources included instructors, subject-matter experts, evaluators, and learners who participated in one-to-one, small group and field test phases of formative evaluation. Characteristic of most product design studies, the researcher provides context specific findings (i.e., the online game improved student enjoyment, immersion and knowledge of Arabic). In addition, issues, problems and lessons learned are discussed to inform other designers of similar products. For example, the researcher suggests "there should be sessions of cooperative work and research activities between language teachers … instructional designers and computer experts to design and develop … effective games" (p. 366). This study is particularly notable because it provides an empirical test of how the phases of formative evaluation suggested by ISD scholars (e.g., Dick, Carey, & Carey, 2009; Tessmer, 1993) can be used in actual practice.

Recent Tool Development and Use Research

Some researchers concentrate on studying the development and use of tools, rather than on the design of products. These tools may support design and development or teaching and learning processes. Many of these studies focus on computer-based tools and some of this research is directed toward automating design and development. For example, Nieveen and van den Akker (1999) focus on a computer system that serves as a performance support tool for designers during the formative evaluation phase of an ID project. In addition, Mooij (2002) conducted a tool study examining the development and use of an instructional management system for early education. Below we describe a two other studies that are representative of recent research on tool development and use.

Development of Performance Support Tool for Teachers

A recent comprehensive study by Hung, Smith, Harris, and Lockard (2010) illustrates research on a tool to support the teaching/learning process, specifically the design and development of a performance support system (PSS) for classroom behavior management. These researchers "adopted design and development research methodology … to systematically investigate the process of applying instructional design principles, human–computer interaction, and software engineering to a performance support system" (p. 61). The study was conducted in six phases that mirrors an ISD approach. Qualitative and quantitative techniques were used to collect data from several sources. For example, a Delphi technique was used with subject matter experts to enhance the design of the PSS. In addition, elementary and junior-high school teachers completed a survey about system requirements, tested the usability of two prototypes of the PSS, kept activity logs during implementation, and participated in post-implementation interviews. The researchers report contextually based findings about their tool (e.g., navigation, functionality, efficiency, and ease of learning). They also discuss how design and development research served as a "conceptual guide to not only maintain a systematic approach to the development process but also to broaden the perspective of the system's instructional implications to a holistic approach that addressed system, user, and development process as a whole" (Hung et al., 2010, p. 78).

Design of a Computer Support System for Multimedia Curriculum Development

A study by Wang, Nieveen, and van den Akker (2007) focuses on the design of an electronic performance support system (EPSS) to help teacher-designers in China develop scenarios for multimedia instruction. The main purpose of the study was "to produce a practical computer support system for multimedia curriculum development by following an evolutionary prototyping approach" (p. 277). The researchers wanted to create an EPSS that was valid, practical and effective. They created four prototypes of the tool and collected data from experts and end users who completed questionnaires and participated in focus groups. Summative evaluation of the tool was also conducted. During this phase of the study, teacher-designers were observed using the tool to create scenarios for multimedia instruction; they also provided suggestions for improving it. Results indicate that participants found the tool to be usable and practical. An unintended outcome was that the tool helped "teacher-designers become acquainted with a systematic approach to multimedia instructional design" (p. 289).

The Wang et al. study is particularly noteworthy because it includes summative evaluation. This type of evaluation is often not included in DDR and is infrequently used in practice.

Research on Models

The second type of design and development research pertains to studies of the development, validation and use of models. These studies focus on the design and development models and processes themselves, rather than their demonstration. While it is possible to conduct model research in conjunction with the development of a product or program, many model studies concentrate on previously developed instruction, and consequently are not project-specific. Model research may address the validity or effectiveness of an existing or newly constructed development model, process or technique. In addition, these studies often seek to identify and describe the conditions that facilitate successful design and development. Since model research studies are oriented toward a broad analysis of design and development processes, they tend to be more generalizable than product and tool studies.

Model research tends to address three major related phases—model development, model validation, and model use. Here we review very recent representative model research in each category.

Recent Model Development Research

Model development research may result in new, enhanced, or updated models that guide the ID process or a part of the process. Such research has produced a rapid prototyping ID model (Jones & Richey, 2000), components of a model of ID competencies (Vallachia, Marker, & Taylor, 2010), and a Web-based knowledge management system model that provides for its continuing development (Plass & Salisbusry, 2002). Model research encompasses a wide range of settings and participants and it employs a variety of research methodologies (see Richey & Klein, 2007).

We examine two recent model development studies that address very different design problems using research methods that are totally different from each other. However, both contribute to the advancement of design and development models.

A Model for the Design of Visual Information

Message design is a specialized task of those who select and develop instructional materials, and it is an area informed by a broad knowledge base. Consequently, Voss (2008) conducted an extensive literature review resulting in the development of a model to guide designers as they work with one particular type of message—two-dimensional visual images that will transfer information to the learner/viewer. This study explores the research literature of message design, cognitive psychology, neurology, and information theory to identify those principles that govern visual communication, mental imagery, and visual memory. The literature and the resulting model suggest that visuals have their own set of rules that are based upon the nature of perception rather than the view of communication as being controlled by language.

While reviewing the literature is an important early step in conducting any research, a literature review is not typically used as a research methodology in the IDT field. However, large-scale reviews such as Voss's provide an opportunity to build an empirically based model that covers many variables. For instance, the Voss model addresses pre-attentive and attentive brain functions, the mental processes of selecting visual images, the varying functions of pictures, symbols and signs, as well as a range of distortions that can occur during message transmission.

Reviews of large bodies of research and theory are likely to cover many settings, be they instructional, transfer, or design and development. Therefore, this technique facilitates the identification of factors that are not context-specific or learner-specific. This is the case with the Voss model.

Identifying the Components of a Transfer Model

Like many researchers and practitioners interested in improving workplace performance, Hillsman and Kuptritz (2010) seek to identify empirically based predictors of transfer. Specifically, they focus on elements in the physical work environment. Their work is an example of a study that can be viewed as content-specific research, but then ID researchers can also interpret their findings in terms of design and development. More specifically, the research can be viewed as model development since it provides justification for including an entire class of variables into a design model directed towards transfer of training.

The Hillsman and Kuptritz study was a multi-methods project (both qualitative and quantitative) that collected data from 50 supervisors who had participated in 4 hours of interpersonal communication training and then applied their new skills working with their employees on the job for 6 months. The research involved conducting 6 hours of field observations, surveys, and structured personal interviews. In addition, there was an archival review of work records.

The results show that workplace design did "contribute to transfer outcomes. Supportive as well as unsupportive workplace design features were elicited as most often facilitating or impeding transfer" (Hillsman & Kuptritz, 2010, p. 23). While this research clearly has implications for workplace design, it also adds to the body of literature that seeks to model those factors that impact transfer of training. Thus, it also informs training designers of those aspects of context that are critical to the success of their interventions. These researchers do not fully develop a design-related model, but instead they identify the building blocks required to construct a comprehensive model.

Recent Model Validation Research

While the ID literature is rife with models of the design process, far less attention is paid to the validation of these models. Such validation is an empirical process that demonstrates the effectiveness of a model's use in a real-world setting (i.e., external validation) or provides support for the various components of a model (i.e., internal validation) (Richey, 2005). In some validation research, experienced design practitioners are used as subject matter experts to authenticate a design model or specific design phases. For example, Cowell (2001) interviews current designers to substantiate the regular use of needs assessment techniques (even though other terms are often used for the process). In other research, learner data confirms the model. (See Roszkowski & Soven, 2010, for their research which validates an updated Kirkpatrick evaluation model.) We summarize two other recent DDR studies which highlight the characteristics of model validation research.

Updating and Validating Gilbert's Behavioral Engineering Model

Thomas Gilbert's Behavioral Engineering Model (BEM) has profoundly influenced designers who work in employee training environments, and it has been credited with the origination of cause analysis. (See Gilbert, 1978, for a full discussion of this model.) Crossman's (2010) research examines BEM's relevance in the contemporary workplace.

The participants in Crossman's study are 600 fire fighters and the specific area of interest is safety culture, the motivation to follow safety rules. The fire fighters completed a survey whose items reflected the environmental elements of the BEM—information (i.e., communication), resources, and incentives. Data were analyzed using correlations and path analyses. Crossman found that the combined effects of the three variable categories did influence safety motivation. Furthermore, she found that incentives directly impacted safety motivation while absorbing the indirect effects of communication of information and resources. The environmental facet of Gilbert's long standing model was validated in this setting.

Crossman's study exemplifies an internal model validation asking whether the parts of the model are justified. It is an empirical study that relates to an actual work environment. It is statistically sound and based in both theory and practice. However, there are other ways to approach model validation.

Testing the Impact of the Multiple Intelligence Design Model

Tracey (2009) uses very different tactics to validate her ID model which blends multiple intelligence (MI) theory with traditional instructional systems design. The study has two parts—a designer usability test and an examination of product impact. As such, it provides both internal and external validation of the MI Design Model.

Designer usability was tested by randomly assigning two Masters-trained designers to a 2 hours team building workshop project using the MI Design Model; two similar designers were assigned to the same project using the Dick and Carey ISD Model. (See Dick et al., 2009 for a full discussion of this model.) Work conditions were the same for each design team. Following completion of the workshop materials, the MI Model designers filled out a model usability survey detailing their reactions to the model. Product impact, on the other hand, was tested by using the two design team's products. Five sessions with eight to ten learners each were conducted using the MI-oriented workshop, and another five similar sessions were conducted using the ISD product. Posttest and attitude-toward-training data were collected. While both groups felt confident in their new skills, participants who were trained with the MI materials scored slightly (but significantly) higher on the posttest and learning seemed to be stimulated by the use of the MI instructional strategies.

Tracey's research supports the use of the MI Design model. Like other design and development studies, it exemplifies comprehensive model validation techniques performed under real-world design conditions.

Recent Model Use Research

While it is not unusual for model validation research, such as Tracey's (2009) study, to address usability issues, there is another genre of design and development research that emphasizes how models are used. Many of these studies focus on the conditions that impact model use; these show the interplay between varying design and development contexts and model effectiveness. For example, Roytek (2000) conducted a comprehensive case study which focuses on two design projects using rapid prototyping procedures; this study is designed to determine which contextual factors, strategies, and events facilitate or impede project success. Other research focuses on the designers themselves to understand exactly how the design and development process is actually used. Visscher-Voerman and Gustafson (2004) conducted interviews with designers working in diverse settings and reviewed related project materials to determine the procedures designers used and their rationales for these approaches. Recent model usability research continues in a similar vein with much of the current work concentrating on the role of technology.

The Rapid Implementation of e-Learning

Many academic programs are faced with the prospect of changing quickly from face-to-face delivery of their courses to on-line learning. Coetzee and Smart (2012) present a case study describing the process of developing a module and placing it on learning management system (LMS). In doing so, they demonstrate the merger of two models—the traditional ADDIE (analysis, design, development, implementation, evaluation) design model and The Technology Process model used in technology development projects. The situation in this study was realistic in that the university instructor was working essentially alone with only one other person giving advice. Resources were limited. There was little lead time and thus the modules were used as developed. The course thus moved from a face-to-face delivery to a blended delivery. Subsequent units were modified based upon student feedback. This case study demonstrates how two recognized models can be modified to meet the demands of a given instructional situation. The models can be scaled up or scaled down to meet the varying needs of a particular intervention.

The Coetzee and Smart study is particularly useful because model use is not examined in a technology-rich environment. This demonstration takes place in university located in an underdeveloped country. Nonetheless, the two models are successfully adapted to the conditions present in their specific context.

Teacher Technology Integration

There are many models directed towards classroom teachers as they integrate technology into their lessons. The existing research, however, provides little data supporting teacher use of either classic ID principles or the consistent use of technology in their classes. Hart (2008) uses a "think aloud" protocol to study how middle school language arts and social studies teachers actually integrate technology into their lesson plans While these teachers were not applying specifically designated design or technology integration models, Hart explores which model components are used by identifying the design decisions made and the rationale for these decisions. Eight teachers (four of whom had graduate education in instructional design) completed a background survey, then a technology design task using the think-aloud techniques, and a post-design interview. Hart found that in general these teachers demonstrated a reliance on mental planning rather than use of design principles. Technology was not incorporated into all teachers' lessons in a meaningful way (even though that was the assigned task). Moreover, when it was used, the technology did not tend to support student higher level thinking. Contextual factors (e.g., accessibility) had the most impact on technology use.

Model researchers typically look forward to positive results that confirm their model's utility. Hart's (2008) research, on the other hand, produces less satisfying results. The data, however, provide an empirical basis for changing models to accommodate the real-world conditions.

Summary of Key Characteristics

We have described 11 studies published since 2007 which are representative of the most recent design and development research. These studies encompass the various types of both product and tool research and model research. They were conducted in a variety of work and geographical settings and address diverse problems currently being faced by the field. The researchers also use a wide assortment of approaches and methodologies to study design and development problems. Table 12.1 below summarizes this recent research.

Source of Design and Development Problems

Design and development research typically stems from problems encountered in the workplace (Richey & Klein, 2007). Of the 11 studies reviewed in this chapter, seven of them are directly rooted in real-life problems. For example, this research was used to answer questions such as: What facilitates transfer of training to the job? How can we help teachers to take on the role of designers? How can we get vital information to individuals and families?

In keeping with the increased use of technology in education and training, it is not unusual for design and development studies to have a technology focus. Over half of the

Table 12.1 An overview of recent representative design and development research

	Problem Source			Setting			Methodology			Evaluation	
Study	Work-place/ society	Technology	Theory	Adult Ed. and Trng.	P-12	Higher Educ.	Quali-tative	Quanti-tative	Survey	Formative	Summative
Product and tool											
Cifuentes et al. (2010)	X		X	X			X			X	
Francom et al. (2009)	X	X	X			X	X		X	X	
Hung et al. (2010)	X	X	X	X	X		X	X	X	X	
Sahrir (2012)		X				X	X	X		X	
Wang et al. (2007)	X	X		X	X		X	X	X	X	X
Model											
Coetzee and Smart (2012)	X	X		X		X	X			X	
Crossman (2010)			X	X					X		
Hart (2008)	X	X			X		X				
Hillsman and Kuptritz (2010)	X			X			X	X	X		
Tracey (2009)			X	X				X	X		
Voss (2008)			X				X				

studies we highlighted had a technology emphasis, and five of the seven studies with a workplace focus also examined problems related to technology. These studies concentrated on online learning, Web site design, technology integration, electronic performance support systems, and gaming. All of these topics reflect emerging technologies as well as current trends in the IDT field.

Over half of this body of recent research also reflects theoretical problems and issues. While some of these studies (such as Voss's, 2008 exploration of factors affecting the perception of visual messages) emanate only from an interest in theory, others (such as Francom et al.'s, 2009 study of online course design using Merrill's First Principles) combine a theoretical orientation with practical concerns.

Most DDR addresses problems which have multiple sources. In our sample of 11 recent studies only the model research with a theoretical focus seemed to have a more singular focus. This conclusion, however, may only be a peculiarity of the particular sample of studies we reviewed.

Research Settings and Participants

Design and development research problems (like ID itself) are typically contained in a specific context which includes distinct participants. ID is now used extensively in business and industrial settings, healthcare organizations, community and government agencies, as well as schools and universities. The 11 studies described in this chapter reflect this diversity for the most part. Four of the five product and tool studies are situated in educational settings—two at the P-12 level and two in higher education. On the other hand, half of the model research reviewed pertains to employee training.

All but one of the recent design and development studies reviewed in this chapter were conducted in a setting that included adults as participants, although in some cases the participants were adult learners rather than instructional designers alone. For example, product and tool research was done in the context of a learning community that included the parents of children with disabilities and county extension agents (Cifuentes et al., 2010). Model research was conducted with managers in a training setting (Hillsman & Kuptritz, 2010) and with fire fighters employed by a local government (Crossman, 2010).

Even recent design and development research conducted in P-12 school and higher education settings focuses primarily on adults. Our review identified three studies that concentrated on school teachers. The product and tool studies by Hung et al. (2010) and Wang et al. (2007) examined the design and use performance support tools for teachers while the model use study by Hart (2008) focused on how teachers integrate technology into their lesson plans. Furthermore, 3 of the 11 studies we reviewed in this chapter were conducted in a higher education setting (Coetzee & Smart, 2012; Francom et al., 2009; Sahrir, 2012). In all three cases, participants included faculty who were responsible for designing instruction for their students.

Research Methodology

The majority of design and development studies use multimethod approaches typically blending both qualitative and quantitative methods (Richey & Klein, 2007). This may be a reflection of the complexities of most projects and the multiple sources of the problems address in such research. However, qualitative methods were dominant. Nine of the 11 studies reviewed in this chapter employed qualitative techniques. We believe that this is a typical phenomenon. The qualitative methods, however, vary widely. They include the use of case studies, participant interviews, focus groups, field observations, activity logs, archival reviews, and think-aloud techniques.

Many studies also employ quantitative methods and may at times use experimental designs. Not surprisingly, evaluation phases of design and development research often rely upon assessment measures. Probably the most common quantitative method involved the use of surveys and questionnaires. For example, Crossman (2010) used survey data collected from fire fighters to validate the Gilbert model and Hung et al. (2010) surveyed classroom teachers to identify the requirements of their performance support system. Standard statistical techniques such as correlations and path analyses were then employed.

Finally, there is a critical methodological issue somewhat unique to design and development research. In many of these studies, the researcher also serves as the designer/developer. This situation is a common and often unavoidable by-product of the practical constraints of studying real-life design projects. These conditions occur in all of the recent product and tool studies summarized in this chapter and in one of the model studies (i.e., Coetzee & Smart, 2012). In these cases, data validity can be an issue, but when special attention is given to instrument design, data collection and triangulating multiple sources of data, the concerns have been addressed. The position of the designer/researcher is comparable to the role of participant observer in qualitative research, and similar data collection tactics are employed.

The Role of Evaluation

Evaluation is a major part of the design and development process and correspondingly plays a role in DDR although it is far more prominent in product and tool research than in model research. Since designers who follow a systems approach typically evaluate the intervention during development, researchers who study the design and development of a product or tool often collect similar evaluation data to determine its impact on learning. As expected, the comprehensive research projects such as those conducted by Cifuentes et al. (2010), Hung et al. (2010) and Francom et al. (2009) include formative evaluation tasks in their studies. However, all of the product and tool studies and one of the model studies we summarized in this chapter included some form of formative evaluation. Sahrir (2012) placed a major emphasis on this process when he empirically tested how the various phases of formative evaluation can be used by university instructors. Typically these data include learner assessments, but it often includes designer reactions as well.

Of special consideration is the study by Wang et al. (2007) which also includes a summative evaluation to investigate the impact of a performance support tool on teachers who develop curriculum. The inclusion of both formative and summative evaluation data is an encouraging trend in the IDT literature and we hope it continues.

Researchers who study design models are less likely to concentrate on evaluation data unless they are studying evaluation models. However, some researchers such as Coetzee and Smart (2012) may include formative evaluation in their studies of model use. Additionally, others develop and implement an intervention to test the efficacy of the model. In this process learner assessment data is often used.

Conclusions

In the past, instructional design strategies were supported primarily by research on the learning process. While that is still a valuable source of information, ID is now substantiated by a much broader array of research. One trend in the field is the use of design and development research. It establishes practical and theoretically sound solutions to the many problems faced in the IDT field. While this type of research is not yet commonplace, it is growing. The studies reviewed in this chapter reflect this phenomenon. Design and development research is being conducted in many parts of the world. It is being applied to many new topics and areas of concern. These researchers are providing the field not only with innovative examples of how such studies are conducted, but with new knowledge about how to design and develop interventions which address critical problems in education, training, and organizational improvement.

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Practices and Potential of Activity Theory for Educational Technology Research

13

Turkan Karakus

Abstract

This chapter aims to examine the practices and potential of Activity Theory (AT) for educational technology research (ETR). AT provides a framework within which to understand object-oriented, collective, and social environments (Engeström, *Perspectives in activity theory* (pp. 19–38). Cambridge: Cambridge University Press, 1999). Activity systems provide flexible frameworks that can be modified according to the nature of the context. In ETR, AT has been used as a tool to analyze and design complex learning situations as well as to analyze the contradictions and barriers in technology integration and to describe the dynamics of organizational knowledge creation. In this chapter, the basics of AT are presented and the available research using AT as a methodological tool in ETR is examined. The use of AT as a metaphorical tool in learning design and artifact development, as an analytic tool in an innovation study, and as a descriptive and prescriptive tool in a knowledge management study is explained. I also refer to the potential use of Actor Network Theory (ANT) as a possible third generation AT (Engeström, Journal of Education and Work 14(1):134–156, 2001) that can be used to understand the symmetrical relationship between multiple activity systems.

Keywords

Activity theory • Educational technology research • Actor network theory

Introduction

Modern technologies and new expectations of learners have enabled modern teaching strategies based on rich, multidisciplinary, collaborative, authentic, and real-life tasks (Van Merrienboer & Martens, 2002). As these new approaches also affect the educational design process, it is necessary to seek new ways of understanding all aspects of the educational context and to suggest new design solutions suitable for different learning situations. Distance learning, social networking, technology integration, and the use of technology by teachers and students are current issues in educational technology research (ETR), according to Ross, Morrison, and Lowther (2010). They also suggested that educational technology researchers have reduced efforts to prove the "effectiveness" of technology, while focusing on conducting rigorous and relevant mixed-methods studies to explain which technology applications work to facilitate learning, in what ways, in which contexts, for whom and why (p. 31).

From this perspective, contextual thinking in the implementation of new technologies becomes more attainable than proving the effectiveness of the technology for each context. Currently, learning is not perceived as an individual action, but as a social activity in which people and artifacts play important roles (Winn, 2002). Therefore, ETR's new focus is the learning environment as a whole rather than the design of the instruction (Mihalca & Miclea, 2007; Winn, 2002).

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Mihalca and Miclea (2007) also point out that ETR has embraced the belief that learning is highly dependent upon the activity of the learner, rather than upon the information and processes provided by the learning environment.

The transfer of focus from individual learning to societal learning (Engeström, 1987, 1999) brought a new complexity to teaching and learning situations that requires comprehensive frameworks for the investigation of these situations. AT, the roots of which were planted by Vygotsky (1978) and expanded upon by Leontev (1978) and Engeström (1987), provides a contextual framework that can be used to understand complex human interactions (Yamagata-Lynch & Smaldino, 2007) and describe the important components needed to design complex learning environments (Jonassen & Rohrer-Murphy, 1999). AT can help us to understand how the actors of any object oriented collective system transform the actions, operations, and other sub-activities into an object and how the contextual dynamics mediate this process (Barab, Barnett, Yamagata-Lynch, Squire, & Keating, 2002). Using a deductive perspective also helps to "break down problems into smaller, more manageable subproblems, set priorities and establish the relative importance of research issues" (Kaptelinin & Nardi, 2006, p. 27). Thus, in any context where purposeful human social activities take place to reach an object, AT enables us to understand that the activities of the community and the outcomes of the activities are shaped by the context of the activities (Engeström, 1987; Kaptelinin & Nardi, 2006; Leontev, 1978).

Basics of Activity Theory

AT is based on mediated action (Vygotsky, 1978) which uses individual action as a unit of analysis. In Vygostky's model, mediated action occurs when there is an individual subject, an object (motivation of the action), and a mediated artifact (Engeström, 2001). Vygotsky proposed that mediated artifacts might be societal artifacts that influence individuals' responses to a learning context; thus, Vygotsky's unit of analysis was still based on the individual (Engeström, 2001). Individual action differs from collective activity, according to Leontev (1978), who believes that individual goal-based actions and operations are part of a larger collective activity system (Engeström, 2001). Therefore, according to Leontev, the unit of analysis should be the activity system, not the individual. Certainly, there are smaller goal directed actions and condition-directed operations performed by subjects to realize the whole activity (Leontev, 1978, 1981) and analysis of the whole activity requires analyzing these actions and operations. While Leontev did not draw a conceptual framework for AT, Engeström (1987) did represent the components of a collective activity system. Thus, after Vygostky's first generation of the activity system, which included a subject, an object and a mediating artifact, the second generation of AT framework was proposed (Engeström, 1987).

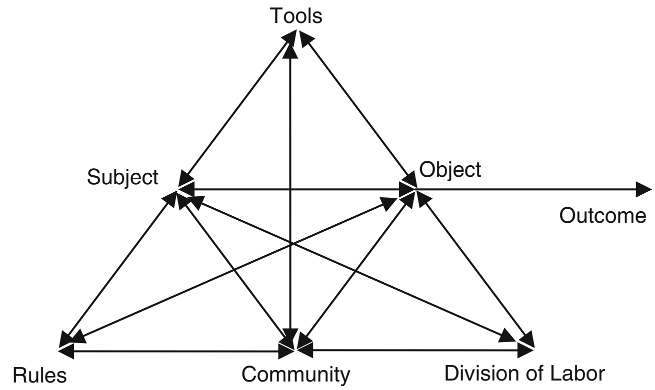

Fig. 13.1 Second-generation activity system triangle (Engeström, 1987)

According to Engeström (1987), each activity is a system in which there is an object (motive) that leads stakeholders (participants, actors, or performers) of the activity to act and perform many smaller activities. At the core of the activity, a subject performs to transform the object into the outcomes. Additionally, there are contextual dynamics that mediate between subject and object. An activity system consists of seven main components that can be located on an activity system triangle (Engeström, 1987; see Fig. 13.1). As seen in the activity triangle model, a subject interacts with other system components to transform the object. When the object is achieved, outcomes of the activity are revealed. The outcome, which is a concrete or abstract artifact of the activity, is also called a transformed object (Mwanza & Engeström, 2005). The tools of an activity system are any tangible or intangible artifacts that mediate between the subject and object. A subject is connected to a community (the context and people with whom the subject interacted) by means of rules (norms or regulations that influence performance in activities). Rules might be considered the actual contextual factors that enable or limit the actions and operations of the subject or community. Finally, division of labor defines the responsibilities of community members. Alterations in the dynamics of these components of activity influence the quality of object transformation and, consequently, the outcome. As seen in the activity system triangle, each component has a dual relationship (tool—rules, rules—division of labor, rules—community, etc.) and all of the mediating components have a direct connection to the subject and object.

The activity system triangle constitutes a descriptive framework that can be used to analyze and evaluate any object oriented context. In general, when using an activity framework, the contextual issues are first represented within the framework and then the contradictions, tensions and transformation of a system to another system are revealed with detailed descriptions. However, it is not possible to understand the context with just a representational model of a learning situation or any other learning context. The following five principles of AT might illuminate the analysis of the context: the activity system as a unit of analysis, multi-voicedness of the activity, historicity of the activity, contradictions as the driving force of change in an activity, and expansive cycles as a possible form of transformation in an activity (Engeström, 2001).

The first principle of AT is that the collaborative, artifact mediated, and object oriented activity system is the unit of analysis (Engeström, 2001). As Engeström and Kuutti (1996) pointed out, actions, operations and smaller activities can be independent, but the entire activity system should be considered when these smaller pieces are interpreted. Multi-voicedness means that a diversity exists within the components of the activity system. The diversity in the background, history, interests and traditions of a community as well as rules and division of labor cause the activity systems to have a dynamic structure with problems and contradictions. Thus, the multi-voiced structure of activity systems enables us to see how the negotiation between or within the components is achieved over time. Two studies that investigate the contradictions in university–school partnerships (Tsui & Law, 2007; Yamagata-Lynch & Smaldino, 2007) might be given as examples of this AT principle. In both studies, the researchers followed a design-based approach to resolve the contradictions caused by institutional differences.

Using the historicity principle, the transformation of the activities and objects, which change over time, can be observed. This principle enables understanding of how the developments occur in the system over time. Yamagata-Lynch's (2003) study constitutes an historical analysis of the transformation of technology usage in a specific school district. In her analysis, Yamagata-Lynch explores the teachers' professional development by comparing the school context before, during, and 1 year after the implementation of technology integration. In that study the contradictions between and within the components of the activity were the main sources of change in the activity systems, as in the fourth principle. Contradictions occur when a component's dynamics change. The conflicts between old and new dynamics are also taken as the bases of acceptance of innovations (Blin & Munro, 2008; Demiraslan & Koçak Usluel, 2008; Nocon, 2008; Russell & Schneiderheinze, 2005).

Finally, as the dynamics and conflicts change and increase, new cycles of activity systems are generated. The change in dynamics and conflicts move the activity system from its current state to a new state. These expansive cycles are crucial for collective activities within which the object is to change the current state to a new one Examples are Engeström's (2001) study that aimed to change the treatment procedures of a health center or Kaptelinin's (2003) study of the development of a user centered virtual environment. As Kaptelinin and Nardi (2006) pointed out, this principle, called "development," is especially useful when combined with the first principle in designing a system.

Actor Network Theory and Activity Theory

The need to compare different activity systems requires new conceptual frameworks beyond AT (Barab, Schatz, & Scheckler, 2004). Actor Network Theory (ANT), as a potential for third generation AT, proposes finding an approach to understand the dialog between multiple activity systems (Engeström, 2001). ANT can be considered to be related to AT (Engeström, 2001; Kaptelinin & Nardi, 2006) as ANT also seeks relationships between the components of the context, but it differs in terms of considering whether human and nonhuman actors have equal roles in the context (Callon, 1999; Kaptelinin & Nardi, 2006; Latour, 1993). ANT provides an approach to understanding the "creation of networks of aligned interests" (Mähring, Holmström, Keil, & Montealegre, 2004) and to examining the symmetrical relationship between nature and society (Miettinen, 1999).

ANT's potential was investigated in Information Systems research where the technology became an active role player in (social) network creation (Engeström & Escalante, 1996; Gao, 2005; Mähring et al., 2004; Miettinen, 1999). In technology integration, change management and the diffusion of innovation studies, ANT can potentially provide a framework for understanding the heterogeneous links between the different activity systems in innovation settings (Fenwick, 2009). However, ANT does not have a clear framework that can be used in a research context (Hitchings, 2003; Mähring et al., 2004) and does not have any fixed components prior to network construction (Broer, Nieboer, & Bal, 2010); instead, ANT allows researchers to understand the historical phases of a network building process. ANT examines how the networks of actors are connected to discover how human and nonhuman entities join a network after the selection, persuasion, and change processes have happened (Fenwick, 2009). Consequently, the unit of analysis for the ANT is the gradually growing network, which includes nodes and links (Engeström & Escalante, 1996).

Although no structured framework exists for ANT, network expansion is defined as a four-step process, also called the sociology of translation steps. These are (1) problematization (subscribing and clarifying the actors), (2) interessement (setting up and strengthening the links between the actors), (3) enrollment (developing agreements between the actors), and (4) mobilization of the allies (optimizing the functionality of the network) (Callon, 1986). These steps explain the success or failure of the dissemination of an innovation (Tatnall & Gilding, 1999).

The fluid structure of ANT makes it difficult to use it in a structured learning setting where the stakeholders are fixed but it might help to explore the collective network building process in free learning and knowledge sharing settings. For example, Broer et al. (2010) illustrated this issue by examining the efforts of the collaborators in two improvement projects related to mental health care and care for the intellectually disabled. In that study, the clients, anchors, friends, acquaintances and professionals were the actors of the network and the purpose of all of the collaborators (professionals) was to improve the recovery process of the clients. In their analysis, Broer et al. began by examining how the collaborators identified a clear understanding of the roles of the network members, such as reducing the roles of the professionals in the lives of the clients instead of continuously stimulating them. This process might be assumed to be an effort to build an optimized network helpful to the clients. In the second phase of the analysis, Broer et al. observed how the collaborators generated ideas on how to guide their clients. In other words, this phase strengthened the network by means of optimized solutions. Each of these steps was nested within the other but still the authors succeeded in explaining the process of building an optimum-functioning network after clarifying, defining, changing and improving the roles of the actors in the network.

AT differs from ANT in that AT examines the inner contradictions and interactions in the different nodes of the networks (Miettinen, 1999). In AT, a subject exists who is in a dialog with the community, rules and tools to transform the object. ANT's framework, on the other hand, reveals the symmetrical relationships between the nodes of the network, when each node has an equal role and strength in the network expansion process (Callon, 1986). In addition, in ANT many nodes exist that might have similar structures and different connections to the network, while in AT a stable framework exists.

Practices and Potential of AT in ETR

Kaptelinin and Nardi (2006) pointed out that AT is descriptive (identifies key concepts and variables), explanatory (reveals relationships and processes), and generative (facilitates creativity, invention, and discovery). In the design, development, and implementation of learning artifacts and situations, AT has enabled researchers to characterize the learning tools for different contexts (Barab et al., 2004; Collis & Margaryan, 2004; Mwanza & Engeström, 2005). By design, AT has also created a metaphor to represent interactions in a learning environment (Barab et al., 2002; Yamagata-Lynch & Smaldino, 2007) and to represent pedagogical structures of learning artifacts (Mwanza & Engeström, 2005). For these studies, AT provided more manageable data for understanding the context and proposing systemic implications (Yamagata-Lynch, 2007). The main issues for analysis in AT are the tensions (Barab et al., 2002; Yamagata-Lynch, 2003, 2007) and contradictions (Lim & Hang, 2003; Lim, Tay, & Hedberg, 2011) within the activities. Exploration of the tensions and contradictions in diverse innovation settings provides the big picture which shows not only the dynamics that have created barriers in the innovation setting (Blin & Munro, 2008; Issroff & Scanlon, 2002; Lim & Chai, 2004; Lim & Hang, 2003) but also the ways in which the contradictions were balanced or negotiated over time (Yamagata-Lynch, 2003).

In knowledge management studies of communities of practice and computer supported communication environments, AT has been used as a methodological tool to describe and prescribe social interactions in context (Engeström, 2000, 2001; Mwanza, 2002). In some studies, learning tools have constituted the tool artifacts of the activity system and the practitioners have sought to learn how these tools interacted with the other components and influenced the outcome (Bellamy, 1996; Cole & Engeström, 1991; Tan & Melles, 2010; Zurita & Nussbaum, 2007). In the next section of this chapter I present five examples of how to use AT. These are as a methodological tool in an historical analysis of contextual changes, a framework for course design, a tool in characterizing contextual learning artifacts, an analytical tool in innovation studies, and a tool by which to explain a developmental study.

As a Tool for an Historical Analysis of an Activity System

As a descriptive theory, AT has been used to describe many learning contexts (Barab et al., 2002). Barab et al. (2002) used it to understand the historical transformation of course dynamics. The authors began by clarifying two tensions (building virtual models vs. learning astronomy and teacher-centered instruction vs. student-centered learning) that arose during an astronomy course. Then, they conducted an in-depth analysis of the actions and operations associated with those tensions. Thus, they could see how a tension was transformed into a solution and how that solution became a component of a next level activity. Every goal-based action was shown on the triangles and then the relationships between the triangles were represented. For example, a student who had trouble in creating a model [subject] understood the model development process [object] by means of a model created by his friend [tool]. Then he used that model [tool] to create his own model [object]. Those representations were helpful in that it allowed readers to understand how the students learned astronomy concepts by means of the social interaction in class. This kind of analysis might allow a characterization of balanced course environments, which is useful in instructional design (Barab et al., 2002).

Cultural historical AT that requires longitudinal observations in a context is a commonly used method (Roth & Lee, 2007; Russell, 1997). Yamagata-Lynch's (2003) study, which benefited from a cultural historical analysis using AT, examined a school district to understand the effect of a teacher professional development technology integration program on the district and the effect of the school district on the program. The results revealed tensions after analyzing the different phases of technology integration (before, during and after). The author then showed, by means of the AT framework, how these tensions affected the integration process and illustrated the historical development of human activities and how these activities became an artifact for a future phase (Yamagata-Lynch, 2003). Both Barab et al. (2002) and Yamagata-Lynch (2003) showed that tensions are crucial elements in the transformation of activity systems, whether or not those tensions are overcome.

A Course Design Framework for Constructivist Learning Environments

In complex learning environments, AT could provide a broad lens to investigate and simulate the dynamics of the context (Jonassen, 2000) and to draw a bigger picture to see how learners learn when they are involved in a particular learning activity (Stevenson, 2008). Jonassen and Rohrer-Murphy's (1999) proposed a framework for constructivist learning environments, showing how the AT activity triangle can be used as a course design framework. This framework can be used in a flexible manner as it consists of many context-based questions. Its extensive examination of the context includes six main processes: (1) clarification of the purpose of the activity system, (2) analysis of the activity system by identifying and describing its components, (3) analysis of the activity structure (activities, actions and operations), (4) analysis of mediators, (5) analysis of the context, and (6) analysis of the activity system's dynamics (pp. 71–78). Therefore, it can be argued that the activity system approach is based on the elaboration of contextual issues and the development of solutions by moderating the effective dynamics of the system. This framework was used to design a blended course (Collis & Margaryan, 2004) and to characterize a mobile learning environment (Uden, 2007). For example, Collis and Margaryan (2004) used four of the steps suggested by Jonassen and Rohrer-Murphy (1999): (1) clarification of the purpose of the activity system, (2) analysis of the activity system, (3) analysis of instruments and resources (to be used in the learning environment), and (4) analysis of the activity system dynamics in the learning environment. Collis and Margaryan (2004) combined the design of work-based activities and computer supported collaborative learning situations to teach health risk assessment in workplaces. Students who had jobs at different workplaces, as well as supervisors and instructors, became the subjects of the activity. Students contributed to the content of the course by investigating the activity system of their workplace. Thus the authors improved both their course design and the learning outcomes in a student-centered manner using this framework.

As a Tool for Characterizing and Designing Contextualized Learning Artifacts and Systems

Reeves (2006) believes that, as design is a contextual, social, and active process, educational technologists should seek strategies that incorporate contextual issues into design as much as possible. AT facilitates the research by modeling pedagogical and contextual issues of learning artifacts and technologies (Barab et al., 2004; Mwanza & Engeström, 2005). As an example, Mwanza and Engeström (2005) used the activity system to create new learning object metadata (LOM) standards for a newly developed project called Lab@Future. This project proposed creating virtual laboratories combining virtual reality, 3D and mobile technologies to engage high school students in learning. In the development of the learning objects, the activity system approach was used to include the pedagogical and contextual aspects of the learning environment in the metadata descriptions (Mwanza & Engeström, 2005). Under the educational category of LOM standards, the project team used the activity system analysis "to enhance the meaningfulness in the interactions and the usefulness in the nature of objects accessed" (p. 463). The researchers showed possible contextual issues that might interact with these tools in the activity system. The learning outcomes were defined as the objects of the activity system. For example, for history, they described the object as "to acquire and internalize historical knowledge as proposed in the curriculum" (p.461).

Mwanza & Engeström, (2005) study might be counted as a suitable example for ETR trends as mentioned by Ross et al. (2010), when one takes into account the context as a basis for designing the learning objective. However, this contextual thinking does not mean that they examined all of the pedagogical dynamics of each learning object to fit in different contexts.

Barab et al. (2004) also used AT to characterize their social network platform. But they also had to build up the network community to make the platform functional and analyzed the process of socialization by means of another framework. In this sense, Barab et al.'s (2004) study might be a good example of using AT with a framework derived from ANT, called the sociotechnical interaction network (STIN). As Barab et al. argued, STIN was different from ANT because while the network structure might be drawn simultaneously in STIN, there was no need for an historical understanding of network building as in ANT. In the study, they created a community of practice platform for teachers by using AT to characterize the context in which the platform would be used. While using the platform, they used STIN to define the community building process and its tensions. After their analysis, Barab et al. suggested that AT might be used as an explanatory tool to understand the network characterized by STIN where STIN constituted a whole activity or any component of a new activity system. Thus, AT and ANT might be used interchangeably to understand any community creation process. In the innovation process, for example, they might be used to explore how people become users of innovation by using ANT and then characterizing the components, tensions or contradictions of the whole innovation setting using AT.

Lim et al.'s (2011) study embraced a similar method to investigate the efforts of teachers to integrate a multiuser environment into the curriculum. Neither study contained information about how the contradictions were resolved over time; however, both of the studies exemplified a third generation activity framework that took multiple activity systems as a minimal model (Engeström, 2001). Representation of the relationships between the different systems might be associated with ANT since its approach is to compare different activity systems; however, Lim et al.'s study only shows the contradictions between existing activity systems and ICT was not considered a separate activity system on its own. ANT is an approach often used when exploring technological innovations (Tatnall & Gilding, 1999) when the technology itself becomes an active part of the network.

As a Tool for Discovering and Describing Reactions to Innovation

Technology integration is a dynamic process used to improve the performance of schools (Tondeur, Cooper, & Newhouse, 2010). Typically, technology integration is not an easy process, considering the social tensions, contradictions and resistance of the users. Each contradiction constitutes an issue that needs to be resolved to advance to the next step of technology integration. The educational technology field plays an important role in understanding these resistances, developing effective implementation strategies, resolving contradictions, and training stakeholders. In this respect, AT has been used to discover how contradictions enable or frustrate changes in the innovation setting (Lim & Chai, 2004; Lim & Hang, 2003; Lim et al., 2011; Russell & Schneiderheinze, 2005; Yamagata-Lynch, 2003).

Lim and Hang's (2003) study of ICT (information and communication technologies) integration into curriculum in schools in Singapore contained three analyses of the activity systems. First, they investigated the primary inner contradictions of each component. For example, they observed how the teachers struggled with classroom management, while trying to use technology to improve the students' higher order thinking skills (contradictions in objective). In the secondary inner contradictions, the researchers focused on the contradictions among the components of the activity system. For example, technology changed the role of the teacher from a traditional teaching role to facilitating learning, which meant that a contradiction existed between the tool and division of labor. Finally, they compared different activity systems and they discovered that the objectives and activities of the classrooms', schools', and educational technology divisions' activity systems differed. Each school was competing to get a higher rank in the educational system league to which it belonged. The students' success rates needed to be high in order for the school to get a higher rank.

As a Tool for Describing and Prescribing the Improvement Developmental Cycles

Knowledge creation, like other types of production, is not an abstract process; contextual and social dimensions influence it. Engeström (2001) expanded the definition of AT to include the expansive learning approach, which accepts that activity systems have their own zones of proximal development where the subjects continuously question the established norms of the system. Thus; expansive learning might be associated with the developmental cycles of resolving a problem. Using this approach, Engeström answered "Who is learning?" [subject], "Why do they learn?" [object], "What do they learn?" [outcome], and "How do they learn?" [actions, operations] for each dimension of AT. Using this matrix, Engeström (2001) showed how an AT framework can be used for historical inquiry and the redesign of knowledge management situations step-by-step in a healthcare setting.

In answering each question, Engeström (2001) used a step-by-step approach. He observed the processes through which a child patient passed until a diagnosis was completed. He started by observing a particular physician. He observed the physician's actions and operations in determining the preliminary diagnostic test results for the patient. After this physician examined the patient, a series of additional diagnostic tests were conducted and different specialists examined the patient in accordance with the policies of the hospital. A patient with a number of problems had to make several visits to different care providers and follow different paths (procedures) to be diagnosed and treated by a care provider. This situation created some disturbances because of uncoordinated communication between the physicians and specialists. The critical pathway (procedures of the treatment), as a tool of the health center system, also caused the patient to make many visits to the health center and care providers. After examining the problems of the system in the health center via a question matrix, Engeström revealed the outcomes as “excessive numbers of visits, unclear loci of responsibility and failure to inform other involved care providers” (2001, p. 143). Then, Engeström presented a new model aimed at improving the healthcare system of the health center. The model required a new kind of knowledge management system to be used by the stakeholders (physicians, specialists, nurses, administrative staff, patients and their parents) in the patients’ treatment activities.

In Engeström’s (2001) study, AT played a crucial role in understanding the history of the case and its contradictions, proposing a solution model and examining the new system. A third generation AT was also used to understand the interconnections between the different activity systems (the health center, children’s hospital, patient’s family). This study is an important example of using the different dimensions of AT to explore, describe and develop a solution for design problems which might also be a base for developmental studies.

Conclusion and Discussion

In this chapter, I have provided several examples of how to use AT as an analysis framework and analytical tool. The expandable nature of AT makes it useful in many disciplines and research areas. I have shown that AT uses a contextual framework to explore contexts that have contradictions, conflicts, and dual relationships. The results constituted examples of designing optimized learning environments and artifacts, understanding technology and innovation integration efforts and creating courses where learners become active players in course design and performance improvement. In addition, I examined ANT and AT to understand whether they could be used as complementary approaches in socialized networked environments. I anticipated that the ANT approach would be a tool that could be used to reveal the interactions and connections between the activity systems.

The contextual approach of AT looks promising for ETR methodologies. In addition, as AT is so flexible, it can be expanded and modified in response to the nature of the research context. For example, Halloran, Rogers and Scaife (2002) extended the use of an activity system by revealing several contradictions within the components of the system instead of contradictions between the components. Similarly, AT has the potential to be expanded and modified for use in any social, object-oriented, collaborative, and tool-mediated context. Many studies have benefited from different applications of AT by dealing with manageable units of analysis, reaching systemic implications, understanding systemic contradictions and tensions, and comparing the findings meaningfully (Yamagata-Lynch, 2010). The types of use of AT are summarized in Table 13.1

As seen in Table 13.1, no unique way exists by which to run AT for a particular research purpose. This diversity might be an issue that researchers need to overcome when deciding the starting point of their analysis. Initially, deciding a meaningful activity system to examine might be challenging (Uden, 2007; Yamagata-Lynch, 2007). This decision is especially important when exploring a series of activity systems or different activity systems at one time (Yamagata-Lynch, 2007). In the rich data, an activity framework needs to remain static to show the unsteady dynamics, tensions, and relationships

Table 13.1 Different ways of using AT as a methodological tool

AT analysis steps	Contribution to ETR research	Specific studies using AT
Analysis of the activity systems of a school district and the teachers before, during, and after a technology integration and the availability of a technology coordinator to reveal tensions. Discovering the relationships between a series of activity systems	A potential framework for deriving practical implications in design-based research	Analysis of transformation of learning (Barab et al., 2002). Diffusion of innovation (Blin & Munro, 2008; Russell & Schneiderheinze, 2005). Redesign of teacher education program (Roth & Tobin, 2002). Technology integration process (Yamagata-Lynch, 2003, 2007)
Step-by-step analysis of an activity system to characterize the learning environment	Exemplary constructivist course design framework	Design of mobile computer supported environment (Zurita & Nussbaum, 2007; Uden, 2007). Design of learning artifacts (Mwanza & Engeström, 2005). Computer supported course design (Collis & Margaryan, 2004)
Characterizing the optimum context of the platform from designer and teacher perspectives. Using another theory for the community building process	Use of different theory(ies) interchangeably with AT to understand different phases of system development	Barab et al. (2004)
An analysis of the activity systems of a hierarchical structure, the internal contradictions in each system and the external contradictions between the different activity systems that are influencing each other	A method of analysis for diffusion of innovations	Diffusion of innovation (Lim & Hang, 2003; Lim et al., 2011). Comparison of different e-learning platforms (Benson, Lawler, & Whitworth, 2008; Benson & Whitworth, 2007)
The analysis of contradictions via four predetermined questions for each principle of AT, proposing new models for problem situations and examining and developing solutions	A potential framework for developmental research	Workplace knowledge management (Engeström, 2001). Educational innovations (Yamazumi, 2008). School–university partnership (Fenwick, 2009; Tsui & Law, 2007)

Table 13.2 Comparison of AT and ANT

Property	AT	ANT
Type of the theory	Descriptive, prescriptive, generative	Descriptive
Framework	All components of the AT are defined	No clear network structure at the beginning
Objective of the activity	A definite objective of the activity system	Creating a durable network of actors having similar objectives
Unit of analysis	Sociocultural activity as a unit of analysis	Process of the creation of human and nonhuman networks as a unit of analysis
Purpose	Sociocultural historical analysis of an available activity system	An historical analysis of a durable network building process
Participants	Human actors that cannot be separated from the activity context	Human or nonhuman actors, which can be separate from or joined to the network
Orientation	Object oriented activity	Process oriented activity
Focus of analysis	Focus on sociocultural activity	Focus on sociotechnical action
Initializing the analysis	Starts with an analysis of the available activity context	Starts with defining the actors in the network
Analysis steps	Varied, but mainly depend on the analysis of dynamics, contradictions, tensions, and development of negotiation in the system	Problematization, interest, enrollment, and mobilization of allies

between the different activity systems. Therefore, researchers should find creative ways to show those relationships.

Another activity-based approach, ANT, needs developing to become a usable framework for ETR. From an ANT perspective in innovation or technology integration studies, the technology itself is defined as an actor of the system with as much importance as the human actor. But ANT still needs to clarify how nonhuman units contribute to the network. Innovations or different nonhuman actors cannot function without humans; they cannot be a power by themselves in the educational environment. In addition, systematic and hierarchical processes of technology integration might constitute a barrier when using ANT because ANT advocates a natural formation of the networks in which no hierarchy exists between the nodes. It does not explain how we can create a network within an innovative setting, but we might use it to explain the natural creation of a network. In other words, it is a descriptive approach rather than a prescriptive or predictive approach. Therefore, ANT might be more suitable for free learning environments, such as community of practice platforms or organizational learning, when no specific actors exist at the beginning of the network creation (Fox, 2000). In this case, AT and ANT might be considered complementary approaches; that is, AT reveals the inner contradictions and problems in a node and ANT creates a vocabulary to reveal whether and to what extent a certain node of the network (i.e., actor) is a part of the network system. A detailed comparison appears in Table 13.2.

Although AT and ANT might be used to complement each other, a need still exists for a method between AT and ANT analysis, as ANT allows the user to see how a negotiated network is built overtime, while AT examines networks in several dimensions, such as history, interaction, and contradictions. Another strategy is needed to see the interrelationships of different available activity systems. For example, in Lim and Hang's (2003) study, the stakeholders of the educational system were stable and the roles and hierarchy were defined. In Benson and Whitworth (2007), the cases, which were examined using the activity approach, were also defined at the beginning. Although the researchers found a method to show the relationship between the activity systems, more systematic questions would analyze the relationships between the activity systems.

Implications

It is clear that more flexible approaches to conceptualizing methodological frameworks are needed. Static representations of frameworks are insufficient when attempting to understand complex learning situations, which is why a third generation of AT needs to be developed. Today, within the investigation of a unique context, it is not enough to understand its complexity; we also need to examine the relationships between the contexts in addition to the dynamics in each of the contexts. In addition to ANT, as Engeström (2001) suggested, more approaches and methodologies are needed to understand the dialog between different activity systems. It is suggested that for each research context other representations of the activity exist instead of just a rigid activity triangle. In this respect, ANT might be a more flexible way of representing the available context. As each actor or component (there might be an infinite number) of the network has different distances from and relationships with each other, they might not always have a dual relationship nor have a direct effect on each other. However, these features of ANT do not provide a well-suited approach to understand current educational contexts as long as these contexts continue to have definite objectives, systematic designs, and developmental learning situations. Therefore, ANT might need to be combined with different frameworks to be used in ETR.

Clearly, an AT framework requires extensive, in-depth, qualitative analysis of the context. Both the AT and ANT practitioners should be a part of the activity to understand the contextual structure. In the examples given, discourse analysis constitutes an important instrument for activity theory-based research. Researchers should be a part of the context to characterize the activity systems and investigate contradictions as well.

Conceptualizing a learning environment with an activity system is not sufficient when attempting to explain the whole context or understand the whole activity (Wells, 2002) and the triangle model does not constitute the heart of the findings (Yamagata-Lynch, 2003). The triangle model visualizes the context to describe it. In order not to represent an activity system, like a "black box" (Barab et al., 2002), the framework should be extended so that it explains the relationship between the dynamics of the context. Wells (2002) especially emphasizes that the dialog within the system should be represented in an expanded triangle model; he drew another framework in which he added "means, experience, realization" to represent a cooperative production system (p. 49). Similarly, the black box issue is present for ANT, even more so than for AT, because ANT does not focus on the inside of the nodes of the networks. Therefore, a combination of different frameworks could be explored to investigate the structure of the relationships in the context.

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Action Research for Educational Communications and Technology

14

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Abstract

Action research refers to the formalized, self-reflective research of practitioners. According to Cochran-Smith and Lytle (Inside and outside: Teacher research and knowledge. NY: Teachers College Press, 1993) action research is "systematic and intentional inquiry" (p. 7). It is often conducted collaboratively in research groups that meet in person or at a distance via communication technologies. Action research transforms the traditional "outside-in" relationship between practitioners and the educational community. It can provide a powerful means for bridging the divide between theory and practice and encouraging practitioners to engage in innovative practices. Action research includes a cyclical process of posing questions, collecting data, reflecting on findings, and reporting results. This chapter provides a comprehensive overview of action research and its history in the USA, Great Britain, and Australia. It also describes the epistemological and ontological differences between practical and critical action research. To inspire future action research in our field, we detail the action research method, including data collection and analysis techniques and provide example studies from the field of educational communications and technology. More specifically, we demonstrate the manner in which action research has already been used to better understand the impact of the integration of technology in classrooms and social settings. At the same time, we describe how action researchers have used educational communications and technology to conduct action research and to teach this research method through online or hybrid classes. Technology can be both the focus and part of the method of the action research.

Keywords

Action research • Participatory action research • Technological pedagogical content knowledge

Introduction and Overview

According to Savenye and Robinson (2004), "Assumptions, questions, methods, and paradigms that formerly dominated research in the [educational technology research] field are changing" (p. 1045). Concerns about the scope and impact of technology integration dominate the field of educational communications and technology and relevant research questions require new strategies and methods. Action research represents a dynamic methodology, enabling our field to address persistent questions within the context of practice.

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In this chapter we introduce action research and its history in three contexts—the USA, Great Britain, and Australia. We also describe the characteristics distinguishing practical and critical action research and the various forms of data collection and analysis that contribute to an action research study. More specifically we review current action research studies focused on the integration of technology. Action research has the potential to transform our field by engaging stakeholders in meaning-making through the process of systematically collecting and analyzing data to improve practice. Elliot (1991) wrote, "It [action research] aims to feed practical judgment in concrete situations, and the validity of the 'theories' or hypotheses it generates depends not so much on 'scientific' tests of truth, as on their usefulness in helping people to act more intelligently and skillfully" (p. 69).

Action Research Defined

According to Cochran-Smith and Lytle (1993) action research is "systematic and intentional inquiry" (p. 7). It has often been linked to Dewey's (1933, 1938) notion of the teacher as a reflective practitioner (e.g., Cochran-Smith and Lytle, 1990), but it can be conducted by anyone seeking to enhance practice, regardless of their context or status. Action research is often conducted collaboratively in research groups that meet in person or at a distance via communication technologies. Due to the intimate nature of action research, the findings can reveal new understandings and knowledge not always readily apparent to outside researchers. As a result, action research transforms the traditional "outside-in" relationship between practitioners and educational researchers (McNiff and Whitehead 2010).

"Action research" is often used interchangeably with "teacher research" or "practitioner research." Borko, Whitcomb, and Byrnes (2008) group action research with "participatory research", "self study", and "teacher research" as a distinct genre of "practitioner research" (p. 1029). We use the term "action research" (unless an alternative appears in direct quotations taken from authors) to refer to the systematic and intentional research undertaken by practitioners about their own practice.

Action research is a cyclical or spiraling process "that integrates theory with practice, through reflection and action planning" (Altrichter, Feldman, Posch, & Somekh, 2008, p. 9). The process includes a series of steps including posing a question, collecting and analyzing data, and reporting findings. Kurt Lewin was the first to describe action research as "a spiral process of data collection to determine goals, action to implement goals and assessment of the result of the intervention" (Bargal, 2006, p. 369). The process spirals as the action researcher reflects on and continues the inquiry, basing decisions about new directions in the research on previous findings. Stringer (2007) described the spiral as repeating the routine of "look", "think," and "act" and Altrichter et al. (2008) pointed to several "'mini' action research cycles" within one project (p. 11).

History of Action Research

A variety of histories of action research have been published (e.g., Carr & Kemmis, 1986; McKernan, 1991; Noffke, 1997). Almost all of the accounts agree that industrial psychologist Kurt Lewin's work in the 1940s did the most to encourage the growth of action research inquiry (see also Bargal, 2006). Lewin's original model for action research developed from the field of group dynamics and included a focus on systematic study in a cyclical process to create new knowledge. Lewin's effort to "find ways to involve social actors with research through group decision making and elaborate problem solving procedures" (Hollingsworth & Sockett, 1994, p. 3) helped to define the process.

Action research eventually evolved from its origins to focus on educational issues. Stephen Corey (1953) first applied action research to educational settings in his work at the Horace Mann-Lincoln Institute at Teacher's College (Ferrance, 2000). By the late 1950s excitement over action research in the USA ebbed. However in the UK and Australia "a strong tradition of 'action research' by teachers began in the 1960s and continues today" (Lampert, 2000, p. 65).

Action Research Movement in the UK

Current scholarship on action research draws heavily upon the work of Lawrence Stenhouse (1985) and his colleagues at the Centre for Applied Research in Education (CARE) in the UK. According to Goodson (1999), under Stenhouse's leadership CARE began to push for acknowledgment of the "educational researcher's social and political purpose" (p. 279). Stenhouse nurtured an emphasis on critical inquiry during his tenure at CARE and encouraged educators to push for social change beginning in schools. "He [Stenhouse] saw teaching and research as closely related, and called for teachers to reflect critically and systematically about their practice as a form of curriculum theorizing" (McNiff & Whitehead, 2002, p. 43). Stemming from the Humanities Curriculum Project (HCP) which began in 1967, CARE "drew deeply on the egalitarian commitments of sections of post-war British society" (p. 279). From the beginning, CARE emphasized emancipatory strategies and critical outcomes for practitioner research. Especially when the conservative financial and economic events of 1976 ushered in the federal "New Right Programme," Stenhouse encouraged educators to push for change beginning in schools. According to Goodson (1999), "During the 1970s, besides conducting a wide range of curriculum development and evaluation projects, CARE became a centre for defining educational research modalities in the public sphere" and its major task became finding "intellectual answers to the problems of empowering education for all" (pp. 283–284).

Stenhouse's ideas were extended by John Elliot and Clem Adelman with the Ford Teaching Project, 1973–1976 (Altrichter et al., 2008; Carr & Kemmis, 1986). Later, Elliot, the coordinator of CARE in 1991, continued the tradition established by Stenhouse of moving beyond objective curriculum research to focus on the process of teacher inquiry. His revised version of Lewin's model argued that, rather than consistently pursue a single aim in practitioner research, the "general idea should be allowed to shift" as the study progressed (cited in McNiff & Whitehead, 2002, p. 46). Elliot (1991) also emphasized a continual cycle of research and action, of planning and implementation. He cautioned against too quickly judging a teaching strategy's value without first clarifying the extent to which it was implemented.

Critical-Emancipatory Action Research in Australia

Stenhouse influenced the work of action researchers in Australia (e.g., Carr & Kemmis, 1986; Kemmis & Grundy, 1997; McTaggart, 1991a, 1991b, 1997). Carr and Kemmis (1986), for instance, wanted to help teachers understand the social and political construction of educational practices and described classroom-based inquiry as "educational action research." Their model of action research involved a spiral process including devising a question, planning, implementing, observing, reflecting, and replanning. They wrote:

> Action research is a form of self-reflective enquiry undertaken by participants (teachers, students or principals, for example) in social (including educational) situations in order to improve the rationality and justice of (a) their own social or educational practices, (b) their understanding of these practices, and (c) the situations (and institutions) in which their practices are carried out. p. 162

Carr and Kemmis also applied Habermas' (1972) early work to conceptualize critical action research within the framework of the "emancipatory interest." They encouraged teachers to critically interrogate their practice and its social impacts.

Robin McTaggart of Deakin University was a colleague of Kemmis and collaborated on *The Action Research Planner* (Kemmis and McTaggart, 1988) which became a well-known text for practitioners and university-based educators around the world. McTaggart (1991a, 1991b) also wrote extensively about his cross-cultural work with Aboriginal people. He repeatedly emphasized the emancipatory possibilities of action research and was severely critical of what he considered to be more benign forms of action research. McTaggart (1997) feared that the action research cycle would lose its radical potential and develop "iconic simplicity" (p. 17).

Collectively the work of Australian and British action researchers created a more critical philosophical tradition for the genre. According to Cochran-Smith and Lytle (1999) this tradition "shared a grounding in critical and democratic social theory and in explicit rejection of the authority of professional experts who produced and accumulated knowledge in 'scientific' research settings for use by others in practical settings" (p. 16). Action research that was grounded in critical social theory emphasized the emancipatory function of action research as a path to greater democracy in schooling and society.

Contemporary Action Research Movement in the USA

Influenced in part by the work of action researchers in Britain and Australia, American educators grew increasingly interested in practitioner-based inquiry towards the end of the twentieth century. Also contributing to this trend, according to Cochran-Smith & Lytle (1993) was a "paradigm shift in researching, teaching, and assessing writing that evolved during the 1970s and 1980s" (p. 6). For example, the Writing Projects were designed to improve the teaching of writing through teacher reflection on practice and examination of student work (e.g., Bay Area Writing Project, 1979). At the same time, influential texts such as Schön's (1983) *Reflective Practitioner* and Berthoff's (1987) phrase "The teacher as RE-searcher" provided the necessary language to articulate an interest in teacher inquiry. By 1999 Cochran-Smith and Lytle identified five major trends in action research in the USA: (1) growth in the prominence of action research in teacher education; (2) development of conceptual frameworks and theories of action research; (3) dissemination of action research findings in journals and conference proceedings; (4) critiques of action research; and (5) belief in the transformative potential of action research in education.

According to educational historian Ellen Lagemann (2000) contemporary action research holds a more prominent position within the American educational research community than in previous times. Increasingly, action researchers present their work at national conferences, including the American Educational Research Association (AERA) annual conference. They share their findings in national and international educational journals (e.g., *Educational Action Research*, *Action Research*, *Systemic Practice and Action Research*, *Action Learning,* and *Learning*) and other outlets.

Theoretical Frameworks

Perhaps as a result of the history of action research, there are differing ideas about its aims and purposes as well as its epistemological and ontological assumptions (Altrichter et al., 2008). For instance, Noffke (1997) offers three "dimensions" of action research as "political," "personal," and "professional." Our review of the literature (including manuals and texts for conducting action research, journal articles, and anthologies chronicling action research studies) revealed more of a bifurcation between those who advocate for practical or critical action research (see also, Cochran-Smith & Lytle, 1999; McCutcheon & Jung, 1990). We found practical action research focuses on the day-to-day issues teachers face, whereas critical action research seeks to better the classroom while also confronting larger political and social issues (see also Manfra, 2009a). Below we describe the diverging conceptions of action research as practical or critical.

Practical Action Research

Practical action research focuses on improving "teachers' professional knowledge landscapes" (Clandinin & Connelly, 1995) and "craft knowledge" (Grimmett & MacKinnon, 1992). In an overview of the different forms of action research, Cochran-Smith & Lytle (1999) explain that "theorizers in this [practical] group assume that some of the most essential knowledge for teaching is practical knowledge" (p. 19). Here the day-to-day work of teachers or other practitioners is of primary importance. The emphasis repeatedly is on "real classrooms and real schools" (Allan & Miller, 1990, p. 196). Proponents of practical action research argue that through reflection on practice, teachers can generate knowledge about teaching and learning. Implicit is the emphasis on the *practicality* of action research for teachers and schools. According to Cochran-Smith & Lytle (1999), "practical inquiry is more likely to respond to the immediacy of the knowledge needs teachers confront in everyday practice and to be foundational for formal research by providing new questions and concerns" (p. 19).

Critical Action Research

Critical action research aims to bring about social change and a more just and democratic society by influencing educational structures (e.g., Gitlin & Haddon 1997; Kemmis & Grundy, 1997; Kincheloe, 1991, 1995; Noffke, 1997). "The emphasis is on transforming educational theory and practice toward emancipatory ends and thus raising fundamental questions about curriculum, teachers' roles, and the ends as well as the means of schooling" (Cochran-Smith & Lytle, 1999, p. 18). Proponents of critical action research refer to the work of a variety of critical theorists, including Freire (1972) and Habermas (1972). For example, Kincheloe (1995) wrote that, "The critical teacher researcher asks questions of deep structure of his or her school or classroom settings—in other words, he or she takes Habermas's notion of emancipatory interest of knowledge seriously" (p. 81). Critical action research seeks fundamental change in social and institutional structures.

Table 14.1 A summary: practical action research compared to critical action research

Practical action research:	*Critical action research*:
• "Practical-Deliberative" (McKernan, 1996)	• "Critical-Emancipatory" (McKernan, 1996)
• Concerned with practical knowledge or "craft knowledge"	• Concerned with social and cultural factors that impact school
• Interest in day-to-day issues of practice	• Interest in democratic participation and emancipation
• May result in improved practice and student performance but not social or cultural change	• Seeks deep change [enlightenment] within the classroom
	• Implicit goal towards improving society

Manfra 2009a)

In some cases, proponents of critical action research criticize "benign" versions of action research because they ignore political and social issues (Kincheloe, 1995). For example, Noffke (1997) argues that practical versions of action research are separated from the "political sphere" and, according to Zeichner (1994), they serve to "further solidify and justify practice that is harmful to students" (p. 66). Kincheloe argues that uncritical action research is "dangerous" in that it "upholds status quo" practices and "reproduces extant ideology" (p. 82). According to this perspective, practical action research only serves to entrench a view of teachers as uncritical actors manipulated by the educational status quo.

The epistemological disagreements in the field of action research have created a division between practical and critical action research. Table 14.1 outlines some of the major differences of these two forms of action research. Currently there is little dialogue in the literature between the two (Manfra, 2009a).

In our discussion of methodology below we choose not to privilege practical or critical action research, emphasizing instead that the diversity of approaches can be liberating for researchers. Similar to MacLean & Mohr (1999) we believe "that teachers are thinkers and inquirers with knowledge about teaching and learning" and, accordingly "we don't 'prepare' or 'train' teachers to ask the 'right' questions in the 'right' way" (p. vii). According to Altrichter et al. (2008), Elliott similarly rejected much of the criticism of supposedly benign forms of action research. "He [Elliot] argues that teachers do not need to be liberated from oppression, but are able to generate knowledge and understanding of their practice through engaging in systematic research and reflection" (p. 12). In this chapter we describe the variety of methodologies and potential outcomes as strengths of action research.

Action Research Methodology

Of course the differing philosophical rationales for action research means there are also "methodological variations" (McCutcheon & Jung, 1990, p. 144). Data collection methods range from conventional quantitative and qualitative approaches to ethnographic storytelling and autobiography. There is general agreement across these methodological differences, that action research involves a cyclical process of action and reflection and a systematic approach to data collection and analysis. Action research is distinct from the everyday work of teachers and practitioners since it goes beyond reflection to interrogate the action through data collection. According to Glanz (1998) there are six steps in an action research project: (1) "Select a focus", (2) "Collect data", (3) "Analyze and interpret data," (4) "Take action," (5) "Reflect," and (6) "Continue and modify" (p. 27). There can be many variations to the steps, yet the basis of the cycle is always the same—reflection in action. Below we provide more details about each of the steps in the action research cycle.

Selecting a Focus

Altrichter et al. (2008) recommend identifying "experiences of discrepancies" as "starting points" for action research (p. 41). That is, practitioners should use action research to confront pressing concerns and issues. Similar to educational research in general, a variety of types of research questions can set the focus and scope of an action research project. The theoretical framework that the researcher brings to the process will impact the research questions asked and the data collected. According to McNiff and Whitehead (2010), action research involves "a commitment to educational improvement; a special kind of research question, asked with educational intent; putting the 'I' at the center of research; educational action that is informed, committed, and intentional" (p. 34).

Ethical Considerations

Before embarking on a project there are important ethical considerations for the action researcher. First, action researchers should be aware of the relevant requirements of their Institutional Review Boards (IRBs). Depending on university regulations, action research may be exempt from full IRB review or prohibited (Brydon-Miller & Greenwood, 2006; Stoecker, 2008). Since most action research focuses on human and social issues, researchers must follow the ethical rules and regulations required in human subjects research. Action researchers must remain "cognizant of the power and privilege we carry with us into our interactions with research participants" (Brydon-Miller & Greenwood, 2006, p. 125). Given its democratic nature, issues of coercion, power, and risk must be addressed by action researchers (Judah & Richardson, 2006) and important ethical principles for researchers should include "negotiation," "confidentiality," and "participants' control" (see Altrichter et al., 2008, pp. 154–155).

Data Collection

As in other forms of educational research, the research question determines the data collection methods used in action research. Action researchers conduct inquiry by collecting quantitative data and/or qualitative data. According to Glanz (1999), "In action research, we apply traditional research approaches (e.g. ethnographic, descriptive, quasi-experimental, and so forth) to real problems or issues faced by the practitioner" (p. 301). Ross and Morrison (2004) provide a useful description of experimental methods and Savenye & Robinson (2004) outline qualitative methods in educational technology research. Throughout the process of data collection, the action researcher analyzes the information gained, draws conclusions, and makes plans for change. Action researchers often triangulate, or collect multiple forms of data, to ensure their findings are meaningful, accurate, and credible (Hendricks, 2009).

According to Hendricks (2009), the methods of data collection in action research fall into three overarching categories: "artifacts, observational data, and inquiry data" (p. 81). Artifacts are items created by participants and usually fall within one of three subcategories: "student-generated," "teacher-generated," and "archived" (see Hendricks, 2009, p. 82). Observational data is generally collected in the form of field notes. Inquiry data is collected specifically to address the overarching research questions, often via interviews or questionnaires. In some instances these categories of data overlap, but, nonetheless, they provide a framework for delineating the various forms of data in the action research process.

Engaging students in action research

Engaging students in data collection provides both rich sources of information and insights about student experiences. Reflecting back on his study about high school drop-outs, Shager (2007) wrote, "They [students] brought a lot of knowledge to the project in the form of anecdotal information and personal experience; as they gathered more evidence, they built upon that knowledge" (p. 42). Rarely do teachers have explicit opportunities to learn from their students. However, the action research cycle provides a framework for engaging students in meaning making within the classroom. According to Lytle and Cochran-Smith (1994), "Researching teachers create classroom environments in which there are researching students" (p. 37). As a result of engaging students actively in the research process, teachers develop empathy and a new "mindfulness" (van Manen, 1990) towards their students. The combination of increased empathy and mindfulness leads teachers to be more responsive to their students. Often this results in changing teaching practices by incorporating more student-centered learning activities. According to Brause and Mayher (1991), "We [action researchers] increase our effectiveness as teachers because we are able to design and institute practices which are sensitive to the needs of our individual students (p. 208). The opportunity to learn from students leads teachers to consider new approaches to teaching that often allow for greater student engagement (Manfra, 2009b).

Keeping an action research journal

Action researchers may also include samples of their own work in their data archives, including lessons plans and other ancillary materials. The action researcher's journal or log is often an important source of more nuanced data, including perceptions about student outcomes and behaviors and written reflections about the data (Altrichter et al., 2008; McNiff & Whitehead, 2010). MacLean and Mohr (1999) advise teachers to keep a "research log"—a "systematic and organized" journal that "will include dates and times, careful quoting, observations and reflections" (p. 12) and "thinking writing" about data (p. 13). According to Strieb (1993) keeping a teaching journal provided her with an effective means for collecting and analyzing data. She wrote, "Keeping a journal has been a realistic way for me to learn about, inquire into, collect data about, and enhance my practice as well as to learn about and plan for the children" (in Cochran-Smith & Lytle, 1993, p. 121).

Triangulating data

In order to make their findings more accurate, action researchers collect a variety of data, from a variety of sources. For instance quantitative, archived data, including statistics, may be paired with qualitative data such as portfolios of student work. In her action research study on African American male student experiences, Nguyen (2007) relied heavily on archived data. She analyzed quantitative data including student enrollment figures, free and reduced lunch statistics, special education status, and achievement data from the district. She paired this data with student interview data to uncover those factors that supported or hindered student success in school. According to Mills (2011), "Observational data… can suggest questions that can be asked in subsequent interviews" and "pairing observation and interviewing provides a valuable way to gather complementary data" (p. 78). For example, Richards (2007) studied strategies to help English language learners (ELL) in her classroom by observing classroom interactions between students and recording revelations about her own teaching in her research journal. She used this data to develop follow-up interview questions for her ELL students. Again, the form and scope of the data collection methods will relate to the aims of the researcher and the overarching research questions. Throughout the process, action researchers engage in data analysis.

Data Analysis

Since action research is an iterative process, data collection and analysis occur continuously. According to Hendricks (2009) "This may mean altering an intervention plan, changing data collection strategies as the study progresses, or modifying the project timeline" (p. 121). Analytical strategies help the researcher make sense of the data and answer the overarching research questions. "Analyzing therefore involves looking at the data, taking account of your categories of analysis, and noting any emergent patterns within them" (McNiff & Whitehead, 2010, p. 175).

When action research studies include multiple types of data, the researcher needs to develop clear analytical strategies to compare and contrast across data and interpret findings (MacLean & Mohr, 1999) Analyzing quantitative data will often involve running statistical operations using software programs or creating charts or tables to illustrate data graphically (see also Ross & Morrison, 2004, p. 1029 for a detailed list of "common statistical analysis procedures used in educational technology research").

Qualitative data analysis can provide a rich description of the subject under study (see also Savenye & Robinson, 2004). To manage the amount of data, field notes and audio or video recordings should be transcribed into a workable format for data analysis. Then qualitative coding schemes should be developed to begin analyzing data and looking for patterns across the data (Glesne, 1999). A "constant-comparative" method (Glaser & Strauss, 1967) or other analytical methods may be used to refine the coding scheme and to make initial interpretations about the data. Data analysis is a complex process, involving multiple iterations. Once all of the data have been organized and analyzed, the action researcher is left with the final stage of implementation and reflection.

Implementation and Reflection

After data collection and analysis the action research cycle continues as the researcher reflects on the implications of the research findings. Glesne (1999) writes, "During the reflection phase, the data are interpreted and the multiple viewpoints are communicated and discussed among those with a stake (the stakeholders) in the process" (p. 13, parenthetical note in original). Throughout the process, the action researcher continuously reflects on and shares the findings (Kindon, Pain, & Kesby, 2007). According to McNiff and Whitehead (2010) action researchers should communicate their findings both within and outside of the workplace via conferences and publications. They write, "The purpose of sharing your work is so that people can learn from it and adopt or adapt your ideas to their own situations, in terms of subject matter as well as the enquiry processes involved" (p. 242). Sharing findings and making research reports available for peer review and critique is an important way action researchers "ensure quality and rigor" (Borko et al., 2008, p. 1031).

Action Research Groups

Action research groups provide support and guidance throughout the action research process and can be an important venue for sharing findings (MacLean & Mohr, 1999). Research groups help members refine research topics and data collection methods through meaningful conversations. "The group challenges each other's assumptions, proposes alternative interpretations, offers suggestions about research methodology, responds to drafts, and often lends personal as well as professional support" (p. 21).

There are numerous examples of large action research groups or networks working together to answer pressing, critical research questions (Cochran-Smith & Lytle, 1993; Mohr et al., 2004). The Madison Metropolitan School District (MMSD) has supported a school district-wide action research initiative focused on creating more equitable classrooms since 1990 (see Caro-Bruce, Flessner, Klehr, & Zeichner, 2007). All teachers and support staff in the district are invited to join action research groups focused on social justice and equity. The district has supported this initiative over the years by providing access to district data systems, leadership development, and professional development. As a result of the collective work of numerous teachers and staff in MMSD, action research has supported the "empowerment of students from diverse backgrounds" (p. 290) and "engagement through culturally relevant practice" (p. 291). The pervading notion in the district is that action research could contribute to research-based understandings regarding equity. Other examples of large teacher research groups include the Physics Teachers Action Research Group in San Francisco (see Feldman, 1993, 1996) and the Classroom Action Research Network (see Cochran-Smith & Lytle, 1993; Hollingsworth, 1994). These collaborative groups support the collective professional development of member researchers and the development of professional learning communities.

Large scale action research collaboratives often include university researchers. Cornelissen, vanSwet, Deijaard, and Bergen (2010) describe school-university research networks in which the "relationships in the research partnership can be collaborative with a high degree of mutual engagement; the research agendas, methods and outcomes are negotiated and collective research activities are undertaken" (p. 148). For example, a collaborative effort in Philadelphia, PhilWP, has been focusing on studying issues affecting urban youth for many years (Lytle, Portnoy, Waff, & Buckley, 2009). The project began as a Writing Project partnership between faculty at the University of Philadelphia and teachers in the Philadelphia school district. PhilWP has had numerous iterations including "'inquiry communities'—single school, across-school, and across-district groups" (p. 26). Action research collaboratives that include university researchers also often engage in participatory action research or community based research.

Participatory Action Research

Participatory action research (PAR) differs from the previously described classroom-based action research because it is "a social, collaborative process" (Hendricks, 2009) that aims to "change practices, social structures, and social media which maintain irrationality, injustice and unsatisfying forms of existence" (McTaggart, 1997, cited in Reason & Bradbury, 2006, p. 1). In PAR the researcher is both a researcher and activist—"collaborating with marginalised or 'vulnerable' others" (Kindon et al., 2007, p. 11). PAR alludes to the work of Brazilian educator, Freire (1972), who used a problem posing method to teach adult literacy and bring about "praxis". There are more direct links in parts of the world where participatory action research is used to improve adult education and empower the working poor. For instance, McTaggart (1991a) investigated Aboriginal education by transferring control of the research process to the "researched." According to Kindon et al. (2007) "The most common methods used in PAR focus on dialogue, storytelling, and collective action" (p. 16). Participatory action research projects involve the subjects of study actively throughout the research process (Kemmis & McTaggart, 2005).

Results of Action

Regardless of the aims, methods, or processes undertaken, action research is intended to bring about change—mainly changing and improving some aspect of practice. Johnston (2005) writes, "The distinguishing characteristic of action research, however, is its focus on *action*…. The action is intended to create change for the better and the study is intended to find out if it does" (emphasis in original, p. 60). Emancipatory action research may result in larger social change, such as bringing about more democratic classrooms and institutions. The potential benefits cited by proponents of action research include: alleviating the gap between theory and practice (Brause & Mayher, 1991; Lytle & Cochran-Smith, 1994; Richardson, 1994; Zeichner, 1994); enhancing teacher education (Cochran-Smith & Lytle, 1993; Levin and Rock, 2003; Price, 2001; Price & Valli, 2005); improving teacher professional development (Alan & Miller, 1990; MacLean & Mohr, 1999; Mohr et al., 2004); improving student learning (Falk and Blumenreich, 2005); affirming and empowering teachers (Falk & Blumenreich, 2005; Mohr et al., 2004); reforming education (Brause & Mayher, 1991); and changing society (Carr & Kemmis, 1986; Grundy, 1997; Johnston, 2005; McTaggart, 1991a).

Educational Technology and Action Research

There are numerous ways that action research can support the goals of the field of educational communications and technology, including improving pre-service and in-service teacher professional development and university-based teaching that integrates technology. At the same time technology can enhance and improve the work of action researchers by supporting new forms of data collection, facilitating the work of action research groups, and providing tools for training pre and in-service teachers on action research methodology (McNiff & Whitehead, 2010). Technology can be both the focus and part of the method of the action research.

Improving Technology Integration

Action research has been used to study the integration of technology in classrooms and schools. A typical model involves university researchers engaging and supporting pre-service and in-service practitioners as they systematically study technology integration (e.g., Cavanaugh & Dawson, 2008; Dawson, 2007; Dawson, Cavanaugh, & Ritzhaupt, 2008). For example, Dawson (2007) reported the professional development outcomes when pre-service teachers collected and analyzed qualitative data during their field experiences. She concluded, "The results of this exploratory study suggest that when prospective teachers are supported through the inquiry process during technology integration, student learning comes to the forefront" (p. 10). In a similar study Cavanaugh et al. (2007) integrated action research into the professional development of Florida teachers using laptops in instruction. Their findings reported on the value of the action research process for improving teacher understandings about technology and instruction.

Action Research and TPACK

Action research appears to be a particularly promising method for studying and improving technological pedagogical content knowledge (TPACK, Mishra & Koehler, 2006). TPACK expands on Shulman's (1987) notion of "pedagogical content knowledge" (PCK) by adding technological knowledge. According to Harris and Hofer (2009), "TPACK can be developed when educational technologies become one of the foci of teachers' reflective action research" (p. 100). Arizona State University has integrated action research into the work of a cohort of doctoral students including administrators, teachers, and other educational personnel. "Using action research as a model for change, TPACK is integrated throughout the action research process and grounded in the unique needs of each candidate's site (Cunningham et al., 2011, n.p.). Similarly Hechter and Phyfe (2011) engaged science teachers in action research studies exploring the facility of lessons that reside in the "space between" each of the TPACK elements—"technological pedagogical knowledge," "technological science content knowledge," and "pedagogical science content knowledge" (p. 4115). Across these studies action research appeared to be an effective means for improving TPACK (Pierson, 2008).

Investigating Technology Education Courses

University based researchers have also used action research to study the effectiveness of their own teaching about the use of digital technologies. For example, over several years a group of teacher educators collected data on the Innovations Mini-Teach project (see Foulger & Williams, 2007; Foulger, Williams, & Wetzel, 2008; Wetzel, Foulger, & Williams, 2008–2009; Williams, Foulger, & Wetzel, 2009). The Mini-Teach project was designed to help pre-service teachers investigate numerous technologies for possible integration in classroom instruction. "Instructor researchers sought to investigate the process, perceptions, and outcomes of students after their experience with the *Innovations Mini-Teach* project" (Foulger et al., p. 31). In order to investigate whether the Mini-Teach project was effective the "instructor researchers" collected data including the culminating wiki projects, focus group interviews, and questionnaires. The authors reported: "Based on their analysis of student voices, the instructors concluded that students gained high levels of expertise with their assigned innovation and became familiar with the range of innovations covered by their classmates and archived in the class wiki" (p. 36). In this case, action research proved to be a particularly robust method for investigating the affordances and limitations of a particular method of instruction on technology integration.

Participatory Action Research and Technology Integration

New computer-based technologies can facilitate participatory action research (PAR) and group action. According to Kindon et al. (2007) technology tools have been integrated into the PAR process as the focus of study as well as to help collect data and convey findings. For instance, Elwood et al. (2007) led a participatory geographic information system (PGIS) project that involved university based researchers and community organizations in using GIS to impact community planning and development. They focused on critical issues such as affordable housing and crime prevention. Other PAR projects have investigated the integration of technology to bring about change in marginalized communities. For example, PAR was conducted collaboratively by university-based IT specialists and social service providers in Taipei, Taiwain to determine the most effective approaches to integrating technology (Chang, Liao, Wang, & Chang, 2010). Another PAR study, "The Pocket School," investigated the use of "a mobile learning model of literacy development for underserved migrant indigenous children in Latin America" (Kim, 2009, p. 415) and involved multiple researchers and stakeholders. These selected examples provide a snapshot of the myriad ways technology has increasingly entered into PAR as an important tool for both facilitating the action research method and as the focus of the research.

Technology-Rich Instruction About Action Research

Emerging technologies and social media have also positively impacted the instruction of action research (see Carroll, Jenkins, Woodward, Kop, & Jenkins, 2012). Perhaps the usefulness of technology to facilitate action research is most obvious in online and hybrid action research courses (Ostorga, 2010). Increasingly university instructors and academic programs are supporting the methodological instruction of future action researchers in technology rich environments. Due in part to increasingly affordable access to technology and the individualized nature of action research projects, action research methods courses seem to be effectively taught and supported at a distance.

Technology and Action Research Networks

Computer based technology also facilitates the work of action research networks, including disseminating research results. Action researchers increasingly use multimedia to share their findings (McNiff & Whitehead, 2010). At the same time, technology supports the collaboration of action researchers by engaging researchers at a distance. According to Cochran-Smith and Lytle (2009) technology has "enabled new inquiry communities to form and communicate on-line" (p. 22). Notable examples include the Bread Loaf Network (see Lewis, Guerrero, Makikana, & Armstrong, 2002), the Carnegie Foundation's CASTL Program for K-12 teachers/teacher educators (see also Hatch 2006, Hatch & Shulman, 2005), and the Collaborative Action Research Network (CARN). According to Cochran-Smith & Lytle (2009) emerging technologies have "spawned innovative uses of technology for sharing inquiries and classroom practices with audiences" (p. 22).

Conclusion

Action research is a complex, cyclical process that systematizes reflection in action. The history of action research and current variations of the methodology reflect divergent views about practical or critical action research. Hopefully proponents of both forms of action research will begin to look across their differences to recognize the suitability of action research to answer a variety of questions in educational research.

The variability in method may actually better serve the field of educational communications and technology where paradigm debates continue to arise (Savenye & Robinson, 2004). Action research can be used to answer myriad educational research questions. It can serve as the methodology of doctoral dissertations, guide the framework of professional development initiatives that focus on technology integration, and address larger social issues. Action research provides exciting opportunities to engage stakeholders in constructing new understandings about education and technology integration and to transform our field. Technology can both facilitate the action research process and serve as the subject of study.

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Trends and Issues in Qualitative Research Methods

15

Marcia A. Mardis, Ellen S. Hoffman, and Peter J. Rich

Abstract

In the almost two decades since the first AECT *Handbook* article on qualitative research debates about research philosophy, design, and purposes have led to clashes of opinion in the field of educational communications and technology as well as in the larger sphere of educational research. At the same time, the number of publications on qualitative methods specific to the field has increased, expanding the understanding of the potential of such approaches to explore, describe, and explicate key issues in instructional design and the application of technology to learning. While other chapters have included examples of qualitative studies related to specific disciplinary topics, this chapter focuses on trends in the use of qualitative research design and emerging approaches more generally. Within this framework, issues of design, methods, and knowledge generation are reviewed and examined through a sample of recent directions in qualitative studies and designs. For each method reviewed, examples are provided along with common issues and potential directions for future use of these.

Keywords

Qualitative research • Interpretive tradition • Case study • Ethnography • Discourse analysis • Cooperative inquiry • Grounded theory • Research quality

Introduction

In the almost two decades since publication of the first article in the AECT *Handbook* on qualitative research (Savenye & Robinson, 1996), debates about research philosophy, design, and purposes have led to clashes of opinion in the field of educational communications and technology (ECT) as well as in the larger sphere of educational research. At the same time, the number of published ECT studies using qualitative methods increased, expanding the potential of such approaches to explore, describe, and explicate key issues in instructional design and the application of technology to learning.

While other chapters have included examples of qualitative studies related to specific disciplinary topics, this chapter focuses on qualitative approaches more generally.

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Within the qualitative framework, issues of design, methods, and knowledge generation are examined. In this chapter, we will

- Explore definitions of qualitative research.
- Provide a framework for discussing various qualitative traditions and methods that have been applied in ECT research.
- Describe some key methods briefly, providing a sample of recent studies that are representative of the approach.
- Review current issues in application and implications for the future of qualitative research approaches.

We should preface the chapter with what is not covered. The chapter is not intended to be a general introduction to qualitative research which is covered in multiple textbooks, but rather is a brief review of current application and issues in qualitative methods within the field of educational communications and technology. Because the scope of qualitative research is beyond a single chapter, our intent is to lead the reader to other authoritative sources for more detailed reviews and explanations.

In this review, the authors focus on methodological strategies and their related data collection and analysis methods that are typically classified as qualitative in scope rather than on the epistemological or political debates that have emerged over several decades. Following Denzin and Lincoln (2008), we recognize that all research is political and implies value judgments about purpose and the warrant of knowledge. We propose that our descriptive approach allows us to present an overview of trends in ECT empirical studies that does not privilege a particular stance in the continuing debate over educational research methods. We also point to the separate chapter in the *Handbook* on the use of technology in qualitative research (Chap. 20), noting that we understand the importance of this topic but have limited our discussion in this review.

The Issue of Terminology: What Is Qualitative Research?

In developing this chapter, a central issue that arises concerns the definition of *qualitative research*. A number of authors have attempted to delineate the scope covered by this concept. To date, no commonly accepted terminology for defining or describing "qualitative" has come into common usage in educational research or more widely in social research.

At one level, qualitative research has been defined in the negative; it is understood to mean systematic social and behavioral research studies that are *not* quantitative (numerical and statistical) in character. Qualitative research more typically is portrayed as focusing on language and meaning, individual perspectives and beliefs, discourse and social interaction, and emergent group processes and culture. Studies tend to be in naturalistic settings involving direct researcher interaction with participants or derived from primary sources and artifacts. It is usually described as an approach to best answer what and how questions, providing rich descriptions to explore and understand complex, multilayered, and multicausal social perspectives and dynamics.

Table 15.1 Levels of qualitative research

Level	Some examples
Methods: Data level	Collection methods: interview, observation, focus group Analysis methods: discourse analysis, thematic coding, categorical analysis
Methodology: Design level	Phenomenology, narrative, ethnography, case study
Theoretical or conceptual level	Feminist theory, ecological theory, activity theory, grounded theory[a]
Epistemological level	Post-positivist, post-modern, constructivist, interpretivist, connectivist, critical

[a]Grounded theory has elements of both methods and theory which are discussed in more detail below

Terminology and Levels of Qualitative Analysis

The term "qualitative research" is used in a variety of ways that are not equivalent, a fact that is particularly confusing to novice researchers. In fact, the terms method, methodology, tradition, framework, and paradigm are not applied consistently from one author to another.

At one level, the discussion of qualitative research focuses on the philosophy and worldview of the researcher and research community, often under the topic of epistemology and ontology. Such discussions applied to qualitative research relate to beliefs about the nature of knowledge and truth statements; the approaches that are brought to interpretation of empirical data; and the relative importance of social equity and change in research purposes. Intense debates arising in the 1980s, commonly referred to as the "paradigm wars," and continuing into the present, focus on epistemological issues, describing qualitative research by such terms as post-positivist, post-modern, constructivist, interpretivist, or critical.

At another level, the qualitative label applies to what may be called methodological strategies or traditions typically associated with research design, such as phenomenology, grounded theory, qualitative case study, narrative research, or ethnography. At a more pragmatic level, the qualitative descriptor is applied to particular methods of collecting and analyzing data, such as interviews, observation, thematic coding, or narrative analysis.

This difference in levels in qualitative research is summarized in Table 15.1. The table generally provides the terminology as we are using it in this chapter, with the recognition that other authors use different classification schemes. As we will show, the boundaries between some of these levels and the overlapping use of specific terms is actually more complex than a simplified table can show.

Qualitative Versus Quantitative Research: A Slippery Divide

In practice, qualitative research is not neatly bounded, nor is there a clear dichotomy between qualitative and quantitative (Ercikan & Roth, 2006). While the paradigm wars between those strongly advocating differing research traditions suggested the incompatibility of quantitative and qualitative approaches, literature in the past decade appears to increasingly acknowledge the artificiality of the divide. Twining (2010) suggests that the degree to which quantitative and qualitative approaches are considered complementary is dependent on the level at which one is looking. Some vocal proponents of the qualitative tradition such as Denzin and Lincoln (2008) continue to champion the need for a highly distinct qualitative discipline essential to the advancement of a critical focus and in recognition of the subjectivity of language and meaning. Yet they acknowledge that at the level of practice, qualitative researchers may use statistical methods or alternatively, approaches that are more literary than systematic.

Symonds and Gorard (2010) show that there is no one-to-one correspondence between types of data collection and analysis to the qualitative or quantitative paradigms, while all methods have inherent strengths and weaknesses in terms of validity. In any given research study, qualitative methods and strategies may be mixed and matched to meet the demands of the research setting, the research questions of interest, the personal characteristics and history of the individual researchers, and the accepted norms of a scholarly community (Bryman, 2008; Greene, 2008; Haggis, 2008; Maxwell, 2010; Willis, 2008). The real-world complexity of social research practice eludes simple classification schemes or tightly bounded definitions for qualitative research. As Gorard and Smith (2006) note, "qualitative or quantitative represents only one, perhaps not very useful, way of classifying methods" (p. 61), yet it remains a currently accepted way to examine as well as teach differing research approaches.

The Tradition of Qualitative Research in Educational Studies and ECT

The expansion of qualitative approaches has long historical roots that precede the formalization of ECT as a scholarly discipline (Denzin & Lincoln, 2008; Fielding, 2005). Initial practices from the early 1900s of field studies in anthropology and sociology were increasingly incorporated into a larger research tradition labeled "qualitative," promoting the expansion of more naturalistic, interpretive, and critical research methods. Linking social sciences and the humanities and following a post-positivist critique of the rational, technical and scientific paradigm of progress, new views of research were explored that promoted pluralism, emergence, deconstruction, contextualism, and criticism as themes of inquiry beginning in the 1960s (Solomon, 2000).

The outcome of these expanded views of research within education was a more nuanced examination of teaching, learning, organizational structures, and change along with expanded tools and methods for research (Willis, 2008). In reviewing the history of qualitative approaches, Denzin and Lincoln (2008) note that each stage in the development of qualitative research has been additive in terms of designs and methods. This has led to an "embarrassment of choices" (p. 27) for qualitative researchers and continuing debate about the purposes and processes of social research. Further, they indicate that qualitative traditions continue to vary nationally and culturally, pointing to diverse strands such as:

> the British tradition and its presence in other national contexts; the American pragmatic, naturalistic, and interpretive traditions in sociology, anthropology, communications, and education; the German and French phenomenological, hermeneutic, semiotic, Marxist, structural and post-structural perspectives; feminist studies, African American studies, Latino studies, queer studies, studies of indigenous and aboriginal cultures. The politics of qualitative research creates a tension that informs each of these traditions. (p. 13)

Usage Studies of Qualitative Methods in ECT Scholarship

The diversity of approaches and tensions among qualitative traditions is equally applicable to ECT and, as this review will suggest, not all qualitative methods and methodologies are equally represented. Despite active exploration of new qualitative approaches in the past decade, quantitative studies appear to continue to predominate in major ECT journals, particularly in the USA (Axtell, Chaffing, Aberasturi, Paone, & Maddux, 2007; Hrastinski & Keller, 2007). In a survey of articles from a single journal covering 2006–2008, the researchers found 58 % of the articles using descriptive research designs, including qualitative studies as well as case studies, developmental research, formative evaluation, observation, and surveys; an earlier study of articles prior to 2001 showed a predominance of experimental designs (Ross, Morrison, & Lowther, 2010). Using a different classification scheme including a focus on methods, Hew, Kale, and Kim (2007) found that qualitative data collection methods were common in published empirical research articles, with 94 including interviews, 82 observation, and 121 content analyses out of 340 articles in three ECT journals from 2000 to 2004.

Randolph, Julnes, and Sutinen (2009) in a content review of computer education journal articles, noted that North American authors were less likely to publish qualitative research studies than those in Europe and the Middle East in both computer education and other educational fields. In a similar finding resulting from a study of ECT journals and

Table 15.2 Types of qualitative research

Research focus	Types of qualitative research[a]	Role of researcher
Individual and perceptions	Phenomenology Narrative Biography	Typically external, privileges the individual(s) being studied but may be empathetic
	Hermeneutic phenomenology Autoethnography Autobiography	Insider or shared perspective
Social interaction and group behavior	Discourse analysis Conversation analysis Computer-mediated discourse analysis	Strongly objective examination of language process and structure
	Cooperative inquiry Participative action research Practitioner action research	Insider view of participants, shared inquiry
	Ethnography Virtual ethnography Case study[a]	Objective approach common although researcher may be an insider to the group studied
Behavioral representations (Human "artifacts")	Qualitative content analysis Visual ethnography	Objective observer, often retrospective

[a]Case studies are commonly seen as intensive study of a group or groups, but the broader definition sometimes used includes intensive study of a single person who typifies a group or phenomenon

conference papers in New Zealand beginning in 1994 (Williamson, Nodder, & Baker, 2001), half were qualitative. Qualitative research can be seen as an important although nondominant element in ECT studies with distinct regional variations.

No formal analytical studies have been published to date reviewing the prevalence of qualitative methodological traditions such as case study, ethnography, phenomenology, etc., in studies published within ECT journals. In the absence of any quantitative basis for selection of studies, this article provides a snapshot approach in terms of sampling to show a range of high quality and emerging qualitative research in ECT.

A Classification of Qualitative Methodologies

In the following sections of this chapter, we explore some of the methodologies in greater depth. We offer a framework for grouping qualitative methodologies that is unique to this chapter, but we think offers one way of looking at qualitative studies that helps researchers see relationships of methods and methodology, as well as the centrality of purpose in research design. Table 15.2 lays out the framework we have used in organizing our discussion. Some of these methodologies are reviewed in more depth, reflecting their more common use in ECT or what appears to be an emerging trend of inquiry.

Interpreting Individual Experience

The study of experience has led researchers to seek out ways to describe an individual's interpretation of a certain event or phenomenon, often from the participant's point of view. In the *interpretive tradition* in ECT research, understanding individual experience is as paramount as learning. While learning is socially and contextually mediated, it is ultimately an individual endeavor (Barg, Gollwitzer, & Oettingen, 2010; Brown, Collins, & Duguid, 1989).

Interpretivistic approaches offer personal, often imperfect descriptions of human cognition (Bengston & Marshik, 2007), behavior (Sutin & Gillath, 2009), emotion (Frie, 2010), or interrelations (Schönpflug, 2008). Perception therefore becomes as important as, if not more important than, an agreed-upon reality. As demonstrated by the Pygmalion effect (Rosenthal & Jacobson, 1992), the way people interpret the world often affects the way they interact with and ultimately act on it and other individuals. Thus, interpretivistic methods seek to understand the individual's interpretation of experience without imposing the researcher's own interpretations of such events. Researchers acknowledge potential influence on interpreting others' interpretation of their own experience by bracketing their own subjectivities (Tufford & Newman, 2010), or by embracing them through a hermeneutical (Van Manen, 1995) or autoethnographical rendering of accounts.

Interpretivistic research tends to describe experience from three different perspectives: (1) the individual, (2) the researcher, or (3) the experience itself. These are each discussed in more detail.

Research Focus on the Individual

The individual may best be understood through *narrative analysis* (Clandinin, 2007) or *phenomenographic* methods (Marton & Booth, 1997).

Narrative analysis methods recreate the participant's view of experience by piecing together snippets of oral or written accounts of experience into stories of lived experience (Clandinin, Pushor, & Orr, 2007), portraying events in the words of the participant wherever possible. The product of narrative analysis is a story that may be expressed as a case, a life history, or a biography constructed from the data collected. These narratives are dependent on the audience to which one is telling the event (Langellier, 2003) and the speaker's relationships to this audience (Cortazzi, 1993).

Narratives may even change with the proximity to or distance from the occurrence of the event (Gergen, 2004). Clandinin et al. (2007) proposed that narrative inquiry has been employed in educational contexts to better understand temporal conditions, social interactions, and spatial influences. Recently, researchers have used narrative analysis to understand the second-grade experience of English-language learners (Brown, 2009), the differing accounts of online learners (Coryell & Clark, 2009), educational policy (Craig, 2009), and international influences on learning (Liang & Lin, 2008).

While also attempting to demonstrate individual interpretation of events, *phenomenographical approaches* seek to understand the breadth of variety of human experiences surrounding an event, process, entity, or effect (Marton & Booth, 1997). That is, these studies' findings explore the many different ways one might experience and interpret the event. Phenomenographical researchers emphasize that they do not describe the primary experience itself, but instead seek to illuminate a second order account (Bowden, 2005). Because the focus of phenomenography is on variation of experience, most phenomenographic studies involve a larger number of participants than many qualitative studies. Studies often include at least 15 participants to get sufficient variation (Trigwell, 2006), although it is possible for a single participant to experience a range of the possible variations (Åkerlind, 2008). Recent educational studies have used phenomenography to understand issues surrounding higher education, such as academics' conception of teaching and learning (Åkerlind, 2007); graduate students' understanding of research (Bruce, Stoodley, & Pham, 2009); general graduate student attributes (Barrie, 2006); professors' perception of the use of e-learning in the classroom (Gonzalez, 2010); and how individuals interact with technological artifacts (Collier-Reed, Case, & Linder, 2009).

Sharing Voices: Researcher, Participants, and Readers

Some interpretivist methods recognize that it is impossible to separate the researcher's own biases from the retelling of another's accounts. Researchers who adhere to this philosophy seek to include their own voices as part of the interpretation of events, often through a *hermeneutic phenomenology* (Van Manen, 1995) or even by describing themselves as learners (Fox, 2008).

Autoethnographic accounts offer a unique window into experience because the researcher is not constrained to be either a researcher or a participant, but rather can embrace that duality, offering greater reflexivity than is possible in other methods that only stimulate reflexivity through secondary means such as interviews and surveys (Anderson, 2006). The work by Magdalene Lampert (2001) to study student thinking in her own fifth-grade mathematics classroom provides a valuable example of the detail and insight that might be gained through autoethnographies. Autoethnographic methods have been employed to understand the role of language in a child's education (Souto-Manning, 2006); to examine the quality of software (McBride, 2008); and to reflect on how to teach qualitative research methods (Humphreys, 2006).

The Personal Experience

Rather than a focus on the individual or the researcher, *phenomenology* and an *analysis of narratives* provide ways for researchers to attempt to describe the essence of an experience itself.

By focusing on the lived experience of an individual (Van Manen, 1995), *phenomenology* seeks to enable readers to better understand and feel what the participant may have felt in the way s/he may have felt it. Whereas phenomenographic methods seek variation (Marton & Booth, 1997), phenomenology looks for commonalities among participants that help describe the shared or lived experience. "Phenomenological analysis becomes a tool for investigating what occurs outside awareness" (Schwartzman, 2007, p. 210). In order to draw out this awareness, researchers conduct in-depth, searching interviews in hopes of making participants aware of that which occurred but they may not have explicitly noticed previously (Seidman, 1998). Recent phenomenological research in education has investigated student attitudes in learning to design software (Schwartzman, 2007); the way a teacher engaged students' authentic learning contexts (Miller, Veletsianos, & Doering, 2008); student perceptions of academic success and failure (Forsyth, Story, Kelley, & McMillan, 2009); perceptions of students with disabilities in higher education (Denhart, 2008); and participants in social networks (Corwin & Cintrón, 2011).

The goal of *analysis of narrative* research is to interpret story elements or structure as opposed to that of narrative analysis, which is to produce rich narratives in the participants' own voices (Crawford, Brown, & Majomi, 2008). An analysis of narratives might present a series of themes, categories, and subcategories, possibly resulting in quantitative counts or statistical comparisons (Møller, Theuns, Erstad, & Bernheim, 2008). Langellier (2003) suggested that an analysis of narratives allows the researcher to focus not only on the content of a participant's story, but on the way it is told. This *performativity* reveals important characteristics of the participant as well as his/her assumptions about the story's audience and what is important for them to hear. Thus, researchers using an analysis of narratives may seek differing accounts of the same event (Pacheco, 2010). Through an analysis of narratives, researchers have been able to demonstrate the importance of education as an exit strategy (Crawford et al., 2008); the effect of policy on English-language learners' academic achievement (Pacheco, 2010); and social change over a lifetime (Sliwa, 2009).

Issues and Trends in Interpretivist Approaches

Despite benefits including close attention to participant perspective and usefulness in approaching a range of research questions, many issues exist in interpretivist work in general and within ECT more specifically. First, despite well-established guidelines by experts in narrative analysis (Clandinin, 2007), phenomenology (Moustakas, 1994; Van Manen, 1995), autoethnography (Ellis & Bochner, 2000), and analysis of narratives (Rymes, 2001), there does not appear to be any continuity amongst the specific procedures researchers follow to employ such methods. Phenomenographic research stands in stark contrast, as most such research relies on methods detailed by Marton and Booth (1997) or other key phenomenographers.

This lack of continuity in many of the described approaches makes it challenging to understand exactly how to apply interpretivist methods to analyze and present research. This problem may further complicate the utility of such research because "research on learning…demonstrates that novices and advanced beginners in any craft…rely heavily on rule-based structures to learn" (Tracy, 2010, p. 838). Thus, it is less likely that qualitative researchers in ECT will engage in interpretivist research, instead applying more well-outlined methods or generic *open-coding* schemes (e.g., Corbin & Strauss, 2008; Spradley, 1980). Exacerbating the problem is that many of these approaches are often used in tandem with each other in the same study without the researchers' acknowledging their potentially conflicting assumptions and processes. While narrative and autoethnographic traditions are commonly employed together successfully (Pacheco, 2010), open-coding and phenomenology are combined under the guise of *case study* along with multiple other qualitative approaches (see below). It is interesting to note that many of the interpretive approaches addressed in this section share the customary method of collecting data, semi-structured interviews, to make them appear more compatible. Though the interview is one of the qualitative researcher's most important tools, relying on it as the sole tool for data collection has inherent limitations and weakens the researcher's ability to strengthen credibility through triangulation (Denzin & Lincoln, 2003; Kvale & Brinkmann, 2009).

Of lesser methodological importance, but of note nonetheless, is the fact that interpretivistic work seems to be gaining ground in Europe (Hallett, 2010; Ingerman, Linder, & Marshall, 2009; Virtanen & Lindblom-Ylänne, 2010), Asia (Yang, 2008), Oceania (Stein, Shephard, & Harris, 2011), Latin America (Gonzalez, 2010), Africa (Collier-Reed et al., 2009) and Canada (Fox, 2008; Lyle, 2009) but is underrepresented in ECT research in North American contexts (Cilesiz, 2011). By contrast, qualitative research published in North American journals tends to be heavily centered on open coding techniques and case studies.

Communication and the Social Group

The study of naturally occurring conversation, face-to-face or online dialogue not mediated by the researcher, is typically initiated using qualitative methods but final analysis may be qualitative or quantitative. Growing interest in discourse practices within ECT research has been propelled by shifting paradigms such as constructivism, situated learning, and communities of practice that emphasize the social nature of learning. Also impacting expansion in use are communication technology developments such as the expansion of ubiquitous social media and distance learning (Maddux & Johnson, 2009). Recent thinking in *connectivism* premised on the networking of knowledge is promoting a renewed look at the nature of discourse (Ravenscroft, 2011).

Types and Processes of Qualitative Analyses of Language Interactions

The primary approaches that underlie discourse-related research were developed in other disciplines including communications, linguistics, and psychology. Language-focused forms of content analysis are most commonly identified by the process of analysis rather than by a single overarching methodological name (Hammersley, 2003; Leech & Onwuegbuzie, 2008). ECT journal articles often refer to empirical research studies of discussion as *discourse analysis*, whether at the level of meaning or centered on group communication interactions. However, discourse analysis as initially developed in linguistics is a narrower, highly formalized approach applied to the study of meaning and context of words (Hammersley, 2008). The related study of formal conversation procedures known as *conversation analysis* is another way of understanding talk-in-action growing out of the larger research framework of *ethnomethodology* (Hammersley, 2003, 2008). Research purposes may emphasize understanding of content, structure, interaction patterns, participation, or social presence (Herring, 2004b), with authority and power being of particular interest in critical theory approaches such as *critical discourse analysis* (Wodak & Meyer, 2009).

Analysis of online discourse occurs in the areas of *computer-mediated communication* (CMC), *computer-supported* *collaborative learning* (CSCL), and *computer-mediated discourse analysis* (CMD/CMDA) as well as in gamer interactions (De Wever, Schellens, Valcke, & Van Keer, 2006; Jeong & Hmelo-Silver, 2010). While existing studies have focused on human-to-human dialogue, an emerging area is analysis of conversation with non-animate agent technologies in support of learning (see this volume, Chap. 20).

From Live Conversations to Online Discourse

Historically, naturally occurring talk was one form of collecting data in field observational studies such as anthropology and sociology (Moerman, 1988), continuing into the present with some recent suggestions for using field notes to record the talk of students in teacher action research (Dana & Yendol-Hoppey, 2009). Focus on conversation was spurred by audiovisual and later digital methods of capturing talk in detail, with intensified focus on theory and methods of analysis since the late 1990s (Evers, 2011; Hammersley, 2008; Rostvall & West, 2005).

With the growth of digital communications for human messaging, discourse analysis began to be applied to electronic discussions. Although there is a recognition that face-to-face and online conversations differ in many ways, the analysis of either follows similar steps once spoken conversations have been converted to text (Davidson, 2009; Hammersley, 2010; Rostvall & West, 2005); computer and online discussions have the advantage of not requiring transcription.

Methods in Analyzing Discourse

In *conversation analysis*, transcripts are examined for evidence of the procedures by which speakers produce utterances and make mutual meaning of ordinary talk, with particular attention to turn taking and sequences of action (Wooffitt, 2005). In all forms of conversational *discourse analysis*, content is "chunked" into meaningful units which may be counted and analyzed statistically or classified thematically in relation to a study's purpose and research questions (Gee, 2011). As Herring (2004a) notes, using discourse analysis methods requires precision and understanding of its techniques, with attention to conventions and limitations.

> As with other forms of content analysis, the CMDA researcher must meet certain basic requirements in order to conduct a successful (i.e., valid, coherent, convincing) analysis. She must pose a research question that is in principle answerable. She must select methods that address the research question, and apply them to a sufficient and appropriate corpus of data. If a "coding and counting" approach is taken, she must operationalize the phenomena to be coded, create coding categories, and establish their reliability, for example, by getting multiple raters to agree on how they should be applied to a sample of the data. If statistical methods of analysis are to be used, appropriate statistical tests must be identified and applied. Finally, the findings must be interpreted responsibly and in relation to the original research question. (p. 343)

Applications in ECT

Early studies using conversation and discourse analysis in ECT focused on face-to-face classroom student interaction while using computers (Dalton, Hannafin, & Hooper, 1989; Wegerif, Mercer, & Dawes, 1998). Classroom studies of interaction continue, particularly in science and mathematics education (Warwick, Mercer, Kershner, & Staarman, 2010). The importance of teacher–student and student–student interactions are key in several major recommended frameworks in the study of teaching and learning (Ball & Forzani, 2007; Hirumi, 2009; Rovai, 2007), providing a major impetus to discourse studies in natural classroom settings. Qualitative studies of communication have also been used in understanding team interaction and processes in design (Duncan, 2010; Games, 2010; Pan & Thompson, 2009).

Increasingly, many of the current ECT research studies come from examination of interaction in e-learning and online professional development (Clarke, 2009; Donnelly, 2010; Kim & Bateman, 2010; Ng'ambi, 2008; Soter et al., 2008; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). While most studies of online discussion rely on methods of discourse analysis or procedures developed in CMC studies, Gibson (2009) applied classic concepts from conversation analysis in his study of an asynchronous postgraduate reading group.

Trends and Issues in Discourse Studies

A number of issues arise around qualitative discourse studies in ECT (Valcke & Martens, 2006). Discourse analysis, conversation analysis, and methods of CMC/CSCL/CMDA are covered by few introductory education or general social qualitative research methods textbooks, in which emphasis is on naturalistic field research and participant–researcher interaction such as interviews. As with interpretivist methodologies covered in the earlier part of this chapter, limited guidelines to help novice researchers may result in decreased or weak applications of discourse analysis in ECT studies. However, as conversation-based approaches grow in popularity, new textbooks are beginning to appear that may help beginners with differentiating the methods (e.g., Wertz et al., 2011).

While the focus within ECT has been primarily discourse analysis relating to discussion and language interaction for learning, finding appropriate theoretical and methodological frameworks can be challenging without a clear recognition of the variation among studies with the common label of discourse studies but very different purposes. The issues of methodology are confounded because *discourse analysis* is not congruent among scholarly disciplines. The term *discourse* is applicable to all aspects of human use of language to communicate. Thus, the study of human language production ranges from a very specialized interpretation with statistical analysis of word usage, sequence, and context in linguistics to the study of policy "discourse" in public documents or candidate speeches in political science. Discourse study also emerges in the humanities in studying literature, often from a critical perspective. In more literary approaches to discourse studies, interpretivist approaches such as those in the previous section may predominate.

The diversity in approaches and lack of a common vocabulary for these studies presents a challenge to those in ECT attempting to apply conversation or discourse analysis without a strong background in the disciplines from which the methods emerged. Reflecting general concerns raised in the broader arena of discourse analysis, ECT studies may lack grounding in earlier research; fail to acknowledge emerging critiques and limitations; and be confounded by imprecise and overlapping terminology (Antaki, Billig, Edwards, & Potter, 2003; Hammersley, 2008). Each variant of discourse analysis has unique processes for transcription, coding, classification, interpretation, and validity (Herring, 2008). Silverman (2006) argued that lack of theory and over-reliance on general thematic analysis of talk in many studies results in weak common sense or normative reinterpretations in the results of poorly designed studies. Others have raised concerns relating to the relationship of communication patterns to effective learning and teaching, with critics urging increased attention to studies that go beyond description of interaction among social groups to more development of theory and use of frameworks related to learning (Dennen, 2008; Naidu & Järvelä, 2006; Spatariu, Quinn, & Hartley, 2007).

Beyond terminology and critiques of application, a number of challenges in such studies relate to discourse interactional process and shifting technologies (see this volume, Chap. 20). Many methodologists have urged greater attention to the differences in content and context between face-to-face and online interactions which might impact appropriate methods, but this remains an area for continued research and theoretical development (Greenhow, Robelia, & Hughes, 2009). The proliferation of studies of digital discourse practices and communities-in-action has been accompanied by exploration of new and more specific research techniques (Hmelo-Silver & Bromme, 2007; Park, 2007; Zemel, Xhafa, & Cakir, 2007). More than in face-to-face studies, concerns arise over ethics and privacy in studying online discussions (Bos et al., 2009; Eynon, Schroeder, & Fry, 2009; Kanuka & Anderson, 2007; Zimmer, 2010).

The Researcher as Practitioner

The ongoing concerns in qualitative research about the unequal relationship between researcher and researched, particularly in critical approaches (Denzin & Lincoln, 2008), promote methods that are more inclusive of participant voices, such as action research, participatory approaches, and collaborative research. While some methodologies such as design research (see this volume, Chap. 20) may be jointly initiated, the role of the researcher remains that of the expert. However, a number of proposals have urged greater teacher voice and empowerment in research, along with recognition of the methods of evaluation and practice, as providing needed context for theory and policy (Loughran, 2002). In particular, Tabachnick and Zeichner, 1999 has pointed to the role of self study as "sensitive to the social and personal complexities of the work," and its contribution to a "deep and critical look at practice and structure" (p. 11). In contrast to the traditions covered above focused on data collection and analysis, participatory researchers typically adopt procedures from the broad palette of social science methods but the emphasis here is on research purposes related to stakeholder involvement and shared understandings, as well as action oriented outcomes.

Cooperative inquiry (CI), a form of participatory research, is designed for institutions responsible for social transformation, a category that includes schools. CI has potential for a field like ECT, with its foundations in improving educational opportunities for learners and exploring new technologies for teaching and learning. The CI tradition has roots in such diverse areas as human–computer interaction, cooperative design, contextual inquiry, and activity theory (Druin, 2010). Although participatory research is a long-established research method, there are limited examples in ECT and therefore little recognition in earlier *Handbook* editions, with a single case study cited in the third edition in the chapter on change agentry (Beabout & Carr-Chellman, 2007). In schools, CI was initially spurred by calls for teacher research (Cochran-Smith & Lytle, 1990), but has gained traction with the push for evidence-based practice and effective professional development (Desimone, 2009; Groundwater-Smith & Mockler, 2009). However, CI is also relevant to workplace and adult learning (Yorks & Kasl, 2002), design studies (Druin, 2010), and instructional design (Morris & Hiebert, 2011).

Because cooperative inquiry is both a methodology and a method, the philosophy behind CI guides the way data are collected. Group members share the values of the endeavor and then, in concert, compile information and develop strategies for implementing solutions, gathering more data, and making adjustments to enactment. CI adds a humanistic quality to scientific inquiry by seeking the opinions of those who are truly experiencing the research questions. Qualitative approaches are often recommended because they fit with the flow of classroom routine and focus on context, process, and relationships in CI, but quantitative methods may also be applied (Dana & Yendol-Hoppey, 2009). Debates exist about the potential for rigor in collaborative inquiry studies (Hodgkinson & Rousseau, 2009; Kieser & Leiner, 2009; Newton & Burgess, 2008), but others have noted that stakeholders are more likely to be aware of potential data sources as well as practitioner or stakeholder wisdom, and are thus able to exploit these in ways not possible by outsiders (Dana & Yendol-Hoppey, 2009).

Cooperative inquiry is an emergent process that contributes to the acquisition and creation of knowledge through strengthening trust and collaborative relationships among group members (Oates, 2002). It is designed to bridge the perspectives and approaches of diverse stakeholders through the phases of mutual inquiry across multiple iterations, cycling between action and reflection in an effort to "heal" their divergent points of view into a common solution (Ospina, El Hadidy, & Hofmann-Pinilla, 2008). The experience of CI requires coinvestigators to share how they react to particular situations and sensitive topics. As such, coinvestigators must build a trustworthy rapport. Participants often find their research creates empathetic connections through previously unrecognized perspectives (Kovari et al., 2004). Some have suggested the process is more applicable to formative evaluation in applied educational settings because of its openness to nontraditional data sources and iterative nature, but purposes may vary.

While some researchers may regard these experiences as insignificant and not objective, Reason and Heron (2004) indicate researchers can "develop their attention so they can look at themselves—their way of being, their intuitions and imaginings, their beliefs and actions—critically and in this way improve the quality of their claims to four-fold knowing" (p. 43). Reason and Heron stressed that such "critical subjectivity" adds strength to cooperative inquiry, allowing coinvestigators to be objective without having to disregard their personal experiences. Instead, coinvestigators use their personal knowledge and the experiences they have shared with others who are involved in the same task to gain an authentic perspective on a particular issue (Paulus, Woodside, & Ziegler, 2010).

For educators and education researchers, collaborative inquiry can be a powerful means to develop cultural competencies and the awareness necessary to function effectively in a variety of educational and political contexts (Kasl & Yorks, 2010; Seidl, 2007). The CI process is particularly useful for ECT because it allows for the merging of perspectives of diverse stakeholders at every stage of using technology in addressing a mutually agreed-upon problem.

Application in ECT

The ever-changing relationship between education and technology in schools is well suited to exploration through CI. Indeed, researchers have noted that a complex or "hypertextual" learning environment as found with increasing technological innovation in education demands user-centered approaches since structures of information are relatively unfixed and are intended to be suited to a particular user's needs (McKnight, Dillon, & Richardson, 1996). However, this focus on interactivity and personalization accompanied by the need to account for rapid technological change results in a recurring complication in determining the effects of ECT on a learning environment. In addition to personal differences, the determination of effect involves capturing the access, skill, structural, and political factors as well as the needs and motivational perspectives across roles and generations, potentially including adult and youth learners, parents, school librarians, educators, technology personnel, administrators, and community members (Hill, Wiley, & Nelson, 2004; Mardis, Hoffman, & Marshall, 2008). The CI method can help participants to articulate learning experiences and requirements in difficult-to-study environments in educational contexts, such as informal education and professional development (Lom & Sullenger, 2011).

In response to this tradition's documented benefits, researchers have used CI to ensure that the variations in interpretation, development need, and use are explicitly accounted for in design of ECT learning experiences, two of which are detailed here. The first example reflects how CI has been used in the development of distance learning platforms that meet the needs of a diverse range of learners and faculty (Palaigeorgiou, Triantafyllakos, & Tsinakos, 2011). With the use of participatory design organized as a Cooperative Inquiry, undergraduate students from two Informatics Departments worked together to describe a learning platform which would accommodate their learning differences and needs, build on their new Web 2.0 tool preferences, and could be seamlessly situated in their daily routines. Students came up with 773 different learning needs that developers had not considered. Through the CI process, students were revealed to have refined views of successful elements of online learning applications. Their findings not only paralleled previous instantiations of online learning platforms, in which course content and contextualization of knowledge were top priorities, but included essential complements that designers otherwise neglected such as various aspects of networking, participation, content distribution, and collaboration mediated through Web 2.0 technologies.

CI has also been applied to the design of interactive activities to achieve learner engagement and effective learning outcomes for a variety of educational purposes (Brown et al., 1989; Druin, 2005; Triantafyllakos, Palaigeorgiou, & Tsoukalas, 2008). The research team headed by Allison Druin at the University of Maryland (UMD) Human Computer Interaction Lab (HCIL) recognized that children today have unique experiences and are savvy about technology in ways that are often unrepresented in design. In response, the UMD HCIL team now includes children in cooperative inquiries. They codesign methods to enable adults and children to share their ideas through brainstorming, use a variety of feedback mechanisms, and provide input on creative change in prototype designs for the International Children's Digital Library (ICDL) a digital library of children's literature from all over the world (http://childrenslibrary.org). A group of six children, ages 7–11, work regularly with the adults in the HCIL to develop and evaluate computer interface technologies that support searching, browsing, reading, and sharing books in electronic form. Both the ICDL's CI approach and its interface have been the subject of numerous studies and commendations (Druin, 2010).

Trends and Issues in Practitioner-Focused Research

The increasing pace of change in ECT is driven, in part, by the need to serve greater numbers of learners and, in many instances, stakeholders through an increasingly multifaceted formal and informal learning complex. Trends in student types can be seen in the growing number of adult learners seeking career re-tooling or advanced education (U.S. Department of Education National Center for Education Statistics, 2007); the increased enrollment in virtual schools (Watson, Murin, Vashaw, Gemin, & Rapp, 2010); and an emphasis on twenty-first century skills in all curriculum areas (Trilling & Fadel, 2009). Likewise, the partnerships that result in charter schools, magnet programs, and alternative programs (Epstein, 2007; Epstein & Sanders, 2006) as well as the globalization of learning experiences bring a greater number of stakeholders to the ECT table (Reimers, 2009) at a time when technology's alienating effects are being seen and felt in education (Turkle, 2011). The use of CI has increased in other applied fields, including community development, public health, social work, nursing, and special education (e.g., Guha, Druin, & Fails, 2010; Ospina, El Hadidy, & Hofmann-Pinilla, 2008). This increase suggests that the blending of qualitative methods with participatory methods is not just becoming more accepted, but may be an essential tool for knowledge-building on the role of ECT in learning environments and meaningful contribution to practice to incorporate diverse perspectives.

Qualitative Research on Groups: Case Study and Beyond

Any qualitative study of groups, be they work teams, classrooms, schools, regional populations, or other human communities, may be addressed through case study research. While not all researchers will agree with broad usages of the term, at a practical level almost any study of a human group could be seen as a case study requiring a bounding by population, locale, timeframe, and/or process. As a term, *case study* is widely used and has long traditions, with some referring to this as a methodology or tradition while others suggest it is the nature of what is studied (Stake, 2008; VanWynsberghe & Khan, 2007). Although case study has also been used to describe detailed studies of a single person (a case) as an exemplar of some larger group (i.e., Luehmann, 2008), this review discusses the concept of case study in relation to empirical research on groups, particularly using qualitative methods.

Case study is centered on systematic empirical research employing multiple methods to generate rich descriptions to understand bounded complex social systems or processes, whether inductive or deductive in design (Stake, 2008; Yin, 2008). Qualitative data collection and analysis often predominate in case studies, but may be accompanied by surveys or other quantitative methods. Such mixed methods studies are lauded because of the ability to reveal a level of detail about content, context, and process that is concealed in purely quantitative studies (Buchanan & Bryman, 2007; Horn, 2008; Onwuegbuzie, Johnson, & Collins, 2009; Onwuegbuzie & Leech, 2004; Symonds & Gorard, 2010). In fact, many argue that the qualitative–quantitative divide is artificial and limiting when applied to the complexities of groups, proposing that methods should be adopted from the range of possibilities on a pragmatic basis to fit the research situation and purpose (Yin, 2008).

Methodologists regularly cited as guiding case study research design include Yin (2008, 2011), Creswell (2007), and in education, Merriam (1998, 2009). Stake (2006, 2008, 2010) is influential in his development of qualitative and multiple case study methodologies.

Application of Case Study in ECT

There are many case study types, including descriptive, exploratory, explanatory, instrumental, critical, longitudinal, deviant, extreme, or intrinsic, with competing paradigms or frameworks in which this research is couched such as interpretive, positivist, constructionist, or critical (VanWynsberghe & Khan, 2007). Qualitative case study in ECT may apply to:

- In-depth descriptions of instructional design projects (Bennett, 2010; Khan, 2008; Larson & Lockee, 2009).
- More evaluative or applied approaches including action research focused on what works (Girvan & Savage, 2010; Kim & Hannafin, 2010; Whipp & Lorentz, 2009).
- Descriptive studies providing detail on a particular process or phenomena (Ghislandi, Calidoni, Falcinelli, & Scurati, 2008; Roytek, 2010).
- Studies examining change processes and effects related to technology innovation in education (Juuti, Lavonen,

Aksela, & Meisalo, 2009; Lawson & Comber, 2010; Wong, Li, Choi, & Lee, 2008).

- Knowledge building studies aimed at generating or testing theory (Arnold & Paulus, 2010; Hong & Jung, 2011; Yanchar, South, Williams, Allen, & Wilson, 2010).
- Critical studies aimed at critique and reform (Arshad-Ayaz, 2010; Lee, 2010).

The popularity of case study research in ECT has been attributed to limited resources leading to small-scale (sometimes called small-n) studies and the presence of prescriptive guidelines in methods books and articles that make the approach more understandable to novice researchers. Case study, particularly as presented by Yin (2008) and Stake (2006), tends to promote a positivist or pragmatic philosophy that aligns with prominent views of ECT as a science and the field's grounding in the technical (Twining, 2010; Willis, 2008). In addition, the exploratory use of case study research provides a way to examine situations that are new or relatively unknown which is pertinent to examining the factors and processes of adoption and use of emerging technologies in teaching and learning.

Many Methods for Studying Groups

While case study may be a dominant form in ECT research on groups, many methodologies may be applied that are purely qualitative in method or are mixed methods with a major qualitative component. Some of these are discussed in detail in other chapters within this *Handbook* so are not reviewed here. However, two of the better known qualitative traditions, *ethnography* and *grounded theory*, should be mentioned although neither has been extensively applied in ECT studies. Both have deep histories of application in education and beyond, are described in multiple books and articles on methods and methodology, and have been the source of heated debates among proponents that have served to highlight strengths, weaknesses and variants in use (Hammersley, 2008; Lincoln, 2010).

Ethnography as a Qualitative Approach

Ethnography with its focus on culture has an associated set of methods and field procedures, culture-centered definitions for what constitutes a group, and a theoretical framework within which results are interpreted emerging from a disciplinary paradigm in anthropology (Hammersley, 2006; Hammersley & Atkinson, 2007; Wolcott, 2008). Traditional ethnographic studies were conducted over long periods primarily through participant observation, supplemented by additional methods of data collection including interviews with key informants, questionnaires, and examination of material artifacts and documents. The term "ethnography" is also used as the name of the resulting research report in which the emphasis is on "thick description" as delineated by Geertz (1973) and holistic cultural interpretation.

More recently, ethnography has been used to classify qualitative field studies in many disciplines that result in rich descriptions. Research in which participant observation over time is used in data collection is sometimes referred to as applying ethnographic methods although these may lack the grounding in culture, prolonged study times, and the goal of holistic interpretation. Wolcott (2001) argued against terming such studies as ethnography, proposing these are merely educational research drawing on "ethnographic approaches in doing descriptive studies" (p. 167).

Recent examples of ethnography in ECT studies include research on faculty who teach online (Yoshimura, 2008), children's experiences in educational gaming (Dodge et al., 2008), use of whiteboards in classrooms (Reedy, 2008), and technology in college classrooms (Hemmi, Bayne, & Land, 2009; Lohnes & Kinzer, 2007). Of particular relevance to ECT research are two more recent variants of ethnography: *virtual ethnography* with a focus on populations in digital environments, particularly online games and virtual worlds (Garcia, Standlee, Bechkoff, & Cui, 2009; Kozinets, 2010; Schuck, Aubusson, & Kearney, 2010); and *design ethnography* as a way to understand impacts of instructional design (Barab, Thomas, Dodge, Squire, & Newell, 2004; Blomberg, Burrell, & Guest, 2003; Bossen, 2002).

Grounded Theory: More than Methodology

In contrast to ethnography, *grounded theory* is a qualitative approach that does not presuppose that the study participants are groups or individual; as such it does not easily fit into the classification scheme used in this chapter.

In grounded theory, the researcher is encouraged to approach data with an open mind not limited by prior conceptions, take a reflexive stance in relation to participant interaction, examine data to saturation to ensure full coverage and trustworthiness, and from the analysis, extrapolate commonalities that lead to theory development (Bryant & Charmaz, 2007; Charmaz, 2006; Corbin & Strauss, 2008; Glaser & Strauss, 1967; Mills, Bonner, & Francis, 2006). Grounded theory may be used with multiple forms of data collection. Unlike the holistic approach of ethnography, analytical techniques emphasize deconstruction through formal mechanisms of coding, then reconstruction of concepts and themes that will lead to building theory or frameworks (Shah & Corley, 2006; Urquhart, 2012). While early development of grounded theory was a response to calls for a more empirical process of qualitative research with systematized and formal methods to parallel positivist research approaches (Glaser, 2002), more recently grounded theory has been advocated within an interpretivist, constructionist, or critical approach (Charmaz, 2006; Mills et al., 2006; Mills, Chapman, Bonner, & Francis, 2007).

Examples of grounded theory application in ECT research include studies of the instructional design process (Ertmer et al., 2008), cross-cultural distance learning (Rogers, Graham, & Mayes, 2007), learning in virtual worlds (Oliver & Carr, 2009), educational game environments (Dickey, 2011), and adoption of wireless on a university campus (Vuojärvi, Isomäki, & Hynes, 2010).

As was the case with ethnography, the analytic methods of grounded theory have been applied within multiple research studies in which the overall methodology and epistemological framing is not present. In a number of cases, grounded theory is merged with other frameworks, including cultural–historical activity theory (Seaman, 2008) or case study in research on virtual networks in Peru (Díaz Andrade, 2009).

In particular, the partial adoption of grounded theory as method is found in research that Merriam (2009) classifies as a *general qualitative study*, which uses open coding and thematic analysis, commonly referred to as the constant comparative method, in the absence of grounding in a more encompassing methodological framework. She notes that general qualitative studies are common in applied fields such as education, in which such research may examine bounded groups such as classrooms or schools, or specific populations such as teachers or learners.

Some critics have proposed that the widespread use of the general qualitative study identified by Merriam (2009) is more a result of under-specification of method and approach in case study rather than an ideal type in social research (Backman & Kyngäs, 1999; Caelli, Ray, & Mill, 2003; Urquhart, 2012). This is an issue in ECT research, where an analysis of empirical research articles in journals by Randolph (2008) found that research procedures were "grossly underreported" (p. 68). Further, Leech and Ongwuegbuzie (2007, 2011) note the unfamiliarity of education researchers with methods of qualitative data analysis other than the constant comparative method used in general qualitative studies. They also point to lack of coverage of varied qualitative data analysis techniques in textbooks as contributing to the limited use of other data analysis methods even when it is appropriate or would strengthen conclusions. Their recommendation is that researchers consider using at least two if not more data analysis methods to triangulate results.

Issues and Trends in Studying Groups

Many commonly applied methods and methodologies in qualitative research on groups are not new but arise from long-standing traditions in social and educational research (Travers, 2009), whether case studies, ethnographies, grounded theory studies or the many others described in this *Handbook*. While the volume of the arguments over appropriate research techniques has waxed and waned erratically over time, the critiques have also opened doors to refinement, convergence, and expansion of qualitative research options as well as new insights on the context, processes and dynamics of human groups.

A number of the challenges relevant to studying groups are also those that are foundational to the challenges of qualitative research as a whole, and are parallel to issues reported in earlier sections of this chapter. These include issues of level of analysis, relationship of methods, methodology and purpose in research design, matching analysis to purpose, and the validation and inference from results (Anfara & Mertz, 2006; Leech & Onwuegbuzie, 2011; Onwuegbuzie & Leech, 2005). While each methodology may use overlapping methods of data collection and analysis, such as interview and observations or formal processes of categorizing data, methodologies vary in other ways including appropriate design of questions, the prescribed level of researcher intervention in the interaction with the participant, and the assumptions about the concreteness of responses and observations in relation to some social or physical reality (e.g., whether a conversation is unique, situated, and emergent or is direct evidence of a person's culture, identity, cognitive or emotional self). Further, methods and methodologies may be merged without adequate attention to impacts on validity or potential contradictions arising from disparate data sources (Bryman, 2007; Morse, 2010). The multiple dimensions of variability elude simple categorization and present challenges to researchers using qualitative methods and methodologies.

The requirement for parallel structuring of theory, purpose, methodology and methods in research is commonly referred to as *coherence* (Kline, 2008; Tracy, 2010). Such coherence may be lacking in research design among novice researchers who initially see methods as a technical issue or normative process, thus following prescriptive guidelines in the absence of a more refined understanding of a particular qualitative method's history and limitations (Walford, 2001). Yet even experienced researchers can run into such problems when approaching a new research technique. Such issues may be most pronounced in case study in which creative repurposing of methods and traditions to best answer research questions posed is both a strength and weakness (Taber, 2010). However, methodological "borrowing" can also be a concern when such traditions as ethnography or grounded theory are used in new ways and outside the disciplinary paradigms in which they developed.

Conclusions

This chapter's review of qualitative traditions and methods reveals an increasing range of possibilities for ECT researchers along with a multitude of qualitative studies examining questions of significance to the discipline. The diversity of theoretical perspectives, methods, and methodologies provide support for Denzin and Lincoln's (2008) perception that qualitative approaches continue to proliferate. Some methods are just beginning to gain prominence, while new methods are emerging that have yet to make a major impacts on the field (e.g., Hesse-Biber & Leavy, 2008). Such advancements hold promise for expanding research designs useful in approaching the complexity of context and content in instruction, technology, and education.

In this final section of the paper, we will take a look at some of the broader prospects and concerns impacting qualitative research in ECT.

Opening New Vistas in ECT Qualitative Research

Perhaps most exciting in terms of new vistas from the perspective of ECT are the repurposing of the traditional methods of qualitative studies in the context of new digital technologies. Not only do new technologies provide additional tools for data collection and analysis (see Chap. 20), but online social technologies, knowledge management systems, powerful search engines, and computerized logging of user actions allow insights not previously possible into human behavior and social interaction. Some examples have already been given in this chapter such netnography or the study of dialogic interaction with computerized agents, with more appearing regularly.

An area of heated debate and also one that has substantial potential to lead to innovation in methods and theoretical frameworks revolves around the issue of explanation and causation in social behavior. In particular, an increasing number of proponents argue for the utility of case study research and the rich descriptions resulting from qualitative studies as legitimate means for theory development and testing, including the potential for meaningful contributions to evidence-based practice (Bennett & Elman, 2006; Chenail, 2010; Eisenhardt & Graebner, 2007; Flyvbjerg, 2006; Larsson, 2009; Shaw, Walls, Dacy, Levin, & Robinson, 2010). Support for the role of qualitative research as an accepted approach to theory on causation comes from multiple perspectives, including those who urge recognition of complex systems and evolutionary processes in social analysis from a positivist perspective (Morrison, 2009) and those who focus on informants' words, views, and sense-making following interpretive traditions (Díaz Andrade, 2009).

A third trend of interest is in the increasing sophistication and numbers of articles reviewing research, both those that are syntheses of research results that include qualitative studies, and those that examine the processes of research itself. At one level, many of these reviews are a form of qualitative study in the categorization of article types or internal content, although most reviews also apply some statistical analysis. While studies such as Randolph's (2008) reporting on the methods of research used in computer education journal articles are a beginning for ECT, some of the reviews beginning to appear in medicine and organizational studies comparing the uses of specific methods and methodologies in published research provide models for using the results of qualitative content analysis for a better understanding of research design. Of particular relevance is the application of findings to practice through meta-synthesis qualitative review in such fields as medicine (Cunningham, Felland, Ginsburg, & Pham, 2011; Donaldson, 2009), suggesting future trends in education.

Prospects in an Age of Quantifiable Outcomes

Despite some positive examples of qualitative research trends described above, the prospects for qualitative research in ECT and education more broadly are unclear. Internal debates about the purposes and methods of research continue, but perhaps more critical are the external critiques raising questions about appropriate methods and purposes in educational research (Denzin, 2009; Hammersley, 2008).

The Politics of Educational Research and the Qualitative Tradition

Externally, particularly in the USA and increasingly in other English-speaking countries, policy-makers are taking a more activist role in defining what is appropriate educational and social science research (Atkinson & Delamont, 2006; Denzin & Lincoln, 2008; Eisenhart, 2006; Liston, Whitcomb, & Borko, 2007). Such policies impact potential funding and lead to internal debates about research directions. With a focus on evidence-based practice and assumptions about proving cause through linear science, the trend, if played out, could increasingly negate the qualitative premise of explicating complex causes and emergent social processes. Such political forces could push qualitative research to a minor status of exploring phenomenon primarily to determine directions for quantitative studies (Denzin, 2009, 2010).

Further, as Denzin and others suggest, current policy debates about education not only have implications for research methods but also raise broader issues about what are considered appropriate research topics by equating "quality" with "useful" in the sense of immediately applicable to practice and "proven" to work (Biesta, 2007). Recent calls by ECT journal editors for effectiveness studies echo this direction (Roblyer & Knezek, 2003; Schrum et al., 2007; Thompson, 2005), while others have argued against such narrowed definitions of scholarship (Gardner & Galanouli, 2004; Hammersley, 2000, 2005, 2008). The role of politics and social values on education is well recognized given the scope and public nature of the institution in modern society, with the fallout as it relates to research direction and the future of qualitative research in the field yet to be determined.

The Internal Problems of Quality

The issues raised by Randolph (2008) of under-specifying research design in ECT empirical studies remain true in the samples of numerous articles reviewed by the authors for this chapter. Given many examples of under-delineated methods and design, it is not surprising to see ECT research discussions imply qualitative research has at best a secondary role to more rigorous quantitative results (Ross & Morrison, 2007). Maddux (2003) has vehemently railed against ECT qualitative research as lacking rigor and produced by those who are incapable of understanding scientific design and statistics—what he calls number fear, while other critics have taken a more moderate approach seeking new designs or promoting mixed methods (Amiel & Reeves, 2008; Creswell & Garrett, 2008).

Inspiration Within and Beyond ECT Borders

Despite some negative indicators, qualitative research is thriving, particularly in Europe and other parts of the world with stronger traditions of philosophy and theory supporting studies produced than in the USA. In addition, qualitative research in other applied fields is being critically examined in terms of rigor and quality, and through critical review being used to impact practice (Maggs-Rapport, 2001; Onwuegbuzie & Leech, 2007). This provides an opportunity not only for self-examination but for ECT to look outside the field for strengthening its own qualitative work.

Improvement Through Enhanced Evidentiary Standards

The debates over educational research are not entirely without benefit. The critiques of the earlier "paradigm wars" and the more recent discussion of validity and generalizability resulting from discussion of the "gold standard" in educational research have pushed for increased consideration of rigor and quality, not only in qualitative but in quantitative studies as well (Fielding, 2010; Gorard, 2002). Desimone (2009) and others have suggested that we are in a period of increased evidentiary standards, requiring more careful definition of terms and clearer delineation of methods that may promote knowledge building and theory (Ball & Forzani, 2007).

Recent articles in social work (Barusch, Gringeri, & George, 2011; Lietz & Zayas, 2010), counseling (Kline, 2008), organizational studies (Beverland & Lindgreen, 2010; Easterby-Smith, Golden-Biddle, & Locke, 2008; Gibbert & Ruigrok, 2010), and particularly health care (Collingridge & Gantt, 2008; Macdonald, 2009; Smith, 2009), provide models of enhanced quality and precision in qualitative methodology. These approaches may portend strategies for the evolution of rigor in ECT qualitative research and lead to reexamination of submission criteria by journal editors (Chenail, Duffy, St. George, & Wulff, 2011; Lin, Wang, Klecka, Odell, & Spalding, 2010). It should be noted that some of the recommendations for research standards emerging in other fields are not explicitly aimed at creating a one-size-fits-all scientific standard of evidence but propose that researchers be more transparent about the theory, epistemologies, and ontologies that framed their study (Freeman, deMarrais, Preissle, Roulston, & St. Pierre, 2007; Koro-Ljungberg, Yendol-Hoppey, Smith, & Hayes, 2009; Lewis, 2009; Tracy, 2010).

Building on Our Strengths

Like all disciplines, ECT research has norms of appropriate content and research design established by the disciplinary community and largely enforced by issues of hiring, publication and funding (Randolph et al., 2009). Willis (2008) has suggested that this community is more pragmatic, positivistic and conservative in its adoption of new research methods and methodologies than other areas of education. Relatedly, Maddux (2001), Maddux and Cummings (2004), and others warn about fads and assumptions that create barriers in developing continuity, urging researchers to build on past theory and research findings.

Qualitative research has potential to do more than it does by thoughtfully building on what we already know and then attentively crossing disciplinary boundaries for inspiration (Czerniewicz, 2008; McDougall & Jones, 2010; Wiles, Pain, & Crow, 2010). The outlook for qualitative research in ECT is high and the options exciting, as new technologies and innovative methods are added to freshen perspectives on our world.

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Program and Project Evaluation

16

J. Michael Spector

Abstract

Educational technology research and development nearly always involves an intervention of some kind aimed at solving a problem or improving a situation pertaining to learning and instruction. Those involved—the stakeholders—naturally want to know whether the problem was solved and/or the extent to which the situation was improved. Attributing any outcomes to the intervention is not as easy as it may appear, as many factors are typically involved, beyond just the technology involved. This chapter describes a holistic approach to educational technology project and program evaluation. The emphasis is on evaluating the entire process from needs assessment through design, development, deployment, and support with particular attention to evaluating every aspect of the process so as to increase the likelihood of successful technology integration. The use of a logic model to organize evaluation as well as research is described.

Keywords

Confirmatory evaluation • Formative evaluation • Logic model • Needs assessment • Program evaluation • Summative evaluation • Theory of change

Introduction

There are of course many different kinds of research. Typically, research is aimed at determining causes and/or explanations for unusual or unexplained phenomena or at making predictions about what might happen when certain situations occur. Explaining what happened or might happen (and why) as a result of particular educational policies and practices and instructional interventions represents an important kind of research not specifically addressed in previous editions of this *Handbook*. Such applied research is typically called program or project evaluation. Critical questions that inform program and project evaluation include the following:

1. To what extent were the goals and objectives of the program or project met or being met?
2. Did the implementation happen as planned?
3. Was adequate preparation and training provided?
4. Was the design clearly aimed at the problem identified at the outset?

One can of course imagine other questions, some of which will arise in the course of this chapter. First, however, it is necessary to distinguish products, policies, practices, programs, and projects. The latter two are easily distinguished. A project is typically aimed at addressing a particular problem situation by introducing something new or different, which can be called an intervention. As a consequence, a project has a goal and objectives, a beginning (could be the start of the needs assessment but is more typically the start of the development of the intervention), and an ending (typically a short time after the intervention has been deployed

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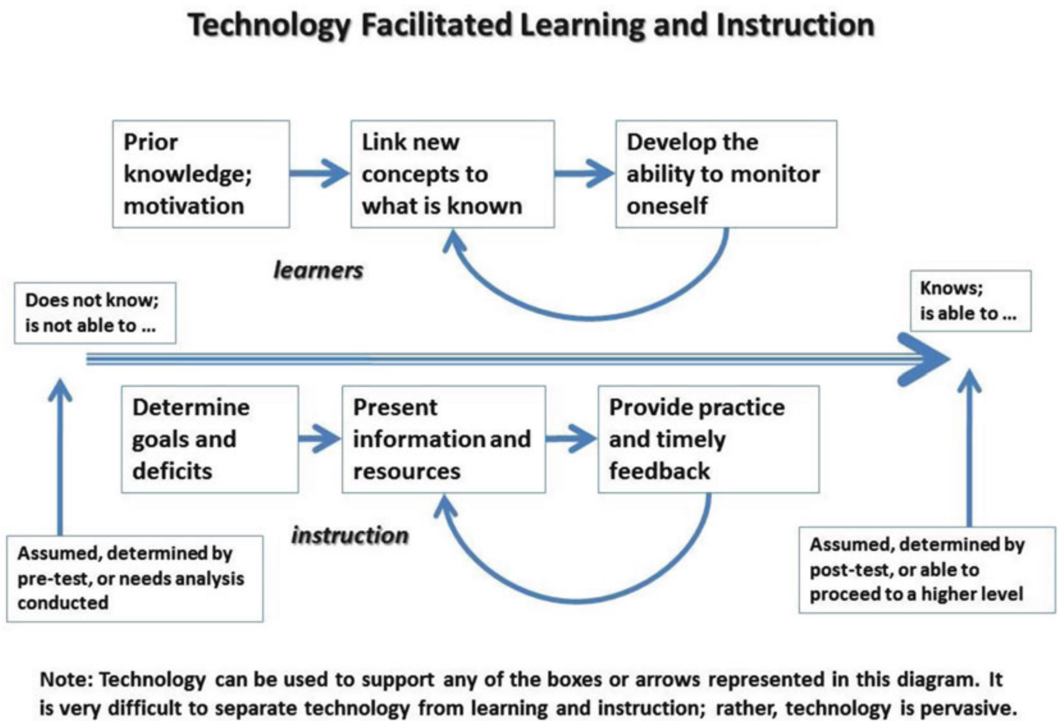

Fig. 16.1 Research on technology in learning and instruction (adapted from Spector, 2010)

and is being used regularly). A program shares many of the same attributes, but unlike a project a program is typically intended to continue in use and evolve over time, so the period of time associated with a program evaluation is longer than that associated with a project evaluation, and changes in the situation surrounding the program need to be actively considered as the program is periodically reviewed. Confirmatory evaluation is a kind of evaluation appropriate for determining if the original assumptions and problem situation are still pertinent to an ongoing program or a long-term project. Projects often mark the initiation of a new program, so there is a close association between projects and programs. Moreover, programs and projects typically alter practice (how those involved conduct their affairs and accomplish specific tasks), and they may involve the introduction of products, policies, and procedures to guide practice and the use of new technologies. This chapter is not focused on the evaluation of policies, procedures, or products, although some of the same principles and techniques are likely to be pertinent in those contexts as well.

Next, there are the notions of learning, instruction, and technology to consider. A technology involves the disciplined or systematic application of knowledge to solve a particular problem or achieve a specific goal (see Spector, 2012). Examples of educational technologies include online discussion forums, animated models, interactive simulations, checklists for procedures, mnemonic memory aids, and much more. Learning involves recognizable and persisting changes in an individual's (or organization's) abilities, attitudes, beliefs, knowledge, or skills (Spector, 2012). Instruction is that which supports or facilitates learning (Gagné, 1985; Spector, 2012). Based on these common definitions, it is obvious that there are close connections between learning, instruction, and technology, as depicted in Fig. 16.1. Just as technology can support any of the boxes in Fig. 16.1, each of those boxes can and should have an associated evaluation activity. Evaluation, properly understood, pervades educational practice and is essential for understanding the impact of projects and programs.

One can conceivably ask many different kinds of questions about a variety of technologies used to support and facilitate learning and instruction. Many of these questions involve the characteristics of scientifically based research, including the notions of baseline studies, comparison and control groups, analyses of significance and effect size, growth curve modelling, and so on (Cronback, 1989; Nagel, 1994; Scriven, 1960, 1994; Spector, 2010; Suchman, 1967; Suppes, 1978).

The history of educational research is rich and diverse, with more than 100 years of empirical investigations (Aldrich, 2002; Knox, 1971; Langemann, 2000; Suppes, 1978). In spite of such a large body of evidence, there is little evidence that the many educational technology innovations that have been introduced in the last 100 years have had a significant impact on learning (Langemann, 2000; Russell, 2001; Suppes, 1978). Several explanations for this unusual

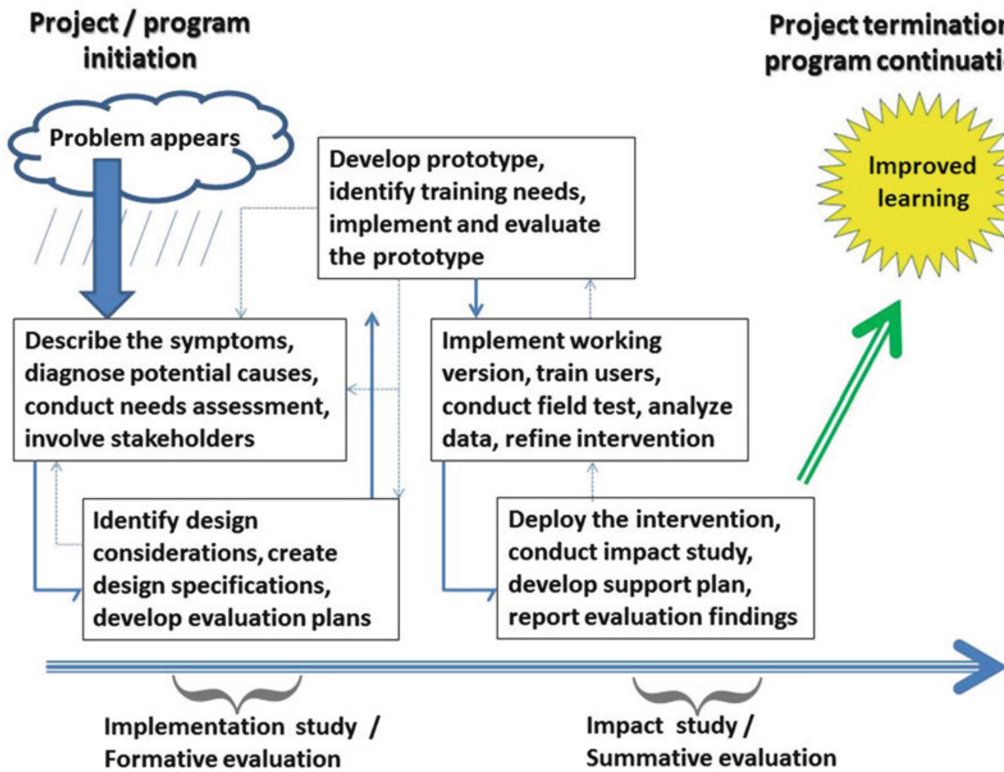

Fig. 16.2 A representation of projects and programs

finding have been provided, many of which focus on the inadequate kind of evaluation research conducted in association with the integration of new technologies into learning and instruction (Langemann, 2000; Russell, 2001; Suppes, 1978). A major inadequacy of prior research on the impact of educational projects and programs involves a tendency to examine superficial indicators of impact without examining the quality of the implementation and training associated with an intervention. Typically, project evaluations have focused on three indicators of success: (a) Did the implementation stay within budget? (b) Did the implementation occur on schedule? and (c) Did the implementation meet the design specifications? Such evaluations are summative in nature—that is to say that they do not provide any information or input that will improve the development of the effort while it is under way. Moreover, associated with such a summative evaluation there might be a research effort that looks at learning outcomes before and after the intervention was developed and deployed. The analysis of the before and after research data often indicates that there is little impact on learning (Russell, 2001; Suppes, 1978), although the three project indicators may reflect success. What is one to think?

The conclusion that will be elaborated in what follows is that a summative evaluation is not adequate and serves little real purpose without the support of a thorough formative evaluation along with a confirmatory evaluation for longer term efforts. Project and program evaluation can and should be aimed at the entire life cycle of the effort and be designed to ensure that the development effort will not only meet the design specifications but also address and solve the indicated problematic situation (see Fig. 16.2). Formative evaluation that is intended to improve an intervention as it is being designed and developed is required; this notion goes to the heart of what project and program evaluation is really about—one does evaluation to help ensure that time and money are not wasted, which means that evaluation must begin early and continue as the effort progresses. One can make the same argument with regard to assessing student learning—the proper emphasis is on helping to improve student learning and not merely on reporting what learning seems to have occurred at the end of a sequence of learning activities.

Confirmatory evaluation is worth emphasizing at this point as it helps distinguish projects from programs and reinforces the formative and summative nature of evaluation. Confirmatory evaluation is aimed at reexamining the problematic situation after an extended period of time, often after a project has been completed and a program has been under way for some time; long-term projects often revisit the needs assessment and requirements analysis phase of a project to make sure that essential aspects of the problem are still the same as originally identified. Confirmatory evaluation is conducted to ensure that the right problem is being addressed and solved. More specifically, confirmatory evaluation involves a systematic program analysis that is aimed at attributing effects to causes as well as reexamining assumptions and the original problem situation; this is important in explaining significant effects as well as the lack of significant effects (Reynolds, 1998).

Logic Models and Program/Project Evaluation

By way of summary, when conducting applied or development research, one may have a new educational technology or system that one believes will be beneficial in some way. This situation is a prime target for research and inquiry. One kind of inquiry often associated with development research is program (or project) evaluation. The basic questions are whether and to what extent an intervention (e.g., an innovative technology or new learning environment or educational system) achieves its intended aims, and why it succeeded or fell short in some way. The emphasis is not on the technology as a product but rather on its use in promoting learning and/or improving performance. One can imagine two kinds of studies emerging from a program evaluation: a fidelity of implementation study (a kind of formative evaluation) and an impact study (a kind of summative evaluation) (see Fig. 16.2). The notion of a logic model can be used to explain the differences in these two kinds of research and evaluation studies (see Fig. 16.3). A logic model portrays a current situation and the associated problem, the implementation of an intervention intended to address the problem situation, and the projected or the predicted outcomes and benefits of that intervention if and as successfully implemented. A theory of change that would explain why and how the intervention would lead from the problem state to the desired outcomes is normally associated with and depicted in a logic model. The fidelity of implementation study could be structured such that the results of the study reflected degrees of successful implementation (as in high, medium, low, or superior, adequate, or marginal involving such variables as professional development and technology support). Having such data is useful in explaining why and to what extent significant differences were or were not found in outcome variables. For additional detail on such studies, see the chapter by Jennifer Hamilton in this *Handbook*.

The problem description is important as that is the outcome of some kind of analysis typically called a needs assessment.

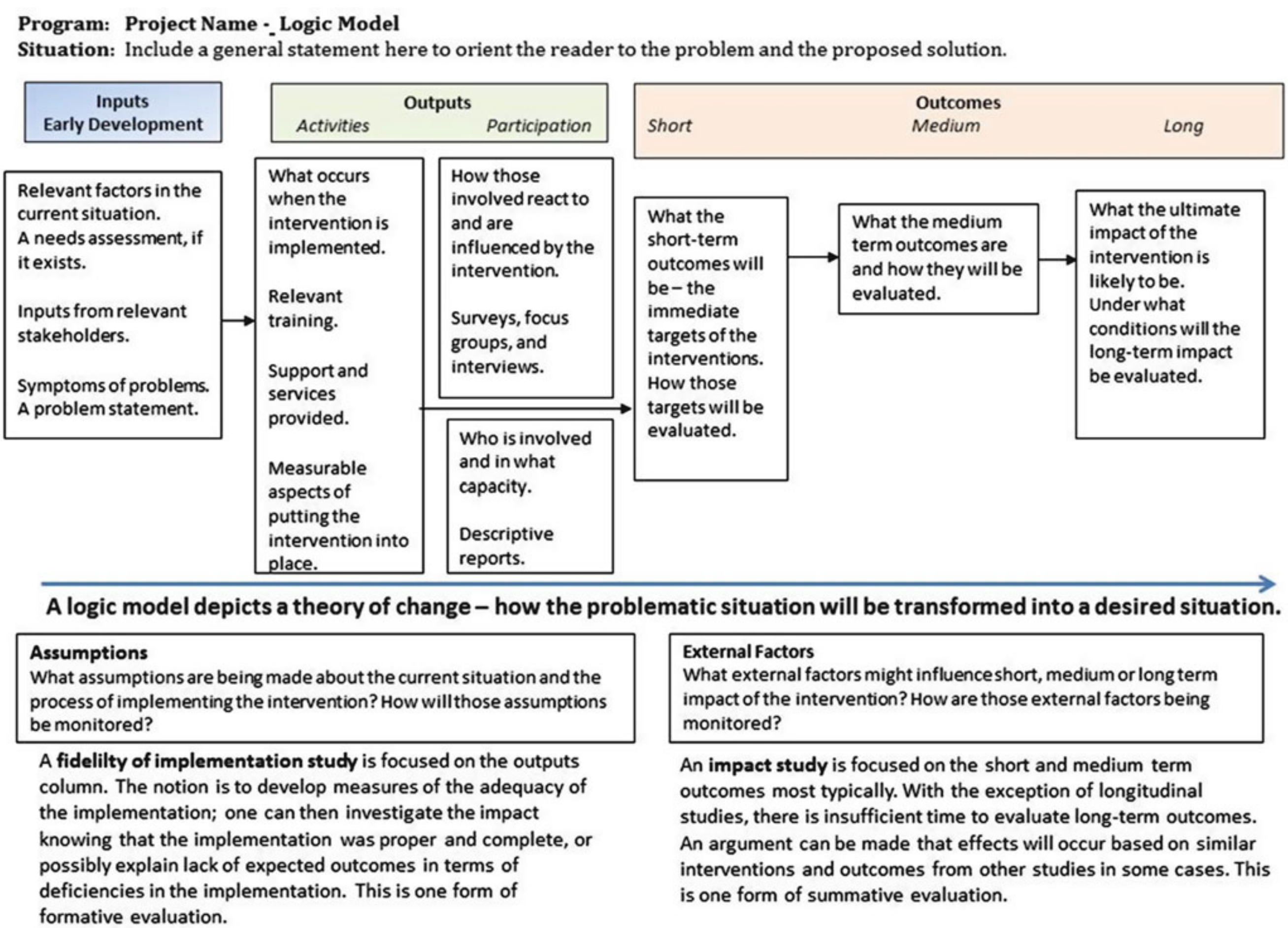

Fig. 16.3 Logic models, fidelity of implementation, and impact studies

The problem indicators become the targets of desired outcomes of the effort, which means that the impact study (summative evaluation) will measure the extent to which the problem situation has improved. However, the responsibility of program evaluation far exceeds simply reporting outcomes, even when resources (time, funds, etc.) are included in the outcomes analysis. The work of program and project evaluators begins with the analysis of the problem situation. Who was involved in the needs assessment? Were all stakeholders involved? Was there a divergence of views? How reliable were the methods and instruments used to collect and analyze needs assessment data? If the problem identification process is flawed, then it is unlikely that the subsequent development effort will produce desired outcomes. Evaluators should observe the early analysis and planning phases and provide formative feedback to help ensure that a comprehensive and high-quality needs assessment drives the effort.

Since nearly all technology implementation efforts involve training users, it is important for evaluators to observe and report outcomes of training plans as well as actual training. Inadequacies in training often result in suboptimal outcomes even when the technology implemented is of high quality. Moreover, planning for change and properly preparing users for a new technology are critical for the successful diffusion of an innovation within an organization (Ellsworth, 2000; Rogers, 2003). Again program evaluators have a responsibility to report any shortcomings or potential problem areas concerning preparing users for an innovation; this responsibility falls into the category of formative evaluation. A formal analysis of how well the project or program is preparing end users for the effective integration of a new technology is known as a fidelity of implementation study. Such a study is primarily aimed at the inputs and outputs in the logic model (see Fig. 16.3) and the degree to which the intervention can realistically be expected to support the underlying theory of change if it is properly or fully implemented.

A primary obligation of evaluators is to alert the implementation team and management of anything that might jeopardize the desired outcomes of the effort at any time during the entire process of planning and implementing an intervention. However, it is quite rare to find a project or a program that involves evaluators throughout the process in this way. Perhaps this lack of ongoing formative evaluation is another reason that few significant differences are reported even for well-supported educational technology efforts.

Evaluation vs. Research

Why include a chapter on program evaluation in a research handbook? Hopefully the answer is obvious enough at this point. In one sense, an evaluation effort represents one kind of applied research in the sense that an explanation for what has happened (or failed to happen) is developed, especially through the quantitative and qualitative data used in the fidelity of implementation study. Evaluators often use the same tools and methods used by other educational researchers. One difference is the focus of evaluation vs. that of other forms of educational research. Evaluation is focused on decisions made during the planning and implementation of an intervention with the aim of helping to improve the effort so as to produce desired outcomes. Other forms of educational research are focused on answering questions that contribute to a body of knowledge or the development of theories to explain a range of phenomenon (see Popper, 1963). Of course it can and does happen that program and project evaluations inform research about the many phenomena associated with learning and instruction, so the distinction between educational project/program evaluation and education research is not sharp and distinct.

An Example

To suggest how the application of this approach to program evaluation might work, a brief discussion of an invented case is provided here. Obviously other approaches, methods, and instruments are possible to use. This case is meant to emphasize the formative nature of program evaluation as this is the most challenging aspect to implement.

A school district has determined that a significant percentage of its students are at risk. In making this determination, the district used an expanded set of indicators that included some things beyond the control of district personnel (e.g., socioeconomic status, physical and learning disabilities, etc.), and some things that district personnel (both administrators and teachers) believed that they could influence (e.g., absenteeism, test scores, pass/fail rates, graduation rates, discipline cases, etc.). The expanded set of indicators showed many more students at risk than teachers, administrators, and parents had previously imagined. District leadership then initiated focus group discussion with administrators, teachers, parents, and students to determine what problems these groups perceived as most relevant to the situation. Two quite different kinds of problems were mentioned most often: (a) instruction that was not well suited to individual student needs, and (b) lack of easy, real-time access to data that would enable teachers and administrators to be more responsive to individual student needs.

This needs assessment took place over the course of an entire year; it led the district to settle on a solution approach that involved an integrated data system that could provide data on individual students and that could also support differentiated instruction and personalized learning. Since the external evaluator was not involved in the needs assessment, there was an initial concern with regard to confirming the problem situation as represented by district personnel. As it happened, the district had documented the process quite thoroughly, so the first thing the evaluator did was to review that documentation and confirm that the needs were real and worth addressing through additional focus group discussions with the relevant stakeholders.

Having settled on an approach to resolve the problematic situation, a grant was submitted and funded, a company was hired, and a project team put in place that included an external evaluator. The goals of the project were focused on reducing absenteeism and discipline rates, increasing graduation rates, and improving test scores. These became the outcome indicators in the project's logic model developed by the external evaluator. The theory of change was based on the notion that personalizing learning and making instruction relevant to individual student performance and interest would result in increased student interest and performance, thereby reducing absenteeism and discipline problems while increasing test scores and graduation rates. That theory of change had some support in the published research literature, and it proved convincing to the funding agency. In this case, the impact study (summative evaluation) was easy to construct and implement since the measures were obvious and the data readily available. As it happened, the outcome measures did not provide sufficient basis to say that the intervention made a significant difference. In part, district personnel and the evaluator believed that this was because there was an influx of new students to the district whose first language was not English and because the economic downturn caused some high school students to take part-time jobs leaving them with less time for studies. These facts partially explained the lack of significant impact in terms of the outcome indicators.

During the project, the evaluator collected information from administrators, faculty, students, and parents with regard to training for and use of the new data system. The focus was on the ability of the system to support teachers' needs for timely information and students' needs to have customized learning activities. Prior to the implementation of the system, the evaluator noticed that the company originally hired to provide the system was not responding to teachers' needs for real-time information nor would the system be able to support personalized learning and differentiated instruction without extensive teacher intervention, which was not possible given existing workloads and enrollments. The evaluator recommended requiring the company to comply with the district's requirements or find a company that would. The district followed the evaluator's recommendations and found a company that was able to deliver a system that was responsive to the needs of both students and teachers. Due to a delay, however, the initial training was not as thorough as it could have been. The evaluator documented the time spent on training and problems that teachers and students had with the new system; the evaluator then recommended additional training and support materials, which were developed, but not soon enough to impact the outcome indicators by the time the funded project ended.

Two things are worth noting. First, the evaluator (who is fictitious of course) was able to add to the explanation of lack of significant difference on outcome indicators due to the implementation study that focused on the development process and the training of teachers. In addition, the district did manage to deploy a new system that is having an impact, although that impact was delayed due to the change in software providers. While the project itself could not report significant differences due to personalized learning and an integrated data management system, the project has evolved into a program that is now reporting significant differences, in part thanks to the formative evaluator's recommendation with regard to the software development provider.

Conclusions

This chapter is intended as an introduction to an important area of educational research called program (or project) evaluation. The treatment of program evaluation here was not intended to be comprehensive or describe specific evaluation methods or tools. Rather, the intent was to stress the significance of fidelity of implementation studies as they serve to explain the findings in an impact study, and to emphasize the responsibility of evaluators to report potential problem areas during a development effort to the implementation and management team. Readers can find a wealth of information on specific program evaluation methods and tools elsewhere (Louw, 1999; Potter, 2006; Rao & Woolcock, 2003; Rossi, Lipsey, & Freeman, 2004).

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Tools for Analyzing Quantitative Data

17

Gerald A. Knezek and Rhonda Christensen

Abstract

Data analysis tools for quantitative studies are addressed in the areas of: (a) enhancements for data acquisition, (b) simple to sophisticated analysis techniques, and (c) extended exploration of relationships in data, often with visualization of results. Examples that are interwoven with data and findings from published research studies are used to illustrate the use of the tools in the service of established research goals and objectives. The authors contend that capabilities have greatly expanded in all three areas over the past 30 years, and especially during the past two decades.

Keywords

Quantitative tools • Data acquisition • Data analysis • Data visualization

Introduction and Overview

Advances in personal computers over the past 20–30 years have made it possible for researchers to apply a vast array of quantitative research tools to data analyses at hand. Just three decades ago many sophisticated techniques required mainframe computer access and ran in batch processing modes that required researchers to wait for hours or days to see the output of a single run. Today, however, the processing power of personal computers (PCs) has improved to the point where the modern day data analyst can run a half dozen different techniques on a massive set of data in a typical afternoon.

In this chapter an overview is presented of tools for analyzing quantitative data, and examples of research in which these tools used are presented as well. The progression is generally from simple to computationally complex; however, even the most sophisticated can typically be executed on a high end personal computer (PC). Relationships among data elements are usually best illustrated with the most parsimonious (unembellished but complete) available techniques. Therefore, trying several analysis techniques will allow the researcher to choose the one judged to be best. Examples of this process are interwoven in this chapter.

Tools for Data Acquisition

There are many ways to gather data from subjects, ranging from simple and traditional paper-based surveys to more sophisticated feedback-based online systems. While paper was the most common method even as recently as the beginning of the 21st century, other techniques have rapidly evolved. The reasons are simple: paper-based surveys are often expensive, time-consuming, and cumbersome ways to gather data required for evaluation or assessment of project activities. Over the past decade many projects have moved away from paper surveys to Web-based acquisition of data from teachers and students. These vary in sophistication, cost, and constraints. Some issues related to appropriateness for certain types of research projects also remain to be resolved. These topics are addressed in the following sections.

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Paper Survey

Paper-based surveys have been the traditional method of gathering responses for many decades. For many populations, such as young children or those without access to information technology, paper continues to be the most viable alternative because paper surveys require little or no special technology to administer or complete and can be tallied by hand. The method is familiar and fault tolerant. However, it is also labor-intensive and time-consuming for large-volume applications. A decision about whether or not to use paper is often strongly influenced by the accessibility of online submission technology for respondents and whether or not there is a time critical need for mass administration and collection of data in a single sitting. It is typical with an online system to gather data from hundreds or thousands of subjects in a few days, and to have the data ready for analysis within a few hours following acquisition. And yet there is often a need for the use of paper surveys or other alternatives that have evolved in the last decade. Manual data entry from a handwritten survey into a machine-readable file is one of the most time-consuming aspects of using paper surveys. The following section discusses alternatives that have been used in the past, along with their strengths and weaknesses.

Mark Sense/OCR

Preprinted forms that utilize machine-readable bubble-coded responses have been common in education for several decades. Typically these can be completed and scored very quickly, and they can be administered simultaneously to hundreds in an environment such as an auditorium, with little administration overhead. Mark sense forms are also expensive when commercially produced, are quite rigid in response format, and require lead time to print in volume. These characteristics make their use impractical in many research environments. Newer optical character reader (OCR) technology that can actually sense which response was circled by the respondent holds promise for improvements in this area. In these kinds of systems, multiple page surveys simply have the staple removed and each page is fed through a photocopier-type feeder mechanism. If the scanner mechanism has a problem deciphering the mark, it stops and requests that the operator make a judgment based on the scanned image.

HTML/Database Approaches

In Hyper Text Markup Language (HTML) and database survey administration systems, the server presents the form to the respondent and gathers the data when the respondent replies to an item, or at the end of a survey when a respondent clicks the “send” button after completing the survey. The server application writes the data into a text file or database for further processing via a statistical analysis package at the second stage. Several competing database approaches vied for universal adoption. Microsoft Access and FileMaker Pro were two that were successfully used for producing near real-time tabular or graphical feedback (color bars) for survey participants—if the number of items and/or simultaneous users were not too large (Knezek & Christensen, 2001).

Perhaps the current pinnacle of this line of development is a system that feeds into a sophisticated database such as those created with MySQL (Cartwright, 2005). However, many of these are based on expensive hardware/software platforms costing much more than the solutions envisioned as more affordable for an individual researcher or school district.

The database approach to online data acquisition is centralized and elegant. Theoretically it should have worked well with standard database packages. However, many researchers in the early 2000s became frustrated with slow operating systems and database bottlenecks, and constructed their own Unix-based data collection systems that wrote simple tab or comma-delimited text files for use with intermediate (data cleaning) packages such as Excel. These files could also be entered directly into statistics packages such as SPSS.

Modern Web-Based Approaches

As of 2011, Web 2.0 systems that combine advertising-based user interfaces, cloud computing (computing power residing at unspecified locations but available on demand), and small administration fees, are clearly becoming dominant. Some examples include Survey Monkey, Google.docs, Survey Tool, Zoomerang and Free Online Surveys. These are similar in that they all offer users the ability to create, send, and analyze online survey results on-demand. Some of the systems offer this Web-based survey tool for free on a limited level (maximum number of questions, responses, etc.) and also offer an upgraded fee-based version. Strengths include the ability to quickly create and gather the data and present results in a graphical format or provide the data to be easily imported into a statistical analysis package. Weaknesses include constraints on item formats and difficulty in managing data integration from multiple-survey (battery) administrations.

Two systems commonly used by university researchers as of 2011 are Survey Monkey and the Google.docs survey system. A Survey Monkey instrument typically presents HTML-formatted selections with mouse-clickable radio buttons as labeled response choices. User responses are written into a text file. Small project versions of Survey Monkey instruments can be developed and administered free of charge. Leaders of larger research projects will find the need to upgrade to the fee-based version of Survey Monkey.

Google.docs provides a free Web-based, online survey system with a variety of question types including multiple choice, Likert scale, short answer, and open response. The data are gathered by the system and provided to the researcher in a Google spreadsheet that can then be converted into an Excel stand-alone spreadsheet or a text file, as the researcher prefers. The survey can be embedded in an email or a Web page, or the researcher can send a link to the administration system. For a quick look at your data, there is a report feature that produces descriptive graphs immediately. One drawback of the Google.docs survey system as of 2011 is that it is difficult to incorporate the descriptive graphs into other documents. A researcher may be forced to resort to screen capture for this purpose. Another drawback is that the entire descriptor written for a multiple choice item is automatically written to the google.docs spreadsheet, making the output from the Google.docs survey system not concise enough for practical use in a statistical analysis package such as SPSS.

Both Survey Monkey and the Google.docs survey system generally function well for researchers, thanks to massive advances in server processing power and the ubiquity of Internet access in many parts of the world today.

Future Prospects

For the future, we see two strong prospects emerging quickly: Mobile survey administration and instant feedback with descriptive results. Smartphones and other handheld devices are certainly capable of presenting a single item from a survey, with which a person might agree or disagree on a Likert-type scale. These devices are also capable of displaying results showing how a survey participant's response (perhaps on a scale produced by combining answers to 5–10 items) compares with other respondents. One can readily envision the response pad system used in large lecture halls today, replaced by smartphone-based systems, where it matters little if the students are in the lecture hall or not. Systems of this nature generally return a bar graph to each participant who replied. Data acquired though a system such as this would seem to have great potential for later analysis, because every participant's answer to each question would be in a common database. This would allow straightforward analyses such as computation of Pearson's correlation coefficients.

The social networking movement, which appears to be sweeping the world in the second decade of the 21st century, also provides new opportunities for data acquisition. Researchers are now gathering data in sufficient sample sizes to complete reliability estimates very quickly, simply by polling associates in Facebook. Emerging social network systems also enable researchers to track subjects longitudinally, for purposes of follow-up studies. For example, Tyler-Wood, Ellison, Lim, and Periathiruvadi (2011) completed an 8-year follow-up study of fourth grade girls, and their matched comparison peers, to assess the long-term impact of having participated in a summer science program designed to engage their long-term interest in this field. The original subjects were located, agreed to participate, and completed follow-up surveys via social networking media. This follow-up study would not have been affordable, and would probably never have been completed, if carried out through conventional procedures.

Data Acquisition Issues and Concerns

Issues related to sampling and attrition, coding errors and data cleaning are common to new and old systems of data acquisition. There is a vast range of opinions regarding acceptable numbers (percentages of potential respondents) that are required for the data to be meaningful and useful. Many formal mechanisms exist for calculating power in a given situation, and for calculating optimum sampling scenarios to achieve preferred results. However, even the best-funded, most carefully planned research projects seldom complies with textbook design specifications after the data are gathered and cleaned. In pretest to posttest paired data acquisition situations, attrition is often a more serious issue than sampling or power. The major issues appear to boil down to what Campbell and Stanley (1963) called issues of internal validity and issues of external validity. The former have to do with whether one trusts that the research study or experiment was justified in the conclusion reached. This has to do with the ability of the instrument to measure change (power), the type of analysis employed, and many other factors including fidelity of the data subjected to the analysis procedure (was it cleaned with decisions made about nonresponders and doodlers, were outliers removed) and the possible effects of subject attrition. External validity is concerned with whether the conclusions the researchers reached can be generalized outside the group used to produce the results. This is closely tied to sampling issues and dangers due to failing to consider the vast diversity of environments where decision makers might hope that a single, local finding might be said to apply. These kinds of issues are common to all alternatives for data acquisition introduced in the previous section.

Several issues specific to online data acquisition are worthy of mention because they remain unresolved even after a decade of experience with online systems by the research community.

Lack of Universal Access

Online systems require that the person completing the survey have access to the response system. This is typically a computer connected to the World Wide Web (www).

If research data are being collected from a school or university computer lab where every student has access, or from teachers where every participant is known to have his/her own laptop at home, then this is not a problem. But if survey responses are being gathered from parents or the general public in economically disadvantaged areas, or from any nation outside the industrialized world, then sampling bias is certainly being introduced. A related problem is emerging even among sites that appear to offer full online access. Many schools block access to any URL that is not on an "approved" list. Survey sites from universities or some sites considered to be noneducational and/or commercial are blacklisted. Getting the IT managers for 50 or 100 schools to add a URL to the approved list is problematic. Because of this access issue, most researchers conducting a large-scale study develop an alternative paper version of a survey instrument, just for situations where online acquisition is not possible. This alternative solution then leads to the question of whether or not paper administration is comparable to online. This question is addressed in the section that follows.

Age Appropriateness/Lack of Basic IT Skill

Paper and pencil is considered universally accessible for the young and old, throughout the world. Online survey completion requires basic IT skills. Young children—perhaps those younger than third grade (8 or 9 years old)—may not be able to operate online surveys, and even older primary school children may require teacher or parent supervision in understanding written questions or alternative response options. Older citizens are often inexperienced with IT systems because the systems became commonplace after the citizens' workforce careers were completed. Both younger and older citizens (as well as those with disabilities) may lack the manual dexterity needed to move a mouse and click on options desired. These and other issues need to be considered when planning an online data acquisition research project.

Reliability of Data Gathered Online

In the early days of online data acquisition, many scholars and practitioners questioned whether this new form would yield responses as reliable as paper forms. Although little has been published on this matter, the research that has been completed seems to indicate there is not great cause for alarm. Vallejo, Jordan, Diaz, Comeche, and Ortega (2007) studied the reliability and validity of online versus paper versions of general health questionnaires and symptom check lists in the medical field. Based on paper (test) and online (retest) completions by 100 psychology students in Madrid, they concluded that the construct validity and the reliabilities of the responses by the students were acceptable and comparable in either form.

Table 17.1 Internal consistency reliability indices (Cronbach's Alpha) for online versus paper-based administrations of the Young Children's Computer Inventory (YCCI)

Likert Scale	No. items in scale	Alpha online	Alpha paper	Combined
Computer Importance	6	0.60	0.65	0.62
Computer Enjoyment	5	0.48	0.44	0.47
Attitude Toward Computers	11	0.67	0.68	0.68
Motivation/Persistence	5	0.41	0.45	0.45
Study Habits	6	0.52	0.52	0.53
Motivation to Study	11	0.65	0.66	0.66
Empathy	9	0.76	0.73	0.76
Attitude Toward School	4	0.73	0.66	0.73
Creative Tendencies	13	0.74	0.79	0.77

Note: Online sample = 907; paper sample = 343

Knezek and Christensen (2002) compared online versus paper and pencil survey instrument reliabilities for school age children in the USA spanning grades 1–6 and representing 17 school districts. In their study, 907 students completed online versions of the Young Children's Computer Inventory (YCCI) while 343 students from comparable schools completed the same surveys on paper. No large differences between the reliability estimates for paper administration versus online administration were found. As shown in Table 17.1, Cronbach's Alpha indices for the online version of the YCCI deviated from the paper version indices by no more than 0.05; there was no systematic pattern for paper versus online being higher or lower; and these trends were consistent for the Alphas in the range considered "acceptable" or "good" (≥ 0.6), as well as those considered substandard or unacceptable (<0.6) (DeVellis, 2003).

Additional research based on item response theory (IRT) and other approaches focusing on the functioning of the items, rather than the classical scale-level approach presented in this section, is needed before definitive conclusions can be reached regarding the comparability of paper-based versus online survey administrations.

Compatibility with Data Analysis Systems

One problem that arises with administering surveys through content management systems (CMS) such as BlackBoard, WebCT, or Moodle, and also through many standard database systems, is how to get the data out of the database and into a tab-delimited or comma-delimited text file for use in a statistical data analysis package such as SPSS or SAS. Typically a researcher will not be sufficiently familiar with systems such as Access (a relational database package), FileMaker (a flat file manager), or an online course management system, to the point where he or she can merge files and write the proper output in a single record as text. Reliance on database packages and CMS surveys appear to create the need for a manager at the server site who can transform these files on short notice.

In summary, data acquisition systems that provide alternatives to paper-based surveys have become well established in the academic world. The current trend is toward technology-based systems that are more timely in providing data for the researcher and more direct in their measurement. Newer automated systems that can quantify human activities previously requiring a single expert or panel of judges are beginning to blur the lines between quantitative and qualitative data acquisition, and hence the analysis tools applied after the quantification stage. Two examples are the video camera-based face-reader software systems described by Schulz-Zander, Pfeifer, and Voss (2008), that can recognize and log emotions conveyed by human facial expressions while the subject is carrying out an information processing task, and film analysis software (Anderson & O'Connor, 2009) that can process and automatically label frames and transition sequences according to changes in color balance and other attributes. Nonintrusive brain-scanning equipment can now record brain wave data as well as images at the same time as various types of learning and performance activities are taking place. One can envision the day when self-report data, which Cattell (1950) has pointed out is typically observation data where the observer is oneself, is routinely triangulated with brain activity data and eye tracker data, as one example. This process might be called concurrent validation by quantitative researchers, but it would also be consistent with triangulation techniques commonly advocated by qualitative researchers (Tashakkori & Teddlie, 2010). Some analysis techniques and tools that could potentially be employed to analyze traditional paper-based survey data as well as multichannel, time synchronized participant responses, are presented in the following sections.

Tools for Data Analysis

A major criterion for selecting an appropriate tool is consideration of the goal or purpose toward which the tool will be applied. Three common purposes for employing quantitative data analysis tools are described here:

Exploratory Data Analysis encompasses *Descriptive Statistics*, the typical goal of which is to use a small number of indices (mean, standard deviation for example) to represent a larger set of numbers, and *Data Mining*, where the researcher typically examines large data sets with many variables, in order to uncover summarizing trends. Some of the most elementary quantitative tools, and some of the most complex tools described in this chapter are for exploratory data analysis. Detailed coverage of data mining, which often also includes visualization techniques, is reserved for the third major section of this chapter.

Hypothesis Testing is another type of goal toward which tools for quantitative analysis are commonly applied. In these techniques, the data set at hand is assumed to be a *sample* drawn from a larger *population*, and findings from analysis of the sample(s) are used to infer conclusions to be applied to the population as a whole. Quantitative analysis tools applied to hypothesis testing commonly contrast the distributions of scores around two or more means (*t*-test, analysis of variance), compute the strength of association between two or more continuous variables (correlation, regression); or count the frequency of occurrence of instances, or perhaps the rank order of entities, without making assumptions about the underlying distributions. The latter branch of *distribution free statistics*, which is also called *nonparametric statistics*, can also form a basis for drawing inferential conclusions. Two commonly used statistical analysis packages described later in this chapter (SPSS and SAS) offer comprehensive data analysis tools for hypothesis testing.

Spreadsheet and Relational Database Packages

Many application tools not created for quantitative data research have become sufficiently powerful to be used for that today. Applications vary from score reversals, to computing means and standard deviations, to aligning pretest with post-test scores, to adding regression lines to graphs and much more. Two common tools, spreadsheet packages and relational database packages, are described in this section.

Spreadsheet Packages

Spreadsheet packages such as Excel are commonly used by quantitative researchers for manual data entry from paper forms, or for intermediate processing/cleaning between the online data collection system and the statistical analysis package. These can also be used for data processing. One simple example is the computation of means and standard deviations, as well as frequency counts for variables in a data set. Variables are usually represented by columns in a spreadsheet program, and cases are represented by rows, so anchoring one's cursor on a cell below a column of data for a given variable allows a researcher to evoke functions such as =AVERAGE(b2:b32), =STDEV(b2:b32), or =COUNT (b2:b32) to compute basic descriptive statistics. These cell-based functions can then be dragged across a row to produce the same sample statistics for multiple variables. If the sort function has been used to divide the data set on a variable of interest (such as male vs. female) and these computations have been replicated for each sex, then the statistics for each portion can be entered directly into an equation from a text to carry out an independent samples *t*-test, or a researcher can simply search online for a *t*-test calculator such as GraphPad Software (2005). A researcher simply enters the values to produce the *t*-statistic and probability value (significance level) for the differences between the group mean values for the two groups.

Spreadsheet-Based Effect Size Computations

Effect size computations such as Cohen's *d* (Cohen, 1988) are a common use of spreadsheet packages. Reporting effect sizes is now strongly recommended for inclusion in publications by the American Psychological Association (American Psychological Association, 2001; Thompson, 1998), but effect size estimates are not yet produced by default in statistical analysis packages such as SPSS, when an analysis procedure such as an independent samples *t*-test, or a one way ANOVA with two groups (similar to independent samples *t*-test) is run. Cohen's *d* effect sizes (for males vs. females, for example) can be computed directly from the computation example previously provided, if just one additional statistic, the pooled standard deviation, is computed through an =STDEV function. In most existing versions of SPSS, as of 2011, the descriptive statistics option of the procedure *One Way* produces a table containing the mean of group 1, the mean of group 2, and the pooled standard deviation. Simply copying and pasting this output into a spreadsheet allows a researcher to quickly produce an "effect size" additional column in the spreadsheet that specifies a cell location for [(group mean 2) − (group mean 1)]/Pooled standard deviation for groups 1 and 2 combined. This is Cohen's *d*. If the spreadsheet manipulation is too complex, one can also simply take the output from the *Descriptives* option of the procedures *One Way* and enter it directly into an online effect size calculator such as the one provided online free of charge by Becker (1999).

MS Access Pre/Post Pairs Matchup

Relational database packages such as Microsoft Access can be very useful for merging separately gathered data sets (such as pretest and posttest) and producing a data file that contains only those entries common to both. In order to run a paired *t*-test analysis, the separately gathered pretest and posttest files must be merged such that the pretest responses for a given individual are in the same record (on the same line of a text file or spreadsheet) as the posttest responses for the same individual. The ability to conduct a paired *t*-test makes our research more credible.

Special Purpose Resources

Many special purpose resources are currently available online, in book form, and through machine-readable media such as DVDs. These are currently free or available for the price of a typical textbook. Selected examples are described in this section.

t-Test Calculators

An independent samples *t*-test compares the means of two groups. For example, a medical researcher could compare whether systolic blood pressure differs between a treatment and control group, between men and women, or any other two groups (GraphPad Software, 2005). GraphPad is a popular *t*-test calculator that is Web-based and free of charge. A researcher simply enters group 1 and group 2 means, standard deviations, and *n*'s (sample sizes), then the calculator produces a *t* statistic with degrees of freedom and two-tailed probability (level of significance). If a one-tailed (directional) hypothesis is being tested using this calculator, the researcher simply divides the computed significance level by two. An example incorporating a *t*-test calculator is included along with effect size calculators, in the following section.

Effect Size Calculators

As described in the section of this chapter devoted to spreadsheet applications, one common measure of effect size (magnitude or practical significance for an intervention) is Cohen's *d*. Cohen (1988) provided the following guidelines for interpreting the magnitude of *d*: 0.2 = small, 0.5 = moderate, and 0.8 = large. Additional researchers (Bialo & Sivin-Kachala, 1996; Kulik & Kulik, 1991) have observed that an effect size ≥0.3 is commonly considered educationally meaningful. If a researcher is armed with this basic knowledge, plus group means and standard deviations for two samples such as treatment and control, then entering this information into an online effect size calculator will enable the researcher to obtain an estimate of the magnitude (importance or practical significance) of an observed difference. Becker (1999) provides an online calculator. The format is shown in Fig. 17.1.

An example of the use of an effect size calculator in combination with a *t* test calculator is in order. In the previously cited study of the effects of a technology-based reading program on reading achievement for first and second grade students (Knezek & Christensen, 2008a, b), the Classroom Reading Level Index values for matched-sites first grade treatment and control groups were approximately even at pretest time but the treatment group was observed to be "somewhat" higher at the posttest time period (see Fig. 17.1). The precise values for the pretest and posttest means graphically

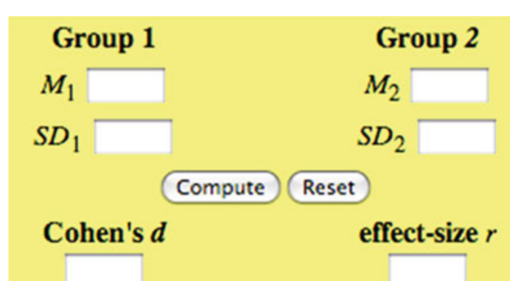

Fig. 17.1 Data entry interface for Becker's online effect size calculator

Table 17.2 Descriptive statistics for first grade pretest–posttest Classroom Reading Level Index

	Pretest			Posttest		
	Mean	St. Dev.	*N*	Mean	St. Dev.	*N*
Treatment	0.768	0.339	123	2.09	0.226	123 (6 schools, 11 classrooms)
Control	0.778	0.386	101	1.76	0.216	101 (7 schools, 13 classrooms)

displayed in Fig. 17.1 are provided in Table 17.2. If one enters the pretest means, standard deviations, and sample sizes into the t test calculator listed in the previous section, the resulting t value is =0.21 with 222 degrees of freedom, $p=0.84$ (NS). This indicates the small difference in means shown in the graph of Fig. 17.1 were very likely due to chance. The effect size resulting from entering mean and standard deviation values into Becker's effect size calculator is ES=0.03, which is extremely small according the guidelines set by Cohen (1988). We judge there is no credible evidence that treatment versus the randomly assigned controls were different at pretest time, and therefore we are justified in analyzing the outcomes of this experiment as a simple posttest only design (Campbell & Stanley, 1963).

For the analysis of posttest data, relevant values for the two groups are: treatment group posttest mean=2.09 (Std.=0.226) for $n=123$ first grade students from 11 classrooms in 6 schools; control group posttest mean=1.76 (Std.=0.216) for $n=101$ first grade students from 13 classrooms in 7 schools. If a researcher enters these values into a t-test calculator, the resulting value is $t=2.69$ with 11 degrees of freedom, two-tailed $p=0.02$, based on the most conservative perspective where each school is considered the proper unit of analysis. From a slightly different perspective, the result based on the assumption that each classroom is the proper unit of analysis yields $t=3.65$ with 22 degrees of freedom, $p=0.001$. As a third perspective, if the researcher believes that the schools and classrooms are just sampling units, and the individual student is the proper unit of analysis, then $t=11.09$ with 222 degrees of freedom, and $p<0.0001$. All three of these views indicate significance at the $p<0.05$ level reported in publications about this study (Knezek & Christensen, 2008a, b), with the more conservative interpretations generally consistent with the visual analysis guidelines based on Cumming (2003) for Fig. 17.1. Entering mean and standard deviation values into an effect size calculator such as Becker's produces an approximate Cohen's $d=1.49$. This would be considered a large effect (Cohen, 1988) and provides assurance that the intervention was educationally meaningful, well beyond the ES>0.3 cutoff published by Bialo and Sivin-Kachala (1996).

Which level of significance is correct? After considering the three alternatives, Knezek and Christensen (2008a, 2008b) elected to report the most conservative ($p<0.05$) interpretation in the refereed journal article about this study. Researchers often face these practical decision points with respect to which outcome(s) to report. Having a visual interpretation such as is presented in Fig. 17.1, can help a scholar decide.[1]

CRC Standard Mathematical Tables and Formulae

CRC Standard Mathematical Tables and Formulae, released in its 31st edition in 2003, continues to be among the most accessed and respected scientific references of its type in the world (Zwilliger, 2003). CRC originally stood for "Chemical Rubber Company." As late as the 1962–1963 the CRC *Handbook* (3,604 pages), which is the original reason for the CRC book of tables, contained a myriad of information for every branch of science and engineering plus useful information for less technical disciplines. Later editions of the *CRC Handbook* focused almost exclusively on chemistry and physics topics and eliminated much of the more "common" information. However, many of the tables in the companion *CRC Standard Mathematical Tables and Formulae*, such as those for the cumulative binomial distribution (for nonparametric sign tests) and Poisson distributions (for large sample, rare occurrence events), are appropriate for calculating the probabilities of numerous psychological outcomes.

An example of the use of the *CRC Standard Mathematical Tables and* Formulae book is provided here. Knezek and Christensen (2008a, 2008b) were concerned that the previously reported analysis of the impact of a technology-based reading program for first and second grade students might suffer from inflated probability levels. They conjectured that this could have been due to the assignment of the weighted mean for the class to every student in the class (Knezek & Christensen, 2002). A nonparametric binomial (sign) test conducted on the 21 first grade treatment classrooms in the data set (Dunn-Rankin, Knezek, Wallace, & Zhang, 2004; Gibbons, 1976), using the average whole class reading level indicator gain of 0.94 for the eight control classrooms in the complete data set as the standard for indicating positive (+) or negative (−) gains in treatment classrooms, resulted in 16 treatment classrooms with reading achievement gains greater than the average gain for the control group classrooms, and 5 treatment classrooms with reading achievement gains smaller than the average gain for the controls. The tabled probability of 16 or more treatment classrooms of 21 total having reading

[1] Note that multilevel analysis could also be used for detailed examination of this type of research question, and for separating out effects at different levels of a multilevel design. However, other issues such as having sufficient degrees of freedom to develop robust solutions also enter with multilevel designs. One practical consideration is the lack of broad-scale researcher access to multilevel analysis software, as of 2011. Multilevel approaches such as Hierarchical Linear Modeling (HLM) (Roberts & Herrington, 2005) are destined to gain in popularity in the coming years.

achievement gains greater than the average for the control group classrooms is $p < 0.014$ (Zwilliger, 2003). This reaffirmed that the gains were not likely due to chance.

Online Binomial (Sign) Test

GraphPad Software (2005) provides free access to a convenient, Web-based binomial test calculator that can produce approximately the $p < 0.014$ result of the previous paragraph, in short order. A researcher enters the "number of successes" (16), followed by the "number of trials" (21) and the "probability of success on each trial" (0.5). In this case the precise resulting one-tail p value = 0.0133.

A binomial test can often be completed from the table-reported data included in a publication. GraphPad reports that a researcher should use the binomial test when there are only two possible outcomes. The researcher should know how many of each kind of outcome (traditionally called "success" and "failure") occurred in an experiment. Also one should have a hypothesis regarding the true overall probability of "success." The binomial test answers this question: If the true probability of "success" is what your theory predicts, then how likely is it to find results that deviate as far, or further, from the prediction. The sign test is a special case of the binomial case where the theory is that the two outcomes have equal probabilities (GraphPad Software, 2005).

Standard Statistical Packages

SPSS (Statistical Package for the Social Sciences)

SPSS was created in 1968 by Norman H. Nie, C. Hadlai Hull, and Dale H. Bent in order to computerize the process of turning data into useful information. SPSS is one of the most widely used programs for statistical analysis and was acquired by IBM in 2010. Newer versions contain a spreadsheet-like interface for data entry and manipulation, plus a point-and-click approach to most analysis procedures. SPSS also has a provision to execute programming language-like commands, the latter of which were the only interface in the earlier versions of SPSS (SPSS, 2010).

Statistics included in the base software package include:

- Descriptive statistics: Cross tabulation, Frequencies, Descriptives, Exploratory Procedures.
- Bivariate statistics: Means, *t*-tests, ANOVA, Correlations, Nonparametric tests.
- Predicting outcomes: Linear regression, Discriminant analysis.
- Dimension reduction: Factor analysis, cluster analysis, multidimensional scaling.
- Scale consistencies: Cronbach's alpha and others.

The graphical user interface has two views that allow the user to toggle between the "data view" and "variable view." It can read data from American Standard Code for Information Interchange (ASCII) test files, spreadsheets and other formats. Output by default is in a proprietary .spv format, but it can be exported to Microsoft Word or captured as a graphic image. It is the experience of the authors that SPSS is often the favorite of applied quantitative researchers (for example, social scientists) and those who infrequently carry out analyses. It is known for extensive documentation containing comprehensible descriptions of analysis routines. Versions of SPSS produced near the end of the first decade of the 21st century were called PASW.

SAS

SAS (originally Statistical Analysis System) began at North Carolina State University as a project to analyze agricultural research but has evolved into an integrated package of analyses tools (SAS, 2011). SAS was originally conceived by Anthony J. Barr in 1966. It provides the following features for the data analyst:

- Data entry, retrieval, management, and mining
- Report writing and graphics
- Statistical analysis
- Business planning, forecasting, and decision support
- Operations research and project management
- Quality improvement
- Applications development
- Data warehousing (extraction, transformation, loading)
- Platform independence and remote computing

SAS normally operates in a command file structure, with sequences of operations performed on data stored as tables. SAS programs have three major parts:

1. The Data definition step
2. Procedure step(s)
3. Macro language manipulations

Graphical user interfaces to aid nonprogrammers exist for SAS, but these are often just a front-end that facilitates the generation of command file-type programs. SAS components are intended to be accessed via application programming interfaces, in the form of statements and procedures. SAS is known for its statistical precision and matrix manipulation. In the opinion of the authors, SAS is often the favorite of those who teach multivariate data analysis.

Other Statistical Packages

There are dozens of other statistical packages available for general and specific analyses. We include just one example that is becoming widely used in university environments.

The R Project for Statistical Computing

R is a free software environment for statistical computing and graphics (Ihaka & Gentleman, 1996). It compiles and runs on a wide variety of Unix platforms, Windows and MacOS.

R is a language and environment for statistical computing and graphics that was developed at Bell Laboratories. R provides a wide variety of statistical and display routines, including linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, clustering, and graphical techniques. One of R's strengths is the ease with which well-designed publication-quality plots can be produced, including mathematical symbols and formulae where needed. R is available as Free Software in source code form (The R Project for Statistical Computing, 2011).

R is an integrated suite of software facilities for data manipulation, calculation and graphical display. It includes:

- An effective data handling and storage facility.
- A suite of operators for calculations on arrays, in particular matrices.
- A large, coherent, integrated collection of intermediate tools for data analysis.
- Graphical facilities for data analysis and display either on-screen or on hardcopy.
- A well-developed, simple, and effective programming language which includes conditionals, loops, user-defined recursive functions and input and output facilities.

R allows users to add additional functionality by defining new functions. Advanced users can also write C code to manipulate R objects directly. R has its own documentation format.

LISREL

LISREL is an acronym for linear structural relations. It was developed by Karl Joreskog and Dag Sorbom in the 1970s at the Educational Testing Service in Princeton, New Jersey (Joreskog & Van Thillo, 1972). LISREL is mainly syntax-based, although recent versions have featured a graphical user interface (GUI).

A common use for LISREL is confirmatory factor analysis, an accepted means of verifying construct validity for a psychometric instrument. LISREL is also used for structural equation modeling, combining the measurement model with the structural model. With this approach, the impact of one or more construct(s) on another can be tested while also testing the extent to which the measurement scales completed by the participants represent the constructs for which they were intended. In brief, researchers can empirically assess their theories formulated as theoretical models for observed and latent (unobservable) variables. If data are collected for the observed variables of the theoretical model, the LISREL program can be used to fit the model to the data (Scientific Software International, Inc., 2011).

Morales (2007) used LISREL to confirm that more than 90% of the variance in classroom technology integration could be explained by a linear combination of a teacher's attitude or *Will*, technology proficiency or *Skill*, and access to technology *Tools*. This was found to be true for a cross-cultural sampling of teachers from Mexico ($n=978$) and Texas in the USA ($n=932$). The structural equation modeling (SEM) approach he employed involved two models (see Fig. 17.2). The first is the structural model, which consists of the latent variables Will, Skill, Tool, and Integration, and the arrows indicating the direction of the influence, i.e., Will, Skill, and Tool are the independent latent variables, influencing the latent dependent variable Integration. The second model is the measurement model, which consists of the indicators, or the measures of the latent variables, and the regression paths that connect each latent variable with their respective set of measures. Generally data from large numbers of subjects, with each subject completing multiple measures, are required to achieve satisfactory fit with this powerful quantitative data analysis technique. Shumacker and Lomax (2004) provide an overview of SEM for a quantitative researcher.

Amos

Amos is a package that works with SPSS and has functionality similar to LISREL. Amos is well respected for its ability to graphically represent the measurement and structural components of a structural equation model. R and S-Plus are also emerging as widely used packages for SEM.

Tools for Exploring Relationships in Data and Visualizing Results

Data mining, scaling methods, and visualization/display techniques have made great advances in recent decades as quantitative analysis tools. Applications of these tools are commonly intermixed in 21st century research studies, and often bridge the gap in the spirit of mixed methods research (Onwuegbuzie & Teddlie, 2003) toward quantifying and analyzing judgments or observations collected for qualitative studies. Data mining enables a researcher to examine large data sets with many variables for the purpose of uncovering summarizing trends. Scaling methods seek to discover or confirm the dimensionality of a set of data or examine the relationships among subjects producing a set of psychometric data. Visualization/display techniques present findings in intuitively recognizable forms that go far beyond the tables of numbers that have been the historical mainstay for quantitative data analysis tools. While tabular output is still available and required for publication precision, most findings determined through tools described in this chapter can be represented visually in the form of a figure. Common quantitative tools such as Excel, and widely used statistical packages such as SPSS, have features which enable straightforward graphical representations of findings. Other tools such as Wolfram Alpha, Mathematica, and MATlab have special capabilities for producing camera-ready graphs. One data visualization tool, Google Fusion Tables, allows users to upload tables and display the data in many alternative forms, including maps,

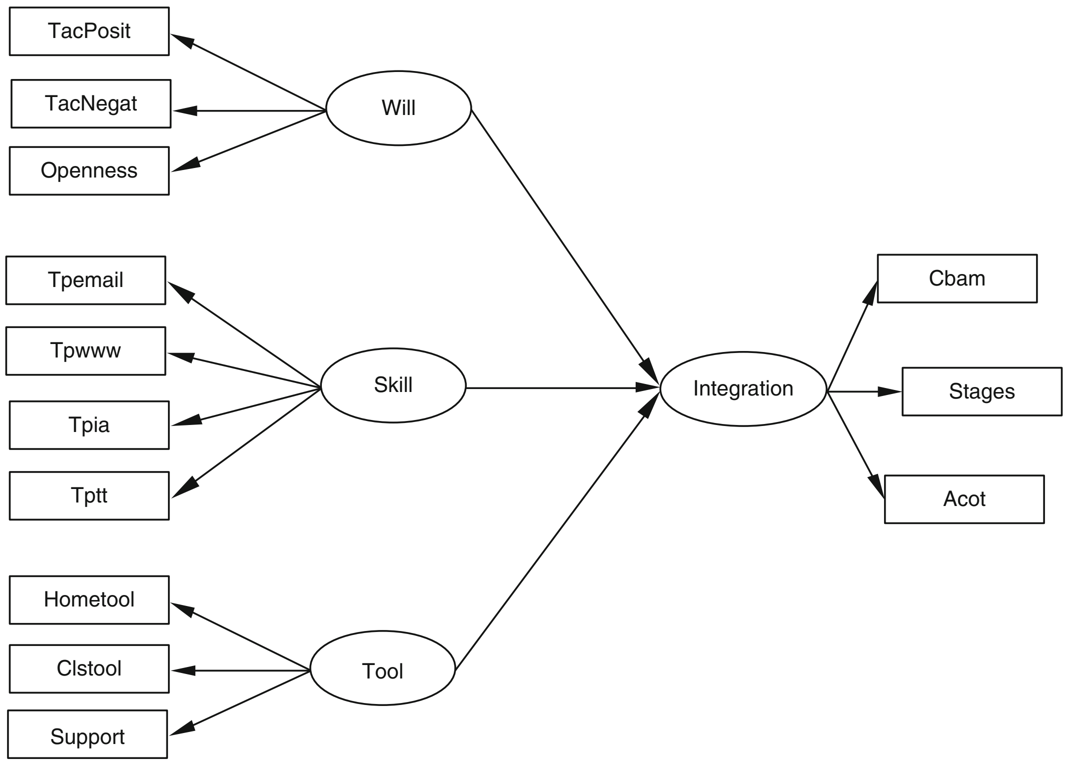

Fig. 17.2 The structural Will, Skill, Tool Model of Technology Integration (WiSTTI Model), with standard measures for each latent variable (Morales, 2007)

intensity maps, motion charts, timelines, and storylines. Some advanced data analysis routines can produce graphical representations of hierarchical associations and underlying dimensional structures, while others can display causal (path) relations or combined measurement and construct relationships (such as structural equation modeling packages). Quantitative tools for scaling methods can often produce displays in the form of associational dendrograms or hyperspace projections of the distances in psychological space between objects. Several examples presented in this section feature data visualization.

The most common purpose for each tool introduced in this section is described within the context of the explanation of its use. Explanations proceed from simple applications, typically useful for alternative presentations of previously produced findings, to more complex analyses that involve data exploration or computations of relationships combined with graphical display.

Spreadsheet Charting

Spreadsheet packages are often useful for producing customized displays of characteristics of data, and the learning curve is often much less ominous than for many graphics display packages. For example, visual representations of mean values and 95% confidence intervals around group means, comparing pre to post, can be produced using the Hi-Lo-Close chart option in Excel. Simply enter upper 95% confidence limit value, lower 95% confidence limit value, and mean value in the slots specified for Hi-Lo-Close. The display is precisely what statisticians such as Cumming (2003) might use to augment or replace arbitrary *p*-level cutoffs to accept/reject null hypotheses, as the field considers moving to what many theoretical statisticians see as the next logical stage beyond routinely reporting effect sizes, on towards using confidence intervals for effect sizes as the primary indicator of the importance (magnitude) of an intervention or a priori effect. As an example, as shown in Fig. 17.3, a cursory glance at the pretest classroom reading level index scores for the control group of first graders reveals that it appears to not be extensively different from the treatment group at pretest time. However, at the posttest time, the treatment group (bottom left display) appears to be a bit higher than the control group (top right display). Cumming has pointed out that since the square box in the middle of each figure element represents the group mean value, while the upper and lower bars surrounding it represent the upper and lower 95% confidence intervals, then greater separation of treatment and control figure elements typically equates to more highly significant *p* levels. A more detailed explanation of the phenomenon is explained in the Effect Size portion of the Hypothesis Testing section of this chapter.

Statistical Package Visualization

Packages such as SPSS contain modules to produce output allowing the researcher to visually explore the variation of the data for particular variables (QI Macros, n.d.). Box plots like those shown in Fig. 17.4 graphically illustrate the median or middle score (Quartile 2) value rather than the geometric mean (average score) illustrated in Fig. 17.3. Whiskers on a box plot typically represent the upper and lower boundaries of the range of the data. Box plots and confidence interval graphs complement each other.

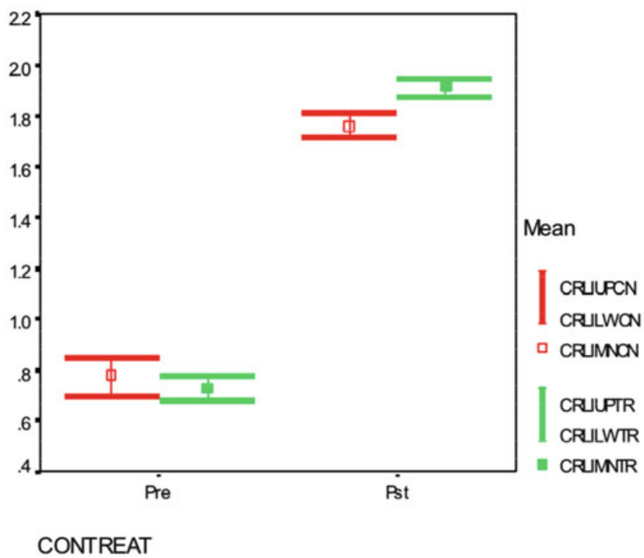

Fig. 17.3 Comparisons between control (*red*) and treatment groups (*green*) on first grade classroom reading level index using Cummings' Confidence Interval Analysis (Knezek & Christensen, 2002, 2008a, 2008b). Note: *CRLI* Classroom Reading Level Index, *CRLICN* control group, *CRLITR* treatment group

Online Aids for Visualization

Wolfram Alpha

Wolfram Alpha is a computational knowledge engine built on Mathematica (Wolfram Alpha, 2011). It is an online service that answers factual queries directly by computing the answer from structured data and often provides a visual display of data. Wolfram Alpha will compute whatever it can from any information put into the search box. For example, "How old was George Washington in 1776?" Or if you just input "George," it displays a graph of the age distribution of the name George as well as many other computations of the name George. Figure 17.5 illustrates the output produced from the query, "How old was George Washington in 1776?"

MATLAB®

MATLAB® (The MathWorks, Inc., 2011) is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. Using the MATLAB product, you can solve technical computing problems faster than with traditional programming languages, such as C, C++, and Fortran.

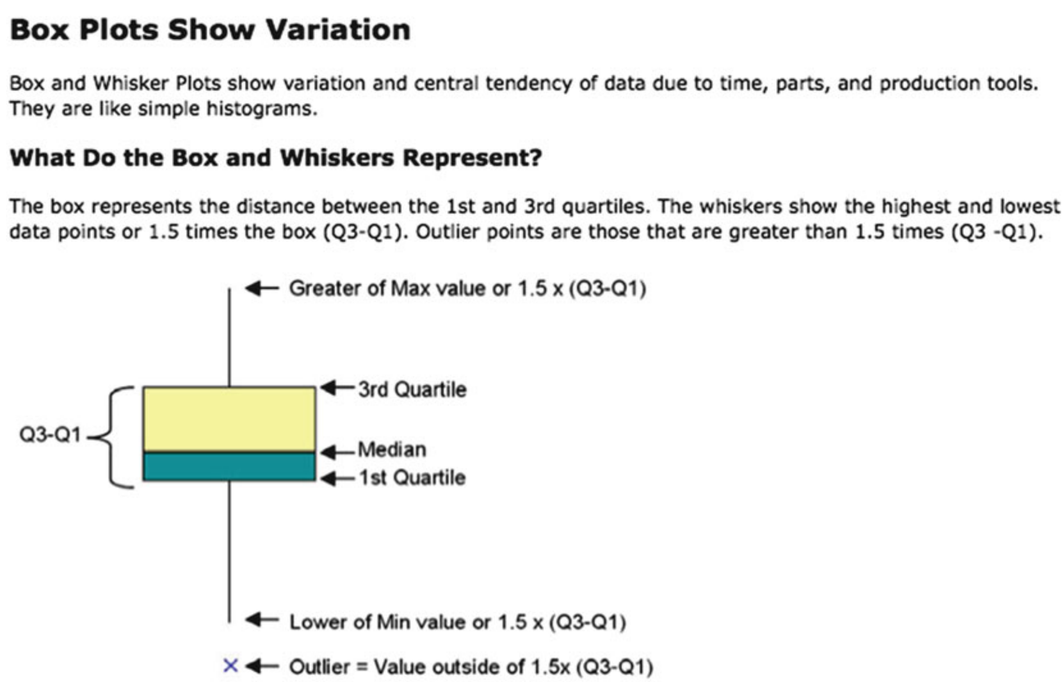

Fig. 17.4 Box plot illustration of variation around median value of a variable

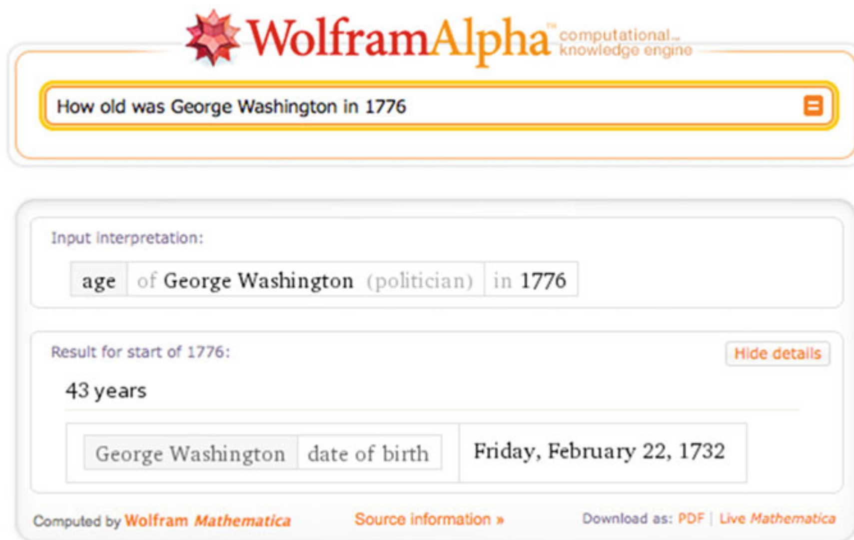

Fig. 17.5 Output resulting from entry of "How old was George Washington in 1776"

Mathematica

Mathematica is an algebra and symbolic math package whereas MATLAB is predominately a numerical computation package. Generally a researcher would use Matlab if wanting to be able to manipulate great quantities of numerical data easily, while a scholar would use mathematica if wanting an aid for symbolic mathematical manipulations. Engineers might find Matlab more useful than Mathematica, while mathematicians might prefer the opposite (Physics Forums, 2007).

Eureqa

Eureqa (pronounced "eureka") is a software tool for detecting equations and hidden mathematical relationships in a data set. Its goal is to identify the simplest mathematical formulas that could describe the underlying mechanisms producing the data. Eureqa is free to download and use (Schmidt & Lipson, 2009).

Eureqa has been used with some success for a form of data mining—to examine data sets with large numbers of measurement points, in an attempt to uncover relationships among variables. This fits well within the overarching definition of data mining as "the nontrivial extraction of implicit, previously unknown, and potentially useful knowledge from data" (Frawley, Piatetsky-Shapiro, & Matheus, 1992 as cited in Wang & Wang, 2009). The following example is provided by Gibson (Gonzalez-Sanchez et al., 2011).

Figure 17.6 is the result of a Eureqa analysis of data from a 7.5 seconds moment in time when a girl who was playing Guitar Hero gets highly frustrated. Eureqa was used to model the activity. All available variables were included in the analysis. The primary dependent variable of interest for the first equation was "Engagement/Boredom." For the second equation the dependent variable was "AF3" which is an EEG lead on the head on the frontal cortex. The assumption setting used was "modulo" math due to the conjectured cyclical nature of the activity. As shown in Fig. 17.6, the model of Engagement in the first equation goes down rapidly to Boredom over just 7.5 seconds, and during the same time frustration becomes high. The resulting equation explains 98% of the variance.

The second equation uses the same approach to attempt to uncover an explanation for AF3. This was initiated due to researcher curiosity about how AF3 might affect decision-making and motor output. Once the equation models get complex enough (they are simple at the bottom to the left and more complex to the right) then Engagement/Boredom shows up! This explains about 96% of AF3. These sorts of models could be used to fine tune classroom teaching/learning simulators such as simSchool (Gibson, 2009; Gonzalez-Sanchez et al., 2011).

Scaling Methods

Scaling methods are concerned with assigning numbers and visualizing relations among things we do not know how to measure. Scaling is a branch of measurement that associates qualitative constructs with quantitative metric units (Trochim, 2006). Scaling methods are generally divided into two broad categories: unidimensional and multidimensional. The unidimensional scaling methods were developed in the first half of the twentieth century and are generally named after their inventor. Three types of unidimensional scaling methods are:

- Thurstone or Equal-Appearing Interval Scaling
- Likert or "Summative" Scaling
- Guttman or "Cumulative" Scaling

In the late 1950s and early 1960s, measurement theorists developed more advanced techniques for creating

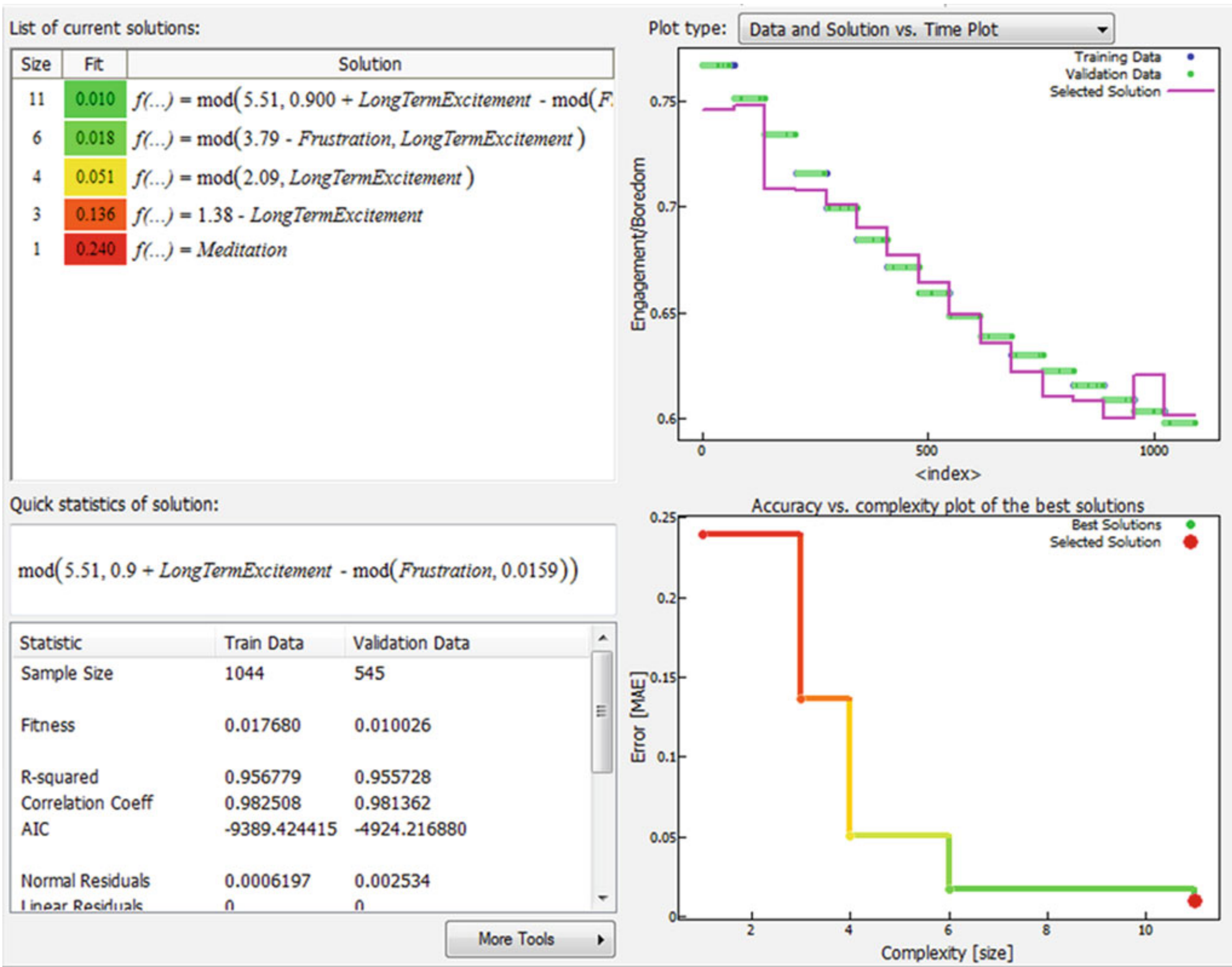

Fig. 17.6 Eureqa output for analysis of engagement/boredom relationship to electroencephalic (EEG) brain activity while playing Guitar Hero

multidimensional scales (Trochim, 2006). Common examples of these include the following:

- Hierarchical Cluster analysis
- Multidimensional scaling
- Multidimensional preference mapping (Dunn-Rankin, 1983)

Dunn-Rankin (1978) was able to apply multidimensional scaling techniques to identify the most salient visual characteristics of letters of the alphabet, and to put forth evidence that most readers use the features to process letter recognition in an integrative rather than sequential processing manner. As shown in the letter wheel displayed in Fig. 17.7, the two underlying dimensions through which most adult readers classify letters are whether letters are curved versus angular, and whether the letter has ascenders or descenders. These two dimensions allow letters to be placed in a circle similar to a color wheel, illustrating the continuous transitions from one letter to the next as the letters are arranged based on human perception, in a clearly defined wheel.

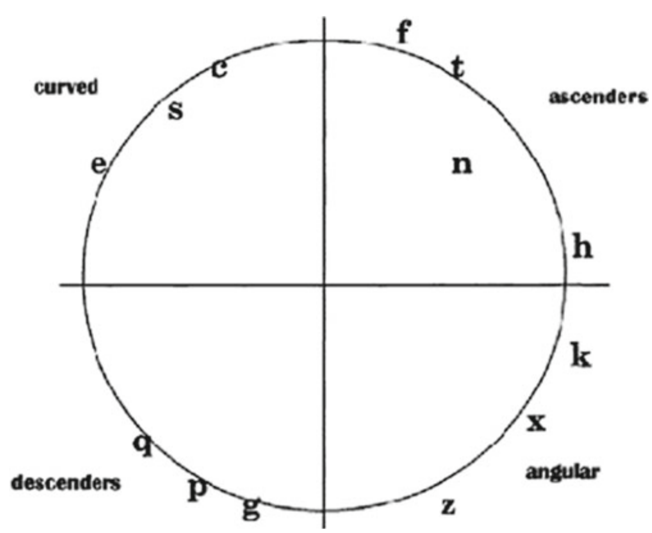

Fig. 17.7 Letter wheel based on multidimensional scaling (ALSCAL) of time latency to respond "same or different" regarding all possible pairs of 13 letters of the English language alphabet (Dunn-Rankin, 1978)

Item	Rank Total	Scale Score
Min	25	0
1	68	86
2	49	48
3	34	18
Max	75	100

```
0    10    20   30   40    50   60   70   80    90  100
+---- +---*+---- +---- +---*+---- +---- +---- +--*-+---- +
        SB-5          SB-4F                 LM
```

Fig. 17.8 Rank-sum scaling analysis of three versions of the Stanford Binet using unidimensional scaling program Ranko (Dunn-Rankin et al., 2004)

Tyler-Wood, Knezek, Christensen, Morales, and Dunn-Rankin (2005) used rank-sum scaling (similar to Guttman Scaling), hierarchical cluster analysis, and multidimensional scaling techniques to examine the measurement characteristics of three versions of the Stanford Binet IQ test. Based on the administration of three versions of the Stanford Binet (SB_LM, SB4, and SB5) in randomized order, to 25 subjects aged 8–14 who had been referred by parents, teachers, and school personnel as gifted, and who were further screened by scoring at the level of 118 or higher on at least one version of the test administered by the research personnel, findings were that the test versions performed differently for students in three categories of giftedness. As shown in Fig. 17.8, a rank-sum (Dunn-Rankin, 1983), unidimensional analysis of the versions of the exam based on scores by the 25 individuals, produced results very similar to a multidimensional scaling analysis (Proxscal) (Dunn-Rankin et al., 2004; SPSS, 2010) of the exam versions, using interval data assumptions and specifying one dimension (see Fig. 17.9). Ninety-nine percent (99%) of the dispersion in among the subjects in their Stanford Binet test scores was accounted for by a unidimensional solution (Tyler-Wood et al., 2005).

As shown in Fig. 17.10, a Hierarchical Cluster Analysis of the subjects, based on their exam scores for the three versions of the Stanford Binet, yielded three apparent clusters.

Further examination of the centroid (median) scores for each test version within each cluster of subjects, revealed the characteristics of each of the clustered subject groups. As shown in Fig. 17.11, Cluster III is a group of subjects that generally have high abilities, well above the norm of IQ 100, but it matters little on which of three versions of the Stanford Binet they are tested. The scores are consistent across the three versions of the exam for this group. Cluster II contains a group of subjects with exceptional IQ, as indicated by the cluster centroids in the range of 130. However, the pattern of the responses across the three Stanford Binet versions is similar to Cluster III. Cluster II subjects perform on the tests like Cluster III subjects, except that the IQ of the subjects in Cluster II is higher. Cluster I subjects might be considered truly gifted, as indicated by a group centroid in the range of

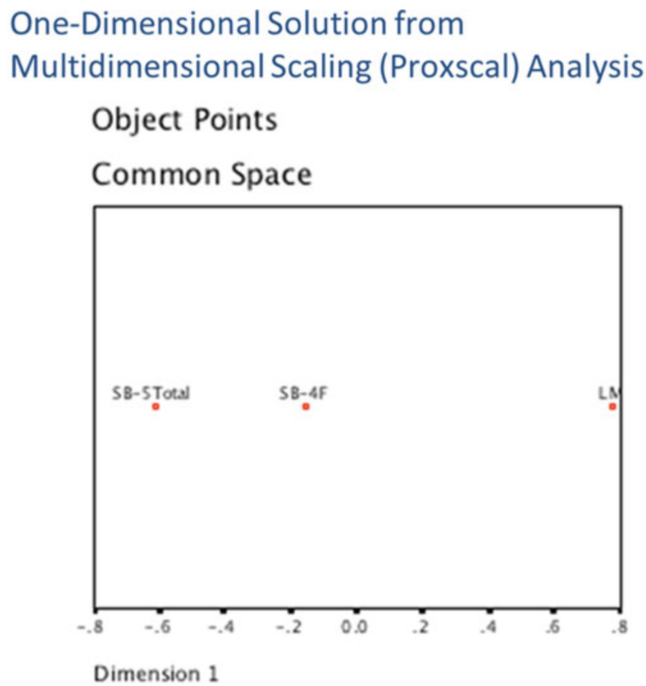

Fig. 17.9 Multidimensional scaling analysis of three versions of the Stanford Binet, using interval data assumptions and specifying one dimension in SPSS Proxscal procedure

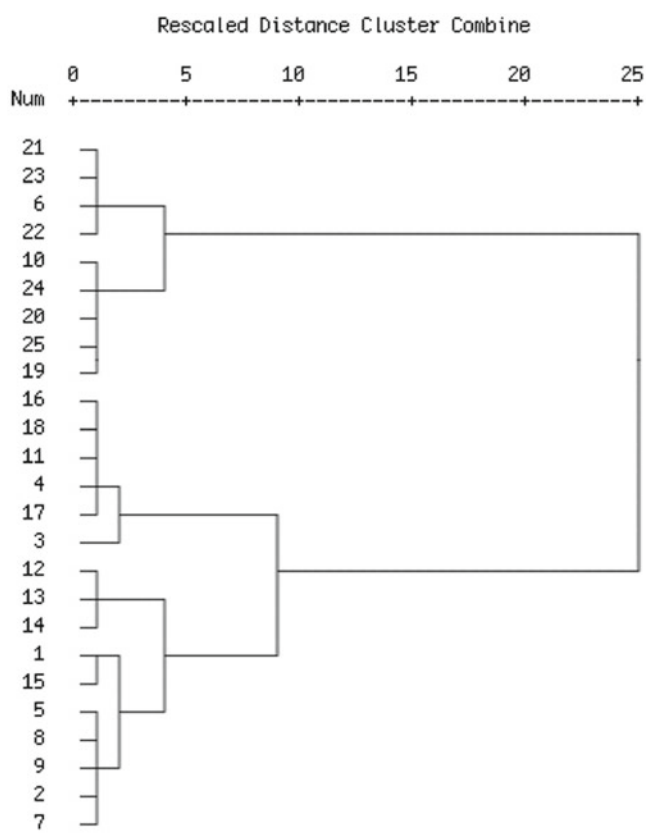

Fig. 17.10 Hierarchical cluster analysis of 25 subjects based scores for three versions of the Stanford Binet IQ test

140 or higher. Their pattern of scoring across the three versions of the Stanford Binet is quite different from the patterns found in Cluster II and Cluster III. For truly gifted subjects, it appears that SB4 (released 1986) and SB5 (released 1998) do not allow them to demonstrate their giftedness as well as the older and more lengthy Stanford Binet Version LM released in 1972.

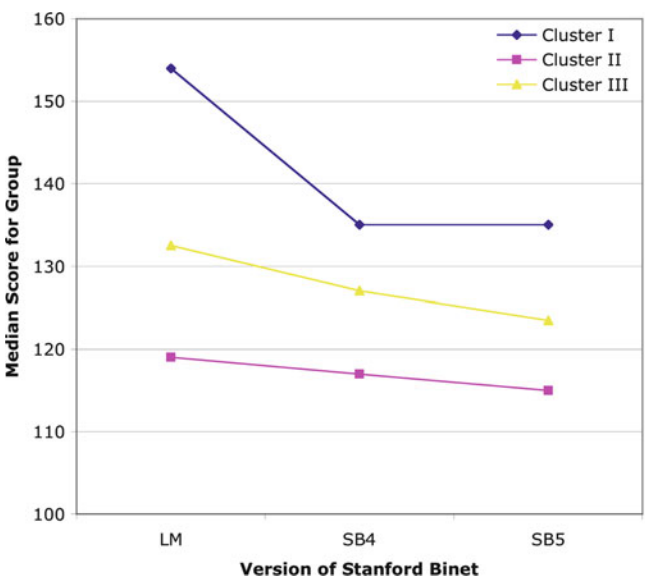

Fig. 17.11 Median score for groups on different versions of the Stanford Binet

Other relationships can be discerned by placing the subjects in the same space as the objects, based on subject preference or affinity for an object. Multidimensional preference mapping (MDPREF) (Dunn-Rankin et al., 2004) can perform this type of analysis. As shown in Fig. 17.12, subjects 5, 11, 19 and 20 have an affinity for the LM version of the Stanford Binet IQ test, while subjects 2, 14, and 16 have a preference for the Stanford Binet version 4. No subjects appear to have a strong affinity with the Stanford Binet Version 5, but many (such as 3, 12 and 13) appear to have an aversion to version 5.

In summary, based on this multiple-perspective scaling analysis of the 1972, 1986, and 1998 versions of the Stanford Binet IQ test, Tyler-Wood et al. (2005) concluded: (a) for above-average IQ subjects in the age bracket of 8–14 years, it matters little which version of the Stanford–Binet IQ test is used to test a subject; but (b) the SB5 (1998) appears to be the least sensitive to true giftedness, followed by the SB4 (1986); and (c) the LM version (1972) is strongly recommended for its ability to register exceptional ability,

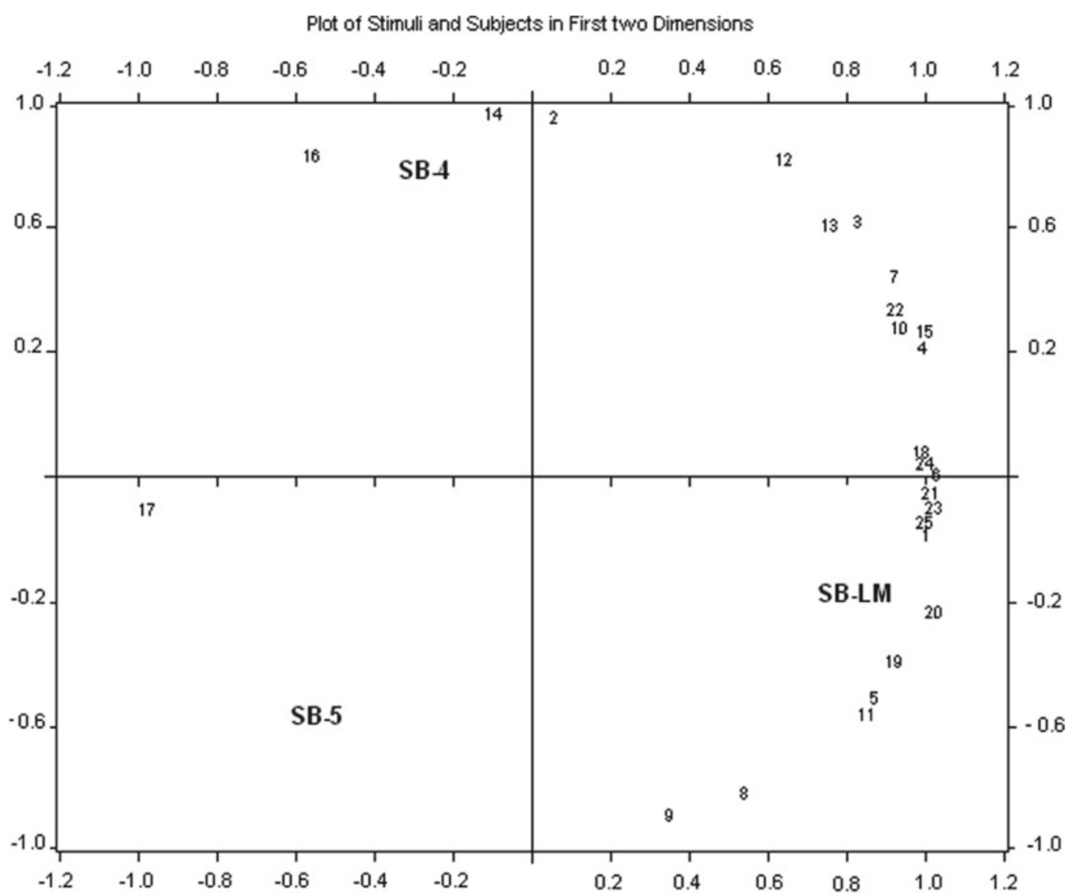

Fig. 17.12 Stanford Binet version affinity by subjects based on MDPREF (Dunn-Rankin et al., 2004)

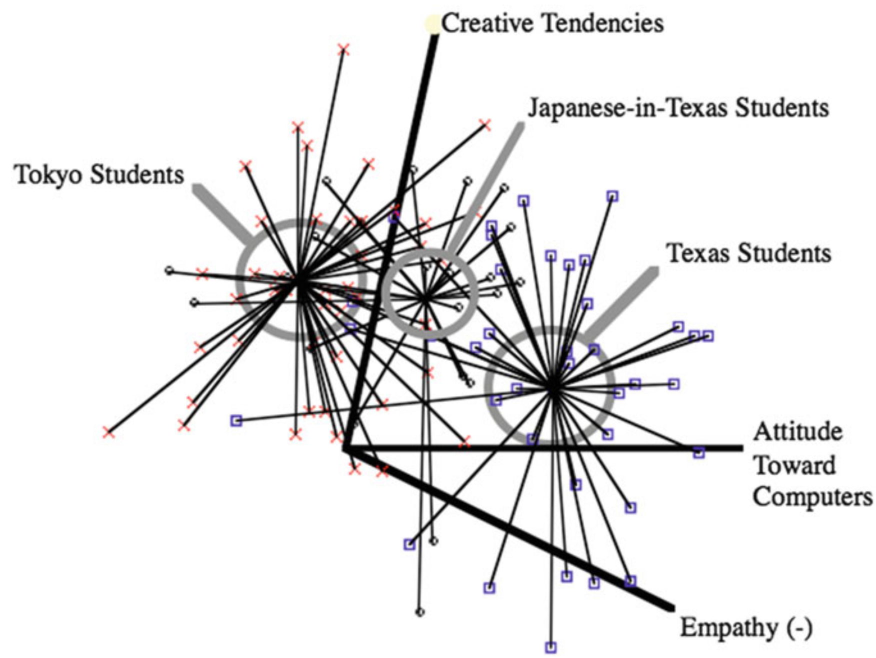

Fig. 17.13 Centroids in three-dimensional space of Attitude Toward Computers, Creative Tendencies and Empathy for first- and second-grade Japanese students living in Japan, Japanese students living in Texas, USA, and Texas students living in Texas

whenever true giftedness is indicated by another credible source (Tyler-Wood et al., 2005).

Many other scaling techniques are available to the researcher to explain and describe as well as explore relationships among psychological objects whose measurement characteristics have not been well defined. Note that these often employ visualization techniques—producing a graph or a picture—for the relationships the researcher wishes to explore. Many of these trace their origins to researchers at the Bell Telephone Laboratories in the 1960s and beyond, the same time and place when Unix was being developed.

Other Visualization Techniques

Many tools exist to enable researchers to place a table of data into a visualization package such that the data become coordinates for display in three-dimensional space. MacSpin was an early package that allowed Knezek and Miyashita (1991) to show that attitudes of first and second grade children of Japanese families living in Texas, USA, actually did lie in three-dimensional psychological space (Attitudes Toward Computers, Creative Tendencies, Empathy) "between" the attitudes of Japanese children living in Japan, and non-Japanese children living in Texas, USA (see Fig. 17.13). Kamakura and colleagues (Naik et al., 2008) have more recently developed a macro-based extension to Microsoft Excel that allows the rotation of three-dimensional scatterplots in much the same fashion as MacSpin.

Currently emerging tools such as the WorldWide Telescope Project of the Microsoft Research Laboratories and the Silverlight Data Visualization Tools of the same lab are believed to have great potential for exploring relationships in biological or social science data (Microsoft Research, 2010). As of 2011, the Microsoft Space Telescope project contains approximately 13,000 images of the landscape of Mars, and a night sky view of objects in our solar system, online, and assessable via the Web, to anyone who wants to explore their relationships. These kinds of systems might one day be capable of displaying all of the neural connections in the brain, for example, or be capable of displaying a complete map of the affective, cognitive, and psychomotor components of an individual's psychological space. There are possibilities for giant leaps forward in the foreseeable future.

Summary/Conclusions

Information technology tools for data acquisition, data processing, and the display or representation of results have advanced rapidly over the past 30 years since interactive data processing first became widely available to the university research community. During just the time passed since the beginning of the 21st century:

- Online data acquisition has become the norm, far dominant over paper surveys.
- Sophisticated data analysis packages are expected to run on normal laptop computers like researchers carry for every day manuscript production and library research needs.
- Multicolored, high-resolution 2D and 3D presentations of major findings have become the norm.

- One can envision the day when fully rotational dimensional perspectives and telescopic macro/micro views are also routinely employed to present or discover relationships in the data.

Statistical data analysis systems have simultaneously become user friendly and very comprehensive. Elegant, special purpose routines have become available (often for free) via the Web. The distinction between analysis, modeling, and display tools is beginning to blur as "math packages" are being routinely employed to produce elegant summaries and visual displays of findings from traditional research. There is no end to this renaissance in sight. In this chapter we have presented just a few examples of the alternatives available to a quantitative researcher. We recognize that before this chapter is printed, there will certainly be at the researcher's disposal many more. Thus, it is our hope that the reader will view the tools and examples presented here as exemplars, rather than an exhaustive list. It is our hope that this chapter is used as a springboard for ideas, from which a quantitative researcher can begin to explore.

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Tools for Analyzing Qualitative Data: The History and Relevance of Qualitative Data Analysis Software

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Abstract

The most common question from novices regarding the use of software in qualitative research is "which program should I use?" when they would be better served by asking "what analytical tasks will I be engaged in, and what are the different ways I can leverage technology to do them well?" In this chapter, we first provide an overview of tasks involved in analyzing qualitative data, with a focus on increasingly complex projects, before we turn to the software meant to support these tasks. One genre of software, known as Qualitative Data Analysis Software (QDAS or QDA software), is specifically designed to support qualitative research, as opposed to tools primarily used for the collection of data (such as audio or video recorders), or presentation of findings (such as presentation or modeling software). We briefly review the historical development of QDA software—including associated methodological questions and issues—before identifying the increasingly diverse array of expected features and functions in most of the current software programs. We then summarize the "user experience" literature and subsequently discuss the boundaries between cadres of qualitative researchers who do use software, and those who do not. Finally, we address potential directions as these programs are being influenced by Web 2.0 developments.

Keywords

QDA • QDAS • CAQDAS • Qualitative research methods • Qualitative data analysis software • Web 2.0

Introduction

This chapter focuses on *tools* for supporting the analysis of qualitative data, particularly on software designed for that purpose. The choice of the word "tools" rather than simply "software" in the title of this chapter reflects the role of technology in the context of complex intellectual work. "Tools" is a broad term, which could encompass the broad array of theoretical constructs that fall under the mantle of qualitative research, analytical practices used in conjunction with various theoretical approaches, as well as the wide range of supportive technologies that are increasingly used for this specific kind of knowledge work; these dimensions of the term are interrelated, but not unified. In addition, a variety of technological tools can be used to achieve the same analytic goal, while very different theoretical approaches often involve the same analytical tasks. This complexity leads us to an important point: the most common question from novices regarding the use of software in qualitative research is "which program should I use?" when they would be better served by asking "what analytical tasks will

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I be engaged in, and what are the different ways I can leverage technology to do them well?" As recent research on qualitative data analysis software indicates, the researcher's expertise and methodological choices are more critical than specific software selections in determining the quality of the analysis (di Gregorio, 2011; Friese, 2011; Kuckartz & Sharp, 2011; Wiltshier, 2011). At the same time, all tools carry "affordances" for new capabilities and opportunities (Gibson, 1977; Greeno, 1994; Norman, 1988). Thus, as a group, these tools hold implications for the practice of qualitative research that merit examination.

We first provide an overview of tasks involved in analyzing qualitative data, with a focus on increasingly complex projects, before we turn to the software meant to support those tasks. This genre of software, known as Qualitative Data Analysis Software (QDAS or QDA software), is specifically designed to support qualitative research, as opposed to tools primarily used for the collection of data (such as audio or video recorders), or presentation of findings (such as presentation or modeling software). We briefly review the historical development of QDA software—including associated methodological questions and issues—before identifying the increasingly diverse array of expected features and functions in most of the current programs. We include reviews of thoughtful analyses about how these programs affect the field of qualitative research, particularly those that explore the intersections of tools, methods, and theories. We then summarize "user experience" literature regarding novices and experts in qualitative research as they begin using software, after which we discuss the boundaries between cadres of qualitative research experts who do use software and those who do not. Finally, we address potential directions as these programs are being influenced by Web 2.0/3.0 developments.

Analyzing Qualitative Data

What Is Qualitative Data, and What Is Analysis?

In order to use software for qualitative research, it is important to have an understanding of qualitative research as a starting point. Just as word processing programs support writing but do not magically transform the user into a *good* writer, QDA software programs support qualitative research, but still require knowledge and skill on the part of the user to produce *good* qualitative research.

Qualitative data is often used as an umbrella term for any nonquantitative data. However, the "umbrella" is extensive, covering a broad spectrum of data with diverse attributes. Not all qualitative data are alike. Examples of data *formats* include textual data (such as transcripts from in-depth interviews or excerpts from newspapers), images (photographs and drawings), or other artifacts. Since the 1980s there has been an increase in the use of audio, video and photographic data as well (Dicks, Mason, Coffey, & Atkinson, 2005; Mason & Dicks, 2001; Pink, 2007, 2008; Rich & Patashnick, 2002; Silver & Patashnick, 2011; Woods & Dempster, 2011). New innovations offer new data sources such as Web pages, tweets or geo-location data captured through GPS devices (Fielding & Cisneros-Puebla, 2009; Jung & Elwood, 2010; Ross, Renold, Holland, & Hillman, 2009). These data come in various *types* such as interviews, focus groups, observations, historical documents, and artifacts. What qualitative data have in common is that they have a lot of information within them (hence, the term "rich" is often applied), often with complex relationships within the data. This "richness" and complexity make the management of qualitative data a nuanced and sometimes challenging endeavor.

The terms "small scale" and "large scale" are sometimes used as a shorthand way to signify the overall complexity of a study. However, given the multitude of factors that affect complexity, these commonly used terms can serve as only as an imprecise estimate of overall scope, especially when applied to qualitative data. A study may be deemed "large scale" simply because it has a high number of participants. However, a "small scale" study with a few respondents may actually be more difficult to manage if it examines a topic in great depth. Figure 18.1 organizes selected characteristics of qualitative research studies into multiple continuums that tend to affect the complexity of the qualitative data, data-handling, and analysis. While by no means a complete set of descriptors, these characteristics serve to better identify those aspects pertinent to our discussion about software.

Each line in Fig. 18.1 represents a stand-alone descriptor on a continuum, with the left-hand side generally being less complex and the right-hand side more so. Of course, the data for any study would have multiple facets, some of which will contribute more than others to data-handling challenges. This figure does not provide a full range of considerations; qualitative studies that would fall toward the "simpler" side of the continuums may still be quite complex due to specific analytic procedures or other characteristics beyond the scope of this chapter. However, the characteristics we have identified include some challenges common to many qualitative studies as they become more complex. Note that the model does not place value on the level of complexity in a project, as the important factor in the design is an appropriate match between the research question and the methods used.

Starting from the top and working down, we begin by considering the range of data formats and types. As we have already described, qualitative data comes in a wide variety of formats and from a wide variety of types. Obviously, the similarity or dissimilarity of the data formats and types within a study will affect the ease or difficulty of data management.

Fig. 18.1 A partial list of study characteristics that tend to affect data analysis complexity

LESS COMPLEX	MORE COMPLEX
Homogeneous data formats/types	Heterogeneous data formats/types
Structured data, possibly controlled during collection	Unstructured or open-ended ("messy") data
One person/homogenous group	Multiple people/diverse groups
Single site	Multiple sites
Data collection at one point in time (snapshots)	Data collection over time (Long-term/longitudinal)
Predetermined and linear data collection procedures	Iterative data collection procedures
Collected/analyzed by individual researcher	Collected/analyzed by a team of researchers

Another dimension that affects data-handling is the degree of consistent structure in the data collection protocol. Data collection strategies might be highly structured, such as open-ended questions on a written survey, or quite unstructured, including data that may not be relevant and/or data that is relevant though not immediately apparent.

The scope of the study, whether in terms of range of participants (one group, multiple groups), number of sites, or time span (collected at one or multiple points) also contributes to complexity. Iterative or flexible data-collection procedures, which allow for adjustments as the study progresses, not only result in "messy" data but usually require additional tracking to clarify the conditions under which the data were collected and the rationale behind changes.

Finally, the presence of multiple researchers adds yet another layer of complexity, generally requiring coordination and communication during data collection and analysis. Team members may be working in a highly collaborative fashion, where ongoing communication and ability to modify the team activities are paramount. Or, the members may be "trained" by a principal investigator who needs to monitor the consistency of activities among team members. In either case, in addition to his or her own analytic work, one or more team members have an added responsibility of understanding and reflecting on the role of other members; potentially engaging in additional communication, feedback, benchmarking, and negotiation of roles.

We stress that none of these descriptors should be considered in isolation. For example, open-ended questions on a survey seem as if they would generate a straightforward set of data, highly structured by the questions asked. And that might in fact be the case. However, if these questions were asked of multiple groups at different points in time, the data could still achieve a high level of complexity due to its broad scope. On the other hand, a study limited to a small group at a single point in time could also be quite challenging to manage if it included a broad array of data sources. While these two hypothetical data sets are quite different, they both exhibit a high level of complexity that needs to be considered in the course of data management and analysis, especially when considering the use of QDA software (Barry, 1998; Kaczynski, 2004).

With increased data analysis complexity comes a greater complexity of data management. Being "close to the data" denotes both familiarity with the content and access to the specific bits that are pertinent to the analysis at a given point (Richards, 1998), and each increase in complexity brings additional challenges of being able to remain close to the data. As a dataset becomes more complex, the basic processes of data management quickly exceed the capacity of the human brain to remember specifics and connections. In their detailed discussion of the origin of NUD*IST (now NVivo), Richards and Richards (1994a) provide specific examples of the dilemmas associated with the handling of paper records in an increasingly complex project. They point to these dilemmas as the primary motivation behind their construction of a software program that can handle a complex dataset while retaining the crucial characteristics present when handling data manually (such as the examination of extracted quotations in the original context).

The question "what is analysis?" is just as complex as "what is qualitative data?" Different approaches to qualitative analysis are shaped by the theoretical approaches of the researcher and his or her community of practice, as well as the characteristics of the research context and setting. A full introduction to the rich and varied history of qualitative research methods and methodology is far beyond the scope of this chapter. We refer you to the overview chapter on qualitative research in this handbook as a starting point, as well as standard introductory texts by well-known authors such as Bogdan and Biklen (1982), Denzin and Lincoln (1998a), Lincoln and Guba (1985), and Patton (2002). Texts on specific approaches to qualitative research include grounded theory (Charmaz, 2006; Corbin & Strauss, 2008; Glaser & Strauss, 1967; Strauss & Corbin, 1990), ethnography (Hammersley & Atkinson, 1983; Spradley, 1979), discourse analysis (Potter & Wetherell, 1987; Wodak & Krzyzanowski, 2008), narrative analysis (Reissman, 1993, 2008), phenomenology (Moran, 2000; Moustakas, 1994), and thematic analysis (Lofland & Lofland, 1995).

In the introduction to the first three editions of the *Landscape of Qualitative Research* (1998b, 2003, 2008) Denzin and Lincoln help situate the evolving practices of qualitative research in historical context. The current position of qualitative research in the larger research landscape is also addressed by Salomon (1991), who discusses the "quantitative-qualitative divide," as well as Maxwell (2004) and St. Pierre (2006), both of whom address "scientifically based research." Creswell (2008), Creswell and Plano Clark (2010), and Tashakkori and Teddlie (2010) elaborate on the combination of qualitative and quantitative research in the form of mixed methods.

However, as Fielding and Lee point out, "Different schools of thought have different analytic postures but there are generic analytic techniques that can be taught and that will support work in most analytic traditions" (Fielding, 2005, para. 22). We now turn to some of the common tasks of qualitative analysis, and how they can be supported with QDA software.

Common Analysis Tasks in Qualitative Research

Each particular approach to qualitative analysis has its own procedural stages and recommended practices. However, as a broad generalization, the various approaches to qualitative analysis share some common activities with respect to qualitative data. Davidson and di Gregorio (2011a) report that when Tesch (1990) identifies 46 "brands" of qualitative research, she makes the point that there are not 46 approaches to analysis. Instead, she identifies ten principles[1] that are common across most types of qualitative research. Lofland (1971) wrote one of the few books in the pre-software era that articulates those common tasks involved in managing and analyzing qualitative data. For other early overviews of analysis tasks, see Goetz and LeCompte (1984), Lincoln and Guba (1985), and Pfaffenberger (1988).

More recently, Friese (2012) described a Noticing, Collecting, Thinking (NTC) approach, which serves as an umbrella for a diverse array of qualitative methodologies. Jackson (2013) also cites parallels between the language in mainstream qualitative texts (American Educational Research Association, 2006; Patton, 2002) and the literature produced by QDAS experts (di Gregorio & Davidson, 2008; Richards, 2005; Richards & Morse, 2012). They identify similar elements of the qualitative research process and emphasize the importance of articulating logical connections between different components of the research.

To organize our discussion, we use the four broad activities of the qualitative analysis process as identified by Lewins and Silver (2007) and revised by Davidson and di Gregorio: organizing data, exploring data, interpreting/reflecting on data, and integrating data (Davidson & di Gregorio, 2011a; di Gregorio, 2010b). Note that we agree with the assertion made by Lewins and Silver that these activities are not conducted in a linear sequence; the overall process is iterative, with many rounds and intersections, amid much reflection during the "interrogation" of the data. We also acknowledge an overlap of activities in actual practice, and thus a blurring of the heuristic boundaries between the four general activities and the specific tasks associated with them.

Organizing the data is both a mechanical activity and an analytical one. Data, codes, variables and ideas all need to be organized. Organizing includes grouping the data in meaningful ways, possibly by data type, source, chronology, or other data characteristics. It also includes connecting bits of data that are related to one another in some way, often by means of folders, sets, links or codes. These connections or groupings may be thematic, theory-driven or data-driven. In addition, they may be created "top-down" from an existing

[1] The principles are as follows: (1) Analysis is cyclic—concurrent with data collection. (2) Analysis is systematic and comprehensive but not rigid. (3) Analysis is reflective and results in analytical notes (memos) that guide the process. (4) Data are segmented as we are unable to process large amounts of data all at once but the connection to the whole is maintained. (5) Data segments are categorized according to an organizing system that is mostly derived from the data themselves. (6) The main intellectual tool is comparison. (7) Categories for sorting segments are tentative at the beginning; they remain flexible. (8) There is no one "right" way to manipulate qualitative data during analysis. (9) The procedures are neither "scientific" nor "mechanistic"; qualitative analysis is "intellectual craftsmanship" (Mills, 1959). (10) The result of the analysis is some type of higher-level synthesis. (Tesch, 1990, pp. 95–97).

framework (deductively), "bottom-up" by using the data as a foundation (inductively), through a process of creatively experimenting with the "best fit" (abductively or retroductively), or some combination of these depending on the particular methodology. Organizing the data is an important activity that manages the large amounts of unstructured information and data that a qualitative study generates. It enables the researcher "to see" the data more clearly by assigning it to a flexible framework. It is an activity that is revisited many times during a study—as more data is collected and as more ideas about the data are developed.

Exploring the data includes becoming familiar with the data by initially reading/viewing/listening to data and commenting on it. Later on in the study, exploring can involve searching for content and connections, possibly via retrieving previously coded segments or following links through the data and reviewing comments and memos. Tools in the software can support the examination of relationships between themes, looking at word frequencies and relationships between words, annotating and clarifying the data, or making preliminary comparisons between groups. Exploring is an activity that gives the researcher a solid familiarity with the data. This may lead to reorganizing the material in the light of new discoveries.

Interpreting and reflecting requires thinking and rethinking. Memo writing and drawing diagrams or maps to identify connections support this activity, which may lead to the recognition of patterns and relationships. Software tools now include visualizations that can give the analyst a gestalt of key issues. Reconsidering first impressions, pushing back to look at a more topographical view of the data, and diving back in to a particular quote are examples of tasks that support interpretation and reflection and can lead to more exploration of the data as well as reorganization.

Integrating data involves connecting it to other knowledge, such as other studies, references, or comparisons across groups. It may even involve integrating data *within* the study, such as data or perspectives from different team members. The primary intent of this activity involves seeing the data holistically and in context with other studies. Note that this is not an endpoint; reviewing related literature can lead to revisiting the data to reorganize, reexamine, and revise prior relationships.

Lewins and Silver (2007) offer a diagram of these activities; through a cyclical representation, the diagram expresses their nonlinear and iterative nature. Data needs to be organized, so interesting bits can be retrieved easily and compared and contrasted with other parts of the data, presenting possible patterns for exploration and reflection. Such reflections can lead to a reconceptualization of the data, and perhaps a reorganization to bring to the fore other issues and other patterns in the data, and so on.

QDA software can assist with many of these tasks. Obviously, it provides a means to *organize* and *explore* the data: tracking information about the data (data types and formats, timing of collection, a list of the codes that have been applied to a source, and so forth) and retrieving data according to specifications is what computers do best. Software can also link across data bits, for example, to establish chronology or locate related pieces. These aspects support *interpretation and reflection*. While the software cannot think for a researcher, it can provide access to the data in ways that stimulate new ideas. The computer can track reflections in memos and link them with the data that inspired them. Comparing findings with other researchers (or with literature examined as data) assists with *integration* (Wickham & Woods, 2005).

The specifics of using software to do these sorts of tasks have been addressed by multiple authors, some focusing on only one QDA software program and some comparing and contrasting different programs. di Gregorio (2010b) and Lewins and Silver (2007) offer examples of how various software programs support the four generic analytic activities as outlined above. Maietta (2008) and Evers, Silver, Mruck, and Peeters (2011) also describe software features through the lens of analytical tasks. Regarding the NVivo software, several scholars (Bazeley, 2007; Leech & Onwuegbuzie, 2011; Richards & Morse, 2012) align software tools and functions with particular methodologies and analytic approaches (e.g., ethnography, grounded theory, content analysis, discourse analysis, thematic analysis, domain analysis, and taxonomic analysis).

Of course, all the common tasks of qualitative analysis can be accomplished without the use of software to support them, and historically have been. However, as computers became more common, some qualitative researchers began to recognize their potential for assisting with these analytical tasks. We turn now to the history of development before returning to contemporary descriptions of QDA software and the debates about the influence of software on methods.

A Brief History of Qualitative Data Analysis Software

What Is QDAS?

As early as the 1980s, qualitative researchers began to recognize the potential for computers to assist qualitative researchers. General-purpose use of the "microcomputers" and programs available at the time (Pfaffenberger, 1988) gave way to special-purpose programs specifically designed to support qualitative research. The features and functions available within QDA software have expanded as computer capacity has increased. Early programs have been updated or replaced by later products that offer a wider range of support for the common tasks of qualitative analysis which include organization, exploration, interpretation, and integration.

While some functions (such as coding text and attaching notes or memos) have been present since the earliest days of QDA software, others (such as directly coding audio and video data) are recent innovations that only became practical with advances in computer technology. Thus, defining QDA software purely in terms of its features is problematic, since those features constantly evolve. As a more culturally situated approach, we define QDA software as programs intended to support the tasks of qualitative researchers. That is, programs developed within the culture of qualitative research and specifically designed for the purpose of supporting that research, as opposed to more general tools created to help organize "messy" information such as spreadsheets and word processors.

Initial Explosion of Development

QDA programs began appearing in the early 1980s and were developed independently by university faculty from several countries including Australia, Germany, and the USA. Examples include Thomas Seidel (the Ethnograph), Lyn and Tom Richards (NUD*IST, later NVivo), Udo Kuckartz (MAX, later WinMax, then MAXqda), and Thomas Muhr (ATLAS.ti). For the most part, these developers were themselves qualitative researchers who created the programs primarily to facilitate the analysis of their own qualitative data, some of whom then moved into providing software to other researchers. Initially, these early software developers were working in isolation, not aware of how others were creating similar software (Davidson & di Gregorio, 2011a; Fielding, 2008). In 1989, the first international conference on qualitative computing was organized by the University of Surrey in the UK, and a dialogue was established between developers and early users (Fielding & Lee, 2007). However, because of the developers' independence, they employed a range of programming languages and software architectures.

By 1990, there were so many different programs that Renata Tesch organized her discussion of "qualitative analysis software" (at that time, mostly MS-DOS based) according to their functions and uses. In 1994, The Computer Assisted Qualitative Data AnalysiS (CAQDAS) networking project was founded in the UK, so that interested researchers could learn about software options from a resource without formal financial ties to any developer. The project has been funded by the UK Economic and Social Research Council (ESRC). In 1995, Weitzman and Miles catalogued and compared 24 of these software programs. By the mid 1990s, the term Qualitative Data Analysis software (QDA software) was being used to identify this specific genre of software (Yuen & Richards, 1994). Readers will also find the synonymous acronyms "QDAS" and "CAQDAS"[2] in the literature.

Initial programs were limited by the computer capabilities of the time, which created both functional constraints and usability issues. In terms of features, they primarily focused on organizing data—often addressed through some variant of coding—in part simply because those tasks could be well-supported by computers. Memoing or annotating data with the researcher's thoughts and insights are additional functions, and these are still core tools in most programs (Lewins & Silver, 2007). The limitations of the functionality in the early stages became a concern in the larger field of qualitative research where diversity of method is highly valued (Seidel, 1998). Tools for visualizing data were slow to evolve, although ATLAS.ti offered visualization of the database early on with its network tool. Later on NVivo and MaxQDA offered specific mapping tools. More recently, charting and other visualization tools have been developed. Hyperlinking was another tool that was slow to develop in practice although it is one of the strengths of working with computers. For more details on the evolution of specific tools, see Fielding (2008), Hesse-Biber and Croft (2008), Kelle (1995), Richards and Richards (1994b), Tesch (1990), and Weitzman and Miles (1995).

Davidson and di Gregorio (2011a) map the time period in which this development was taking place alongside the qualitative methods stages of "Blurred Genres" and "Crisis of Representation" described by Denzin and Lincoln (2003, 2008). According to di Gregorio and Davidson, the "Crisis of Representation" in general qualitative research corresponded to a "Typology Era" in QDAS, in which users become concerned with methodological alignment of software and research projects:

> As a consequence, much thought was given to the paradigmatic or methodological perspectives of the developer, as it was believed that these were embedded in the software design and would shape the work of users in specific directions congruent with the developer's methodological bias, regardless of the user's intent. (Davidson & di Gregorio, 2011a, p. 630)

The "Crisis of Representation" ended in mid-1990s, but this early perception about and critique of QDAS persists to this day.

As a group, QDAS followed a software development arc similar to other software such as word-processors. The arc (Norman, 1998), begins with a multitude of early products

[2] The CAQDAS networking project Web site identifies "Computer Assisted Qualitative Data AnalysiS" as the original source of the acronym, although subsequent print sources often use "Computer Assisted Qualitative Data Analysis Software" (See the "About Us" page: http://www.surrey.ac.uk/sociology/research/researchcentres/caqdas/about/) Both are in use today.

that collectively expand and define the feature set. After the initial explosion of development, the feature set becomes more well-defined and functionality becomes more consistent across programs. Competition increases, and the number of different products in the market declines. Often, a few major products take the lead, and continue to "leap-frog" one another in terms of new features and functions. After the core features are in place, software development paths vary. Products may eventually become "feature-heavy," leaving a market opening for more streamlined versions; new technical advances may change the market entirely; or the user experience (aspects of interaction, such as ease of use) may simply become the differentiating factor between products (Norman, 1998). However, as we noted, the world of qualitative research was evolving as the QDAS development arc unfolded (Davidson & di Gregorio, 2011a; Denzin & Lincoln, 2008). Thus, the intersections between the two development paths of qualitative research and QDAS helped to shape the *perceptions* about these programs as they approached the convergence stage (Davidson & di Gregorio, 2011a).

Convergence

As the originally specialized QDAS programs converged into a more recognizable set of features, the number of programs decreased. As of this writing, the CAQDAS networking Web site focuses on reviews of only nine software programs. According to Norman, once a technology has reached a mature stage, technical distinctions between products fade into the background as the technology becomes more comprehensive and inclusive (Norman, 1998). In terms of basic functionality, QDAS has reached that point.

Davidson and di Gregorio (2011a) identify ATLAS.ti, NVivo, and MAXQDA as the dominant programs at the end of the "Post-Experimental Inquiry" stage of qualitative research. During this period, experienced QDAS users began to look across programs, compare their features and develop broader perspectives on the common qualities that should be expected (di Gregorio & Davidson, 2008; Lewins & Silver, 2007). Unfortunately, these conversations did not reach the wider audience of qualitative researchers, many of whom had turned away from QDAS either because of lack of access, frustration with earlier limitations, or because they believed "the rumors they had heard about epistemological problems" (Davidson & di Gregorio, 2011a, p. 632). At the same time, researchers began writing about using generic programs to manage their data, such as Word or Excel (Hahn, 2008; Ritchie & Lewis, 2003). Ironically, these epistemological concerns seemed less prevalent when researchers managed their data using software that was *not* intended to support qualitative research, as if these products were somehow more methodologically innocent.

QDA Software Today

In this section we first describe the most common (and generally expected) software features and functions. Next, we address the "user experience" through the research on the individual user's interactions with the software. Finally, we examine the cultural factors surrounding the use and avoidance of QDA software, through a "community of practice" lens.

Common Tools

The metaphor of a "tool" is often applied to these software programs; however, given the complexity of both qualitative research and the software used to support it, a more appropriate metaphor might be a "tool*box*"; that is, a collection of tools that can be used in different ways (Gilbert, 2002). A single functionality can be used to address different activities of qualitative research (organizing, exploring, interpreting, reflecting), and a single task can be supported through various tools. For example, creating memos can be used to organize data (using a narrative with embedded links to group related items), to reflect on data and the research process through writing, or to interpret data through an explanatory note that might even become integrated into a report. Similarly, the task of organizing data can be accomplished with sets, folders, coding, creating memos, linking, and so forth. (As stated previously, the specifics of matching functionality and task have been discussed in detail by multiple authors.)

Two of the original CAQDAS staff developed documents highlighting the common functions in QDAS (Lewins & Silver, 2007), thus contributing to the understanding of the software packages as a coherent class. Their list of fundamental capabilities includes the following:

- Assign multiple codes to a single portion of text/audio/video/photograph.
- Cross-reference the relationships among codes for constellations or patterns.
- Import nominal, ordinal and/or interval data as a means of comparing subgroups in the data.
- Track researcher ideas through the use of links and memos.
- Provide output in the form of reports that can be used for analysis and presentation of findings outside of the software.

Additional features are also available many in the products, such as:

- The ability to code an increasing range of data formats, such as audio, video, or pdf files.
- The ability to track multiple users within the system, or even to limit some users' access as "read only" in order to manage teamwork.

- The ability to create visual representations (models and charts) of data.
- The ability to access program functions in multiple ways (menus, keyboard shortcuts, contextual menus) and to customize the interface.

These four additional features possibly cross into the stage that Norman terms "excess quality uninteresting to consumers" (Norman, 1998). The dilemma for developers is that given the diversity of qualitative data and research methods, one researcher's *featuritis* may be another's *essential function*. Since adding capabilities also adds complexity, the developers face the challenge of balancing a wide feature set with usability.

User Experience

"User experience" refers to the subjective aspects of working with a system—the user's perceptions and responses. It is influenced by usability, by interface design, by the characteristics of the user, and perhaps by practical considerations such as cost, the availability of support and training, and less easily defined attributes such as appearance or prestige.

However, just as Word and WordPerfect had comparable word-processing functionality in the 1980s but nonetheless attracted loyalists who insisted on the supremacy of one over the other, so different qualitative researchers staunchly defend their particular QDA software. Some of this can be explained with a more careful look at the research on user experience. As Norman (1998) reminds us, user experience often becomes the differentiating factor between mature products. In one of the first published investigations about the adoption of QDAS, users reported preferring a particular program because it "fits with their thinking" more than another (Gilbert, 2002).

Although it was common a decade ago to run across comparisons of software in expository literature and the way these different software influenced the research process (for example, Barry, 1998) a more recent investigation yielded new and different results. Organizers of KWALON, the Netherlands Association for Qualitative Research, developed a process whereby experts in several of these software packages (ATLAS.ti, Cassandre, MAXqda, NVivo, and Transana) independently analyzed a common data set (Evers et al.).[3] In addition to posing some specific research questions to the participants that guided the independent analyses, the organizers also asked for responses to questions about the software: How the tools related to the analysis strategies, what

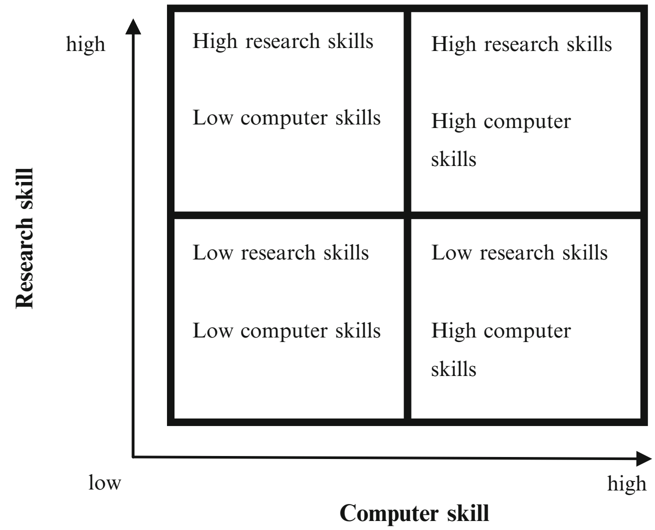

Fig. 18.2 Skill dimensions of individual users (adapted from Gilbert, 2006)

tools helped, which ones got in the way, and if the software influenced the analysis (for examples of responses, see Dempster & Woods, 2011; Friese, 2011).

Two qualitative researchers, one a QDAS novice and the other a QDAS expert, were asked to present their observations of the KWALON study in overview articles. The expert observer (di Gregorio, 2011) said that despite the different emphases in the researchers' descriptions of the process, they came up with very similar conclusions about the primary research questions. This suggested that the overall impact of a particular QDA program in analyzing the data was negligible. di Gregorio attributed this to the fact that the researchers were experts in the software they used as well as experienced qualitative analysts. Therefore, the researchers were not swayed by an unreflective application of a software tool, but were able to expand and reflect on their interpretations with the assistance of software. The novice observer (Schuhmann, 2011) reported that although the software influenced the types of data that became the focus within the larger data set, she also stated that without exception, the experienced researchers articulated their confidence that software expanded their perspectives and opened up new ideas in working with the data, rather than narrowing or confining such perspectives.

The KWALON findings support our previous observation that the distinctions between programs have become less critical now that the technologies have matured. It also reinforces the importance of researcher expertise in terms of understanding both qualitative research and the software tools that have emerged to support it.

With respect to users of QDA software, Gilbert (2006) classifies users according to their skill levels as both researchers and computer users (Fig. 18.2). The different quadrants

[3] Unfortunately, the KWALON experiment did not include investigations in the data set that were not facilitated by software, so no comparison point is available between managing the data with and without QDAS.

have different needs and expectations, and therefore different user experiences.

Using QDA software well requires both general computer skills and—even more importantly—an understanding of qualitative research methods. Users with low computer skills will naturally struggle with the software, regardless of the level of their research skills. Indeed, experienced qualitative researchers who are not proficient computer users sometimes view QDAS with outright suspicion, mired in concerns that these programs will somehow mislead the researcher. At the same time, users with low research skills and high computer skills run the risk of "following the software" too much—using features "because they're there" instead of intentionally selecting the functions that support their research goals.

Difficulties Adopting and Transitioning to Software

Inappropriate use by some novices adds to the unfortunate misconception that the software determines the method, or even worse, that software *is* a method. The conflation of software and method is exacerbated by the lack of training some novices receive in their academic course work on qualitative methods. Use by senior qualitative researchers in academic circles is limited, though the software has achieved broader acceptance in applied (nonacademic) qualitative work (Fielding & Lee, 2007).

In addition to some of the potential misunderstandings that can emerge when novices are left without guidance, expert qualitative researchers also face the challenge of jumping to conclusions about software use too quickly during their transition to using QDAS. The literature reveals five difficulties researchers experience in the transition to QDAS.

- "Missing paper" and initial concerns about "Closeness to data." Beginning software users miss the experience of working with paper, and often conflate the tactile experience with familiarity with the content (Fielding & Lee, 1998; Gilbert, 2002; Richards, 1998; Welsh, 2002). In contrast, experienced software users report feeling *more* knowledgeable about their data after they also gain expertise in the software (Gilbert, 2002; Lee & Fielding, 1996). Despite these reports to the contrary, the reputation persists that software creates "distance" from data. This belief may become less of an issue with generations more accustomed to working with computers.
- "The coding trap." Ironically, this is a problem of being too close to data, and focusing on detail at the expense of synthesis. With increased fluidity and efficiency of coding in software, users engage in nonproductive coding because they do not know when enough is enough, or are uncertain about what to do next and postpone decision-making (Coffey, Holbrook, & Atkinson, 1996; Gilbert, 2002; Richards, 2005).
- Managing analytical distance. Closeness has traditionally been prized in qualitative research but at the same time there is a need to gain a perspective on the whole. While some researchers have criticized software as not allowing them to get close to the data (Weitzman & Miles, 1995), others have commented on the new closeness made possible by QDA software (leading to the "coding trap" described above). Users have had to develop conscious strategies to manage both closeness and analytical distance (Gilbert, 2002; Johnston, 2006).
- Lack of meta-awareness about software use. It is easy to make a mistake when using "computer power tools," such as creating a query that doesn't ask what you think it does. Experienced users of QDA software (and other complex programs as well) usually develop ways of checking that the program did what you actually *meant* it to do, as opposed to what you *asked* it to do (Gilbert, 2002; Sin, 2007).
- Concerns about software inappropriately driving the researcher's methodology (Schwandt, 2007). This includes standardizing the qualitative research process (Coffey et al., 1996) or following the temptation to turn qualitative data into quantitative results without a methodologically clear reason for doing so (Schönfelder, 2011).

While these issues can occur with the use of software, they can also, with practice, be managed. However, some of these initial concerns in the transition to QDAS may prevent a researcher from developing sufficient expertise with the software to use it well, or even to fully understand its implications for use. Equally erroneous negative ("it will drive the research") and positive ("using it makes research more valid") claims are made by those who fail to achieve expert status in both QDAS and qualitative methods. These misconceptions are discussed in more depth as we look at the context of QDA use.

Experienced Researchers Who Make the Transition to QDAS

Experienced qualitative researchers who use qualitative data analysis software tend to report multiple advantages, particularly when handling increasingly complex projects (Fig. 18.1). These researchers often identify an overall perception of increased access to their data (Bringer, Johnston, & Brackenridge, 2004; Garcia-Horta & Guerra-Ramos, 2009; Ku Saillard, 2011; Richards, 2002). More specific benefits include:

- Ability to maintain an increased volume and diversity of information in any given project (Basit, 2003; Darmody & Byrne, 2006; Ozkan, 2004; Sin, 2007).
- Increased opportunities for teamwork (Sin, 2007), particularly in geographically dispersed teams (Dempster & Woods, 2011; Wiltshier, 2011).

- Efficiency of data management (Carvajal, 2002; Mangabeira, Lee, & Fielding, 2004; Wickham & Woods, 2005).
- Increased portability and durability of data, since digital data is more compact than physical data (Corti & Gregory, 2011; di Gregorio & Davidson, 2008).

The general literature on the adoption of technology describes and defines groups of users based on their willingness to explore a new technology, from "innovators" and "early adopters" to "laggards" (Moore, 1991; Rogers, 1995). Early adopters are enthusiasts willing to deal with the idiosyncrasies and usability issues of an immature product. In later stages of development, with a mature technology, the market changes; targeted users are more conservative and pragmatic, desiring ease of use, convenience, and results. The "chasm" between early adopters and "majority users" has been the source of a broad literature on technology adoption, and "crossing the chasm" has entered technology marketing terminology as a short-hand for reaching a broad proportion of a target audience. Though QDA software is now a mature product technologically, in many ways it has not "crossed the chasm" in terms of reaching the mainstream market of qualitative researchers, though there are various "communities of practice" in which its use is common.

Communities of Practice: Negotiated Meaning Around QDA Software

Modern researchers expect to use software of some nature—even if just using a word processor to cut-and-paste—in the course of their research. However, they often approach the use of such generic software quite uncritically. Unfortunately, although QDA software experts have been engaged in rich discussions and debates about issues related to software use for quite some time, the mainstream qualitative methods literature has failed to incorporate some of the most interesting and relevant strands of this discourse. Thus, general researcher beliefs about the use of QDA often either exaggerate or minimize the role of software in research.

We approach these researcher beliefs from the perspective of Communities of Practice (Lave & Wenger, 1991; Riel & Polin, 2004) and "negotiated meaning" (Wenger, 2008). As we previously discussed, use of QDA software is affected by the practices of the larger qualitative research community—or, more accurately, multiple research communities, since qualitative research encompasses multiple disciplines and both academic and applied work. Among these varied and sometimes overlapping communities, the presence of QDA software in the field helps to define three specific groups that are relevant to the current discussion: (1) novice researchers who are trying to understand the role of software through their limited peripheral participation (Lave & Wenger, 1991); (2) experienced qualitative researchers who do *not* use QDA software, and (3) experienced qualitative researchers who use QDA software.

While we have discussed the evolution of this genre of software and some of the perceptions of qualitative researchers as they move to the computer to handle their data, we have not yet addressed the ways QDAS experts have integrated their discussions of software and methods or the extent to which mainstream methods literature has largely ignored these discussions. These are important issues to address, given the different discourses available to novices about software in mainstream qualitative methods literature and the literature produced by QDAS experts.

New tools do offer new affordances—new capabilities and opportunities—and often carry implications for ethics, privacy, and representation that should be addressed directly and thoughtfully. As Wasser and Bressler (1996) observe, there is a complex and interesting "interpretive zone" where the embedded assumptions of researchers and technologies meet. However, the alarmist writings about software in mainstream methods literature usually fail to acknowledge that manual methods are not "tool-free." Much of this literature also fails to unpack the implicit assumption that avoiding certain tools will somehow ensure the trustworthiness of research. The reality is that *every* tool influences practice—from audio and video recorders to word processors or even note-taking—and researcher reflections on methods must also include reflections on the thoughtful use of appropriate tools.

QDA experts have engaged in reflections on this "interpretive zone," and they have focused on a diverse array of important qualitative research practices in the context of software use. Examples include exploring multiple meanings in the data (Richards, 2002), challenging researcher assumptions and first impressions of the data (Garcia-Horta & Guerra-Ramos, 2009), becoming aware of gaps in the collected data (Wickham & Woods, 2005), revisiting data with a new conceptual lens (Sin, 2007), fending off an uncritical reification of method (Ozkan, 2004), examining the ethical implications of working with digital data (Spickard Prettyman & Jackson, 2006), reflecting on the social construction of evidence (Kaczynski & Kelly, 2004), and unpacking some of the tacit views of research transparency among qualitative researchers (Jackson, 2009). Unfortunately, there is evidence that their discussions regarding the dynamic interplay between software and research rigor are not extending beyond their own community of practice. Jackson (2003) and Johnston (2006) demonstrate that the scholars who contribute to methods discussions in QDAS publications rarely contribute to mainstream qualitative text books. Three notable exceptions include *Handling Qualitative Data* (Richards, 2005), *Readme First for a User's Guide to Qualitative Methods* (Richards & Morse, 2012), and *Qualitative Research Design for Software Users* (di Gregorio & Davidson, 2008).

Just as discussions of software are minimal or lacking in most textbooks, they are equally lacking in discussions of methodological rigor or the most recently published guidelines regarding the implementation and publication of rigorous qualitative research in education. Examples include *Scientific Research in Education* (National Research Council, 2002), *Standards for Reporting on Empirical Social Science Research in AERA Publications* (American Educational Research Association, 2006), and *Standards for Reporting on Humanities-Oriented Research in AERA Publications* (American Educational Research Association, 2009).

When software is addressed in mainstream qualitative research literature, it is most often described by researchers who do not typically engage in the community of practice of QDAS experts. These mainstream qualitative methodologists (e.g., Creswell, 2008; Denzin & Lincoln, 1998a; Silverman, 1993) rarely publish articles dedicated to QDAS, nor do they participate in forums or conferences that focus on the use of QDAS. As Jackson (2003) has illustrated, the widely used texts by such scholars position software as a tool to consider long after making methodological decisions and view it as little more than an expeditor of the most mundane research tasks.

In short, in mainstream qualitative literature the relevant opportunities and challenges of QDAS are overlooked. As di Gregorio and Davidson (2008) observe:

> The current divide between QDAS users and non-QDAS users (often the most experienced analysts) means that our most significant commentators on methodological issues are failing to engage in the discussion of the new affordances and also pitfalls that QDAS offers. QDAS should not be seen as something that can be added on in a chapter on qualitative methodology. It needs to be integrated in the whole discussion on methodological practice. (p. 14)

The lack of reflection on software tools in the discussion on methodological practice is a particular disservice to novice researchers, now coming from a generation expecting to use computers as a matter of course. Johnston (2006) focuses extensively on the problems this false dichotomy between software and method creates during the instruction of graduate students, observing that the methodological learning curve for her students is more difficult because it is not being properly informed by the relevance of software. Carvajal (2002) also notes that both inside and outside of the university, in the context of computer lab trainings where the focus of instruction is often on specific software tools, a problem is created for novices who do not understand methods and may even conflate software and methods. Davidson and Jacobs (2008) elaborate on the individual as well as institutional factors that promote and prevent integration of software and methods within academic settings, with special attention on the professional journeys of faculty and doctoral students.

The problem of separation between software and methods has been observed by those who do not use software, as well as those who do. In *The Dictionary of Qualitative Inquiry*, Schwandt (2007) cautions his readers about the unexamined bias of all tools. Schwandt argues that the creation and use of particular tools influences the ways researchers see (and create) themselves and their research environment and states that, "While developers and frequent users of qualitative data analysis tools may customarily reflect on these embedded predispositions, it is not entirely clear that the casual user does" (2007, p. 35). However, according to the above-mentioned QDAS experts (Carvajal, di Gregorio and Davidson, Jackson, Johnston, etc.) it is precisely the segregation of QDAS literature from mainstream methods publications that contributes to the lack of deeper reflection on the relationship between software and methodology.

The efforts of di Gregorio and Davidson (2008) to engage in discussions around this interpretive zone (detailed in Chap. 2 of their book) serve as a recent move in the direction of integrating software and methods in qualitative research. It is a good beginning and one that we hope to see continue, particularly as the use of QDA software increases in applied qualitative arenas (for examples, see di Gregorio, 2006; di Gregorio & Davidson, 2008). On one hand, the use of QDA software sometimes offers methodological insights or creative new ways of understanding and approaching the data. On the other hand, the use of diverse methods in qualitative research helps push software users to consider the kinds of things we should or should not do with software (and certainly influences the recommendations we have for software developers).

New Directions and Implications

The first decade of the twenty-first century has seen massive technological changes in how we communicate across space and time. The evolution of Web 2.0, as the social and information-sharing aspects of the Web have been dubbed, has affected how we shop, bank, search for information, and communicate with each other. Revisiting the software development arc described earlier and viewing it with respect to Web 2.0 tools, we are in the early stages of innovation, where products proliferate and standards are still in early stages of evolution. The evolution is complicated further by the increasing prominence of mobile applications and multiple points of access to information stored in "the cloud." Web 2.0 presents profound challenges for both "traditional" qualitative research and QDAS; not least is the pressure from researchers who have been raised during this period and who thus expect to communicate online, share research materials in the cloud, or blog and work in wikis. In this brave new era,

Table 18.1 Comparison of QDAS and Web 2.0 tools

	QDAS	Web 2.0
Organizing tools	Coding	Tagging
	Sets, families	Grouping
	Hyperlinking	Hyperlinking
Reflective tools	Memoing	Blogging
	Annotating	Annotating
	Mapping	Mapping
Exploring tools	Model, map, network	Visualizing
	Text search, coding search	Searching
Integrating tools	Memoing with hyperlinks	Blogging with hyperlinks
	Merging projects	Collaborating through wikis

Davidson and di Gregorio (2011a, 2011b); di Gregorio (2010a, 2010b)

qualitative researchers can no longer afford to ignore digital tools (Davidson & di Gregorio, 2011a, 2011b).

The current wave of innovation promises a variety of new tools applicable to qualitative research, but also holds implication for new practices, new research needs, and even new researchers. For example, business and government communities are now involved in making sense of vast amounts of unstructured data that this new technology generates (Berners-Lee, 2009; Wang, 2006).

Davidson and di Gregorio (2011a) have termed the development of new QDA tools with Web-based capability "QDAS 2.0." There are two primary development paths for QDAS 2.0 tools specifically designed to support qualitative work. First, existing QDA software developers are starting to open their stand-alone programs to take advantage of collaborative Web technologies. Second, new developers are creating entirely new QDA 2.0 tools using Web-based programming. However, as mentioned above, qualitative analysts are not the only ones who are interested in managing unstructured data. Businesses, governments, news agencies, and ordinary folk are keen to interpret the unstructured data generated by Web 2.0 activity, and tools are being developed to support such by entities such as IBM and Google (di Gregorio, 2010a; Greif, 2009).

In addition to these intentional development paths, there are now many Web-based tools that offer support to some aspect of the qualitative analysis process, and we expect that some users will create their own "mashups" of these tools to meet their research needs. Table 18.1, from di Gregorio (2010a, 2010b), compares features that support the qualitative analysis process in QDAS with those Web 2.0 tools that can do the same.

In addition to new tools, new forms of participating in research have emerged. Davidson and di Gregorio (2011b) have dubbed what is beyond QDAS 2.0 as "Cloud QDA," in which the tools themselves reside in the cloud. Characteristics include technical changes, such as the use of computer algorithms in addition to human coding to analyze large quantities of text, "trawling" through textual data generated through tweets, emails, news feeds, and the like. Even more important innovations include new collaborative structures, such as the use of social-networking features to create a network of analysis peers, or "crowd-sourcing" and "folksonomies," which invite more participation from lay analysts. Reflecting the new models for software, new payment models, such as monthly fees for use, are also evolving.

As this is an area that is developing very quickly, any attempt to list these new tools would be out of date before this chapter is published. However, we have set up the wiki for Digital Qualitative Analysis Tools (DigiQAT) at http://digiqat.pbworks.com, to track of new tools being developed to support qualitative analysis. A wiki allows developers and users world-wide to add information and update existing information, so that information remains current.

It is important to acknowledge that the development of cloud computing is not without issues and challenges. How can the anonymity and privacy of individuals be protected in an open Web-based world? How can the security of qualitative data and analysis be guaranteed? Who owns data on the Web? What are the rights of researchers, participants and platform hosts? What challenges are posed by the participation of "lay analysts," who may understand software but not methodology? New ethical standards are currently being developed by researchers in the field, but with technology changing so rapidly these standards need to be constantly reviewed (Bassett & O'Riordan, 2002; Buchanan, Delap, & Mason, 2010; di Gregorio & Davidson, 2009; Raento, Oulasvirta, Eagle, & Eagle, 2009).

In this tumultuous new environment, the methodological knowledge of experienced qualitative researchers is of great value, but is in danger of being marginalized or overlooked unless researchers can enter the "interpretive zone" of these technological tools more fully. Using these tools *without* an understanding of their implications carries great dangers. We hope that as these new tools develop, they will be accompanied by the kind of reflection upon process that is currently evident in the literature produced by QDAS experts, and that new researchers will continue to critically examine both their research processes and tools.

Summary

Contrary to some common notions about the standardizing influences of QDAS, the complexity and diversity of qualitative data and analysis was the initial impetus for the development of QDAS. Furthermore, the specific functionalities currently available in this genre of software have converged into a fairly standard toolbox that may be very broadly and diversely applied. Most concerns raised about individual programs are overly alarmist (or alarmist for the wrong reasons) and tend to be raised by individuals with limited qualitative research knowledge and/or limited QDAS expertise, or individuals who have failed to keep current on the capabilities of QDAS. However, at the same time, we find the affordances of this genre of software worthy of examination, discussion, and rich critique. Indeed, that discussion should be extended to *all* tools for qualitative research, including common programs such as word processors or spreadsheets when they are adapted for use in research.

New tools are being developed by researchers, businesses and governments to manage the increasing accumulation of unstructured data in order to address questions that are qualitative in nature. Trends to watch include "Cloud QDA," mobile access, modularization of functions (leading to "software mashups"), new ways of accessing software (both in terms of technical access and payment models), and—perhaps most importantly—new forms of collaboration. In this rapidly changing climate there is ample room for rich discussions about technology as it relates to qualitative research tasks (such as data collection, coding, writing, and distributing findings) as well as more substantive debates/issues (such as ethics, trustworthiness, bias, and social justice).

When we hear casual and unsubstantiated claims that software is either a panacea or a plague, we are concerned that the polarizing discourse is essentializing a quite complex interaction between software and method in practice. While this interaction certainly deserves more rigorous research attention, we can conclude from the existing literature that the relationship between method and software, as practiced by qualitative researchers, can be positive and productive if the researcher is reflective, critical, creative, and open to recognition of error. It can be quite damaging and negative if the researcher is unaware of his or her own lack of skill, blind to bias, lazy, myopic, or overconfident. As we move into the twenty-first century, where the use of software is accepted almost too unquestioningly, reflection on such issues becomes increasingly imperative for qualitative methodologists.

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Section III

Assessment and Evaluation

J. Michael Spector and M. David Merrill

This third section of the *Handbook* is focused on new methods, technologies, and tools to support educational assessment and evaluation. How methods, technologies, and tools have matured and new ones been developed and validated in practical settings are described in several chapters. The intent is to report what is new and avoid repeating what has been published in previous editions of the *Handbook* (Jonassen, 2004; Jonassen, Harris, & Driscoll, 2001; Spector, Merrill, van Merriënboer, & Driscoll, 2008). This section provides an up-to-dateness of research about and with new and emerging assessment and evaluation technologies.

The section begins with a chapter that addresses a topic not previously covered in the Handbook but one that is of global concern—namely, addressing the costs and benefits of educational technology. Thomas Luschei notes the general lack of research about actual cost–benefit analyses of large-scale technology innovations in education and training. The merits and limitations of cost-effectiveness, cost–benefit, cost–utility, and cost–feasibility analyses are described in general. Luschei then describes the methodological issues and challenges of applying these methods in actual settings. More research in this area is encouraged, especially in developing countries where the economic benefits from a cost-multiplier perspective are likely to be significant.

The chapter by Jennifer Hamilton and Jill Feldman on evaluation is also completely new. The traditional perspective on program evaluation is that what is reported is relatively straightforward and simple—namely, the degree to which the program objectives were met. However, there is an increasing interest in being able to connect aspects of an implementation with specific outcomes in order to explain why specific outcomes were or were not obtained. Moreover, the focus has shifted from a simple analysis of outcomes to an ongoing evaluation of a program as it evolves from planning through development and then to implementation and deployment. Formative evaluations along the way have become increasingly significant as evaluators take a more active role in helping program managers achieve intended objectives. Formal methods to evaluate the fidelity of implementation are now required by many funding agencies so that evaluators are positioned to explain why a program did or did not achieve intended objectives. This chapter presents researchers and developers with a practical guide to plan and conduct meaningful program evaluations.

There follow two chapters focused on assessment in domains previously not covered in the *Handbook*—namely, informal learning environments and problem solving. Savenye identifies two areas of informal learning that have received considerable attention in the research literature—museum learning and informal science education. It is well established that much important learning occurs outside school settings. Some informal learning activities can be planned and also assessed. Both quantitative and qualitative methods for such assessments are described by Savenye. Jonassen addresses how to assess problem-solving skills. While research on problem solving has been covered in previous Handbooks, methods to assess improvements in problem solving as a result of training and education have not been addressed. Jonassen provides an overview of assessment methods and coding schemes pertinent to assessing critical cognitive skills, causal reasoning, and other problem-solving skills.

The chapter by Ifenthaler and Pirnay-Dummer on model-based assessment methods and tools is well aligned with the issues raised by Jonassen as it reports on various tools aimed at supporting the kinds of assessments that Jonassen argues are needed for the domain of problem solving. Of particular note is the development of Web-based tools reported in this chapter and the shift that has occurred from a focus on summative assessment to emphasis on formative assessment and dynamic feedback to learners while working on complex and challenging problems.

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This sequence of chapters on new areas of concern (informal learning and problem solving) and new assessment tools (Web-based tools that provide dynamic formative feedback) is followed by a reflective chapter on the value and significance of performance assessment. While this topic has been addressed many times and in many contexts, Andrews and Wulfeck argue that performance assessments have returned as the primary means of determining the efficacy of training and how well learners have mastered intended objectives. Many methods and tools to support performance assessment are reviewed as the authors argue that technology now makes it cost-effective to conduct meaningful and predictive performance assessments in many different contexts.

The chapter by Valerie Shute and Yoon Jeon Kim on formative and stealth assessments exemplifies how technology has empowered performance assessment to the extent that nonintrusive formative assessments can be built into a technology-based learning environment. How dynamic formative stealth assessments have been and can be effectively accomplished is described in this chapter.

There follow two chapters that complete this section of the Handbook. One pertains to the task of evaluating information and communication technology (ICT) competencies. Evaluating ICT competencies is important for planning learning environments and for properly preparing teachers, trainers, and students for those environments. However, technologies change quite rapidly and knowledge and skills vary widely from one region to another, so evaluating ICT competencies remains a challenge. Tristan and Ylizaliturri-Salcedo argue that ICT competencies represent a subset of digital literacy competencies, and are essential for the twenty-first century workers. Several approaches for assessing these skills are presented and discussed in this chapter. The final chapter in this section by Kaufman and colleagues then describes how one can and should use data to drive decision making in the classroom. It is clear that commercial enterprises are using data gathered from past purchases and those with similar characteristics to drive how they advertise to specific Internet customers. Likewise, similar technologies and methodologies make it possible to use data to personalize learning and instruction. A data-driven decision-making model is presented to guide such efforts in the future.

The practice of educational technology as a professional discipline requires reliable and effective methods, tools, and technologies to support assessment and evaluation. Professional practitioners need to be able to assess individual learners and learning experiences and evaluate the efficacy of innovative programs. In order to maintain progress, the discipline requires ongoing and cumulative research on assessment and research methods and tools as well as research on specific innovations and implementations. For this reason, we have placed this assessment and evaluation section of the *Handbook* in volume one along with foundations and methods as part of the core discipline of educational technology.

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[*] An asterisk next to a reference entry throughout this Handbook indicates a reference that the author(s) considers to be central to the topic.

Assessing the Costs and Benefits of Educational Technology

19

Thomas F. Luschei

Abstract

Educational technology is often cited as a means to improve educational outcomes and reduce costs, leading to greater quality and efficiency in learning and instruction. Yet research that attempts to assess the costs and benefits of educational technology is limited, making it difficult for educators and policy makers to make efficient decisions. This chapter reviews international research on the effectiveness, costs, and cost-effectiveness of educational technology and provides a set of core conclusions from this literature. The chapter also describes methodological challenges to assessing costs and benefits of educational technology and suggests areas for future research. The chapter concludes with lessons learned for educators and educational decision makers.

Keywords

Benefits of educational technology • Costs of educational technology • Cost-effectiveness analysis • Efficiency

Introduction

Educators, researchers, and policy makers often point to educational technology as a means to enhance educational access and outcomes while decreasing costs (Rumble, 1999, 2001). Equipped with convincing evidence of efficiencies, educational decision makers can implement technology-related policies and practices that promise the largest return for a given investment. Yet several challenges beset the empirical verification of efficiency gains stemming from the use of educational technology. To begin with, researchers have not reached consensus as to whether educational technology yields significant benefits and what those benefits are. Estimation of the costs of educational technology presents further challenges, such as measuring both direct and indirect costs and identifying the appropriate "ingredients" (Levin & McEwan, 2001) of technology-related interventions. Additionally, few researchers have attempted to systematically assess and compare both the benefits and costs of educational technology. This chapter discusses the challenges of assessing the costs and benefits of educational technology, summarizes and synthesizes related research, identifies key methodological challenges, and indicates fruitful areas for future inquiry, including a call for cross-disciplinary research in assessing the efficiency of investments in educational technology. The chapter concludes with a set of concrete lessons learned for educational decision makers and educators.

Efficiency and Cost Analysis

What is the point of comparing the costs and benefits of educational technology? In theory, educators and policy makers should use information on both to help them allocate scarce resources among competing priorities. As Levin and McEwan (2001) note in their textbook on cost-effectiveness

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analysis, decisions based on knowledge of both benefits (or effectiveness) and costs of a particular intervention "can reduce the costs of reaching particular objectives, and it can expand what can be accomplished for any particular budget or other resource constraint" (p. 6). In other words, such analysis can lead to *efficient* decision making.[1]

Assessing Efficiency

The systematic analysis of information on costs and benefits of competing alternatives falls under the umbrella of cost analysis, which comprises several approaches to assess efficiency, including cost-effectiveness analysis, cost–benefit analysis, cost–utility analysis, and cost–feasibility analysis (Levin & McEwan, 2001). Below I briefly describe these approaches.

Cost-Effectiveness Analysis

Cost-effectiveness analysis can help educational decision makers to evaluate various alternatives based on both their costs and their effectiveness in achieving a common desired goal, such as improving student achievement, increasing graduation rates, or reducing school dropouts. For example, we can use cost-effectiveness analysis to compare how well various types of instructional technology increase students' test scores and how much monetary investment is required for each unit of test score increase. The technology resulting in the largest increase, for a given unit of cost, is the most cost-effective. Alternatively, we can identify the technology with the lowest cost for a given level of test score increase. In the first case, we hold inputs constant; in the second, we hold the outcome constant. One drawback to cost-effectiveness analysis is that it only allows us to assess alternatives according to one specific measurable goal or outcome. We cannot use cost-effectiveness analysis to compare the impacts of alternative interventions with different objectives or on different outcomes, such as test score increases and dropout reductions. Nor can cost-effectiveness analysis help us to determine whether the benefits of a given project outweigh its costs, because benefits and costs are measured in different units (Levin & McEwan, 2001).

Cost–Benefit Analysis

With cost–benefit analysis, we can assess the monetary value of both the costs and benefits of alternatives, which helps us to compare projects or gauge whether a specific project or alternative is worthwhile. When comparing projects, the most efficient alternative is the one with the highest ratio of benefits to costs, or the lowest ratio of costs to benefits. Because this approach assesses inputs and outputs in terms of monetary values (e.g., dollars), it allows us to compare alternatives with different objectives or outcomes. Cost–benefit analysis also allows the comparison of investments across different sectors, like education, health, and transportation (Belfield & Levin, 2010). The disadvantage of cost–benefit analysis is that it can be very difficult to measure the monetary value of the major outcomes that are valued in education, such as increased learning. Cost–benefit analysis is best suited for evaluating educational interventions that have some market-oriented outcome, such as training programs designed to increase earnings or decrease poverty (Belfield & Levin, 2010). Some studies have estimated the private and/or social returns, in terms of wage increases, that result from investments in technology-related endeavors like distance education (e.g., Carnoy & Levin, 1975). However, in evaluating educational technology, cost–benefit analysis is rare (Rumble, 1999). As a result, below I refer primarily to the *effects* or *effectiveness*, rather than the benefits, of educational technology.

Cost–Utility and Cost–Feasibility Analysis

Cost–utility analysis is similar to cost-effectiveness analysis, but the outcome in question is the overall satisfaction or "utility" of a targeted stakeholder group, such as students, parents, or the general public. The goal of cost–utility analysis is to identify the intervention that (1) results in a given level of utility at the lowest cost or (2) results in the highest level of utility for a given cost. The concept of utility allows researchers to combine multiple measures and outcomes of educational interventions into a single measure. Researchers can also weigh outcomes differently, according to the preferences of relevant stakeholders. However, results may differ considerably depending on the methodology and weights used. Although such studies are rare in educational research, they are more common in health-related research (Levin & McEwan, 2001).

Cost–feasibility analysis estimates only the costs of alternatives to identify those that do not violate a given budget constraint. Although this analysis allows us to determine whether a given alternative is feasible given a specific budget, it does not provide sufficient information to choose among various alternatives (Levin & McEwan, 2001). Related to cost–feasibility is cost-efficiency or least-cost analysis, which assesses costs per enrolled student or graduate. This approach assumes that the quality or the effectiveness of educational alternatives and graduates is the same (Rumble, 1999).

[1] Rumble (1986) offers a helpful distinction between effectiveness and efficiency: "It is possible to be effective without being efficient, but it is not possible to be efficient without also being effective. Effectiveness will depend upon the quality and quantity of the output. Efficiency will depend not only on these factors but also on the consumption of resources as an input to the system" (pp. 69–70).

Cost-Effectiveness of Educational Technology

Cost-effectiveness analysis requires (1) measuring the effect or the effectiveness of competing alternatives in producing some desirable outcome; (2) calculating the costs of each alternative; and (3) comparing costs and effectiveness. Below I discuss each step and identify evidence related to educational technology.

Estimating Effects or Effectiveness

In cost–benefit analysis, the "benefit" refers to an actual monetary value of the outcome of an educational intervention. In many cases a more appropriate approach to assessing efficiency is through the estimation of the effect or the effectiveness of an intervention in reaching a given goal, and then comparing this outcome to the costs of the intervention. A key issue in assessing effectiveness or effects is the establishment of a causal link between the intervention and the outcome of interest (Shadish, Cook, & Campbell, 2002). In other words, does the intervention in question actually cause the desired outcome, or do measured "effects" of the intervention stem from an unobserved variable or relationship? If the intervention does not cause the outcome of interest, its value to educators is questionable. I return to this discussion in the section on methodological issues below.

The Effects and Effectiveness of Educational Technology

Research on the benefits and effects of educational technology is so large and diverse as to defy coherent summaries or reviews (Ross, Morrison, & Lowther, 2010). To narrow this discussion and make it applicable to a discussion of costs and benefits, I limit this section to research that attempts to measure the effects of educational technology on some student outcome. Even so, the task remains large. Decades of educational research have identified a wide range of benefits of educational technology, including unique "affordances" made possible by technology (Kozma, 1994), greater accessibility for students, and support for the work of teachers (Kozma, 1994; Ross et al., 2010). Other researchers have pointed out the limitations or the drawbacks of specific technological interventions or educational technology writ large (Clark, 1983, 1994; Cuban, 2001).

Educational technology may impact a number of student outcomes, including achievement, attendance, engagement, persistence, or attainment in school. Most commonly, educational research attempts to measure technology's effect on some measure of student learning, usually student test scores. The preferred method to measure this effect is the calculation of an "effect size," or the difference in achievement between a treatment group that receives some educational intervention and a control group that does not receive the intervention (Ross et al., 2010).[2] Given the large number of studies that estimate effect sizes of educational technology interventions, the most efficient way to summarize this literature is through the examination of "meta-analytical" studies of the research. Meta-analysis, or the synthesis of large number of related studies, can provide an "average" estimate of the effect size of educational interventions and provide a general answer to large and important questions (Bernard et al., 2004, 2009).

Many meta-analyses have been conducted in the field of educational technology; by and large, these studies support the conclusion that students who receive the "treatment" of technology learn as much as or more than students in control settings without educational technology. Of course, results vary according to the types of technology evaluated and other factors. Below, I review evidence regarding computer-based instruction, distance education, and online instruction.

Computer Technology

Analyses and meta-analyses of the impact of computer technology have become so numerous that they allow for the elaboration of "second-order" meta-analyses, which review a large number of meta-analytical studies. For example, Tamim, Bernard, Borokhovski, Abrami, and Schmid (2011) reviewed 25 meta-analyses estimating the impact of computer technology on student achievement. Types and uses of computer technology in these studies included computer-assisted instruction, computer-based instruction, digital media, information and communication technology, hypermedia, simulations, and word processors. The authors found that students in technology-enhanced face-to-face classrooms have higher achievement levels than students in classrooms without technology. Specifically, the mean effect size attributable to technology use is 0.35, which translates to a 12-percentile point advantage for an average child in a classroom with computer technology, relative to an average child in a classroom without computer technology. Tamim et al. (2011) also found differences in effect sizes according to both grade level and the purpose of technology use. The effect size is larger when computer technology is used in K-12 classes, relative to postsecondary settings. The authors also found a larger effect size associated with the use of computer technology for instructional support, compared to the use for direct instruction, suggesting that "one of technology's main

[2] An effect size represents the difference between the means of the treatment group and the control group, which is standardized by dividing by either the pooled standard deviation or the standard deviation of the control group (Harris, 2009).

strengths may lie in supporting students' efforts to achieve rather than acting as a tool for delivering content" (p. 17). Although the authors do not make this link, these two findings may be related: If K-12 teachers are more likely to use technology to provide instructional support, while postsecondary instructors rely on technology principally to deliver content, this difference may help to explain differential effects of computer technology across K-12 and postsecondary settings.

Given growing expenditures on technology in schools, economists have also become concerned with the impact of this spending on student outcomes (Machin, McNally, & Silva, 2007). Results of related studies are mixed and seem to point to the importance of context. In a randomized study of a program in Israel, Angrist and Lavy (2002) found little impact of a large-scale introduction of computers in schools. Similarly, Rouse and Krueger (2004) used an experimental design to evaluate a language and reading computer program in the United States known as *FastForword*. The authors found that the program was not successful in raising reading skills or language acquisition. In contrast, Machin et al. (2007) used a quasi-experimental method to examine the impact on student outcomes of additional expenditures on information and communication technology in the United Kingdom. The authors found a positive impact of these expenditures on English and science performance, but not in mathematics. In an experimental study in urban India, Banerjee, Cole, Duflo, and Linden (2007) found that a computer-assisted program for math instruction had a strong positive impact on student math score increases. The program increased math scores by 0.35 of a standard deviation in the first year and 0.47 in the second year, and was equally effective for all students along the ability distribution. All of these studies together underscore the importance of context in assessing the effects of technology-related or any other educational interventions.

Distance Education

In their meta-analysis of 232 studies comparing distance education to face-to-face instruction, Bernard et al. (2004) found that distance education and traditional classroom instruction are comparable in terms of their effects on achievement. At the same time, the authors found considerable variability across studies, leading them to conclude that "some applications of DE are far better than classroom instruction, and that some are far worse" (p. 397). Additionally, the impact of distance education on student attitudes and retention is slightly worse in comparison to classroom instruction. The authors also found differences between synchronous and asynchronous approaches to distance education, suggesting an advantage for asynchronous approaches in enhancing achievement and student attitudes, but a disadvantage for asynchronous instruction in terms of its impact on course completion.

Online Instruction

A growing number of studies have found that online instructional approaches are as effective or more effective than face-to-face approaches in raising student learning. For example, a meta-analysis by the United States Department of Education (2009) found that students in online settings had greater learning outcomes than students receiving face-to-face instruction. Effect sizes were larger for programs that blended online approaches with elements of face-to-face instruction. However, the authors caution that the blended approaches often made use of more learning time and instructional elements not included in face-to-face instruction, which could help to explain these differences.

Calculating Costs

The second step of cost-effectiveness analysis is the measurement of costs, or the monetary value of the resources sacrificed in applying one intervention over other alternatives. It is critical to recognize that in directing resources toward a given project, we forgo the benefit that would have accrued to another similarly valuable alternative. As Harris (2009) explains, "economists define the costs of resources as the value of a resource in its next best use—the 'opportunity cost'" (p. 5). The most straightforward method to estimate costs of educational interventions is the "ingredients" model, which is also referred to as the "resource cost model" (Levin & McEwan, 2001). The ingredients model requires the researcher to (1) identify and specify all the ingredients involved in the intervention, (2) determine the cost of each ingredient, and (3) analyze costs using an appropriate decision-making framework (Belfield & Levin, 2010).

Since many educational programs take longer than 1 year to implement, costs must be adjusted for inflation by a consumer price index (Levin & McEwan, 2001). Independently of inflation, costs incurred at different times have different values; money that we receive or spend in the present is more valuable than the same amount received or spent in the future. To adjust for this difference, we must employ an appropriate "discount rate" in calculating costs. Previous studies have used bank interest rates, the average rate of return of investments in the private sector, and a combination of the two (Harris, 2009).

Costs of Educational Technology

The vast majority of studies that assess the impact of educational practices and policies (including technology-based interventions) neglect any consideration of costs (Harris, 2009; Levin & McEwan, 2001; Rice, 1997). Yet educational technology's potential to massively expand access relative to traditional classroom teaching, thereby lowering "unit costs," or costs per student, has provided one of the strongest rationales for its use (Jamison, Klees, & Wells, 1978; Rumble, 1999).

Proponents of educational technology have also argued that technology can help to transform education from a labor-intensive endeavor, relying on an inefficient one-teacher-per-classroom model, to a capital-intensive endeavor that provides a much more efficient "mass production" alternative (Eicher, Hawkridge, McAnnany, Mariet, & Orivel, 1982; Wagner, 1982).

The limited research makes clear that in comparison to many other educational interventions, educational technology projects often require a large initial investment of "fixed costs," or costs that do not vary according to the number of users involved (Levin & McEwan, 2001). In order to justify these large fixed costs, such interventions must reach a large number of users and take place over a long period of time (Jamison et al., 1978; Tsang, 1995). At the same time, there is substantial variability in both fixed and variable costs across different types of media (Jamison et al., 1978). For example, Bates (1995) concluded that among various media studied, only radio and audiocassettes had both low fixed and low variable costs. In contrast, high-quality broadcast television had high fixed costs but no variable costs, while preprogrammed computer-based instruction and multimedia had high fixed and high variable costs.

Jamison et al. (1978) calculated per student costs of nine instructional media projects, five using television and four using radio. Across both types of projects, they found large variability in size, scope, application, and costs. In general, they found that (1) costs of instructional radio were one-fifth the costs of instructional television per student per hour; (2) cost estimates varied considerably depending on the discount rate used; and (3) given large fixed or present costs, the technology projects studied must last 10–20 years in order to lower unit costs to a reasonable level. The authors conclude that despite methodological complexity and shortcomings "approximate cost analyses can be done, and done in the timely and relatively straightforward way that can provide useful input decisions" (p. 243).

Rumble (1999) argues that although educational technology has had its strongest application in the area of distance education, cost analyses of distance education projects are rare. Most of the existing studies have used least-cost or cost-efficiency approaches, which assume similar quality or effectiveness across alternatives (Rumble, 1999). Fewer studies assess cost-effectiveness, and even fewer attempt cost–benefit analysis. In a review of relevant studies, Rumble (1999) concluded that "distance education can be, *under the right conditions*, more cost-efficient than traditional classroom-based education" (p. 126). Relevant considerations include size, number of courses offered relative to student population, longevity of courses, choice of technology and media, administrative costs, and type of staff employed. Rumble (1999) also suggests the possibility that "mixed-mode" institutions that combine on- and off-campus teaching may operate at lower costs than purely distance education institutions.

In assessing costs of network-based or online instruction, Rumble (2001) finds that various studies identify and treat costs very differently. For example, analysts disagree on costs that should be taken into account, use different terminology to describe cost elements, disaggregate and aggregate costs in different ways, and use a variety of frameworks. Rumble's own framework divides costs into three categories: course development, course delivery, and administrative costs. Development of instructional materials includes the preparation of text, audio and video materials, computer-based tutoring, and simulation, among others. Costs of course development can vary tremendously depending on the media used. Rumble (2001) cites a study by Arizona Learning Systems (1998) that found course development costs to range from \$6,000 for a course using simple outlines and assignments to \$1 million for a course using virtual reality. Additionally, synchronous online courses tend to be less costly than asynchronous courses due to the use of fewer media. Costs of online course delivery include delivery and reception of materials, opportunity costs for students, tuition, tutors, equipment, and costs of communication between students and administrative staff. Rumble (2001) concludes that in general, course delivery costs for online instruction are smaller relative to costs of traditional face-to-face instruction. Administrative costs of online instruction include costs associated with administrative staff, quality assurance and evaluation, Web site development and maintenance, buildings and furniture, and other equipment.

An important measure of costs in comparing online instruction with other alternatives is the amount of time invested by students and instructors. According to Rumble (2001), online tutoring costs, in terms of time spent by instructors in communicating with students, can be substantially higher relative to other instructional approaches. In a study of online learning programs at Syracuse University, Spector (2005) found no significant difference in outcomes between traditional face-to-face instruction and online courses; however, to achieve similar outcomes, students invested slightly more time in online courses. Faculty, who were experienced online teachers, invested considerably more time in online courses compared to traditional face-to-face courses.

Although Rumble (2001) finds that on average, online instruction may allow cost savings over face-to-face instruction, there is less evidence regarding the costs of online education relative to other types of distance education. He finds that the limited available evidence suggests that "e-education is pushing the costs of distance education up" (p. 85). This means that those who cannot afford such education are "being written out of the game" (p. 85).

Comparing Costs and Effectiveness

Once the effectiveness (E) and cost (C) of an educational intervention are determined, we can calculate an effectiveness–cost ratio (ECR) by dividing *E* by *C*:

$$\text{ECR} = E/C$$

The ECR represents the units of effectiveness of a given alternative for one unit of cost; the alternative yielding the largest ECR is the most cost-effective. Other researchers use a cost-effectiveness ratio (CER), which is calculated by dividing the cost of an alternative by its effectiveness. In this case, the most cost-effective intervention is the one with the lowest CER (Levin & McEwan, 2001).

Cost-Effectiveness of Educational Technology

Whereas information on benefits or costs in isolation is helpful to educational decision makers, the systematic comparison of both provides a much more powerful decision-making tool. Unfortunately, cost-effectiveness studies of educational technology are rare and evidence is mixed. Although there is a great deal of evidence regarding the effects of educational technology, it is difficult to combine this evidence with cost analysis, especially in the case of meta-analysis. Despite its value in assessing the effects of educational technology, several problems limit the use of meta-analysis for cost-effectiveness analysis. While meta-analysis provides general estimates of the effectiveness of a type of intervention, policy makers generally look to cost-effectiveness analysis to make decisions about specific programs or policies. Furthermore, it may be difficult or impossible to identify costs of relevant ingredients when effectiveness estimates reflect the average of many studies from different contexts and interventions (Levin & McEwan, 2001).

Due to the limitations of meta-analysis, evidence on the cost-effectiveness of educational technology comes primarily from evaluations of specific projects, usually conducted by economists, using various types of media and technology. For example, Levin, Glass, and Meister (1987) evaluated the cost-effectiveness of four primary-level educational interventions: a longer school day, computer-assisted instruction (a drill and practice program developed by the Computer Curriculum Corporation), cross-age tutoring, and reduced class size. Whereas the effect size of peer tutoring was highest among the four interventions (0.97 for math, 0.48 for reading), costs were lowest for reducing class size by five students, followed by lengthening the school day by 1 h. The mathematics CER was lowest for peer tutoring, followed by adult tutoring. Computer-assisted instruction was the fifth most cost-effective of eight interventions. In reading, the CER for computer-assisted instruction was second lowest among the eight interventions, following peer tutoring. Although computer-assisted instruction was more costly than increasing the school day and decreasing class size (except by 15 students) and less effective than adult tutoring, it was more cost-effective in raising reading achievement than all of these interventions. These results illustrate the importance of both costs and effectiveness, as determination of the "best" alternative depends on whether the decision-making criterion is costs, effectiveness, or a ratio of the two. This example also illustrates the common use of student test scores as a measure of effectiveness. While increases in student achievement are certainly an important outcome to consider, the degree to which they can be attributed directly to technology interventions—rather than to other unmeasured factors—raises some concern about whether these interventions would cause similar test score gains in other contexts.

Tsang (1995) identified several lessons regarding the cost-effectiveness of new educational media (p. 391): (1) although evidence suggests that new educational media help students to learn, the use of such media in traditional school settings is not cost-effective; (2) small media are more cost-effective than large media; (3) in sparsely populated areas, distance education may be the only way to educate children; (4) distance education for school equivalency is both effective and cost-effective; (5) to be effective, the use of educational media requires technical staff for operation and maintenance; and (6) because different types of media are often used together, it can be difficult to determine which type of medium is most suitable for a given project.

Angrist and Lavy (2002) found no evidence that the large-scale adoption of computers in Israeli schools helped to raise student test scores. They also concluded that the costs of such adoptions make them extremely inefficient. They estimated the cost of the Israeli program at $120,000 per school not including training costs, or the equivalent of one teacher per year per school. Rouse and Krueger (2004) estimated the cost of the *FastForword* reading and language program at $770 per student, not counting cost of the space or the indirect costs of rearranging schedules to accommodate the program. The authors conclude that the program is not cost-effective, except possibly for school districts with many students with needs addressed by *FastForword*. In contrast, Banerjee, Cole, Duflo, and Linden's (2005) evaluation of a computer-assisted mathematics program in urban India found that the program was both effective in boosting student test scores and very cost-effective. The authors estimated the cost to be only $15.18 per student, including the cost of computers. The authors also make an important distinction in computer use, alluding to the strategy of an Indian nongovernmental organization called Pratham. Banerjee et al. (2005) conclude that although computer-assisted instruction may not be the most cost-effective educational strategy in India, "turning computers already in the schools to productive use, as Pratham did in this program, is clearly a very cost-effective proposition" (p. 33).

Evidence regarding the cost-effectiveness of technology interventions is particularly salient in developing countries, where resources and educational access are much more limited. In such contexts, distance education—supported with available technology and media—can be an important way to increase access while reducing costs. There is some evidence of economies of scale of new educational media projects in these contexts. Moreover, "small" media projects, such as instructional radio, are much less costly than "big" media projects like television (Tsang, 1995).

As a result of rapid expansion of primary education in the 1990s and 2000s, coupled with increasing educational requirements for teachers, many lower income countries have turned to distance and online education to prepare and certify large number of teachers (Gulati, 2008; UNESCO, 2006). For example, in Indonesia, national legislation requires that all primary teachers hold a 4-year postsecondary degree and certification by 2015. This requirement has resulted in a massive national effort to upgrade and certify over one million teachers. Given the magnitude of this endeavor and the vast Indonesian geography, the Open University of Indonesia will play a central role in meeting teachers' demand for required degrees through distance education (Luschei, Dimyati, & Padmo, 2008).

Little systematic evaluation of Indonesia's or other large distance teacher education projects have provided evidence that they are either effective or efficient. In their analysis of distance teacher education programs in Indonesia and Sri Lanka, Nielsen, Tatto, Djalil, and Kularatne (1991) found that cost-effectiveness varied according to country circumstances and course subject. In Sri Lanka, distance education was more cost-effective than both conventional pre- and in-service training programs, whereas in Indonesia distance education was more cost-effective than conventional preservice training programs in language but less cost-effective in mathematics. However, if one only considers the costs invested by the government, distance education programs in both Indonesia and Sri Lanka were much more cost-effective than conventional face-to-face programs. On the other hand, opportunity costs for students are high. The authors also conclude that distance teacher education is particularly cost-effective in subjects that are "verbal and information-oriented, as opposed to math and skills-oriented" (p. 4).

Methodological Issues

Several methodological challenges stand in the way of rigorous evaluation of the cost-effectiveness of educational technology. Russell (2010) argues that the goals of large-scale technology adoptions in education are often ill defined, which makes the identification and measurement of appropriate outcomes difficult. Russell also underscores the importance of assessing *implementation* of technology, not just its presence in schools. Russell cites the experimental study by Angrist and Lavy (2002), which found that the provision of computers in schools does not increase student test scores. Russell argues that this study measures the impact of the *presence* of computers, rather than their use. Moreover, measures of technology use must extend beyond frequency of use and explore types and objectives of technology use in a more nuanced way (Russell, 2010).

A second important issue is the identification of causal links between technology-related interventions and student outcomes. To determine whether an educational intervention does cause the effect it is designed to, researchers use correlational, experimental, quasi-experimental, and meta-analytical techniques. Correlational methods or multiple regression analysis are most popular among educational studies, and these studies have potential for high external validity because they examine differences between treatment and control groups under natural conditions (Ross et al., 2010). But selection bias is often a major concern for such studies. That is, when attempting to assess outcomes of "treatment" and "control" groups, are individuals located in each group as a result of random chance, or through self-selection? If the treatment (or control) group self-selects into a group, then the estimated effect of an intervention on that group may be due to unobserved characteristics of the group or the individual, rather than the actual intervention (Ross et al., 2010).

Experimental and quasi-experimental studies can help to solve problems of selection bias, but they are not always feasible in practice. Experimental studies may also suffer from low external validity because conditions under which groups are assigned to treatments may not match the true conditions of technology adoption (Ross et al., 2010). Quasi-experimental methods, such as regression discontinuity, interrupted time series, and propensity score matching, also hold promise for assessing causality, but they cannot always fully control for observable and unobservable characteristics of individuals. Nonetheless, the use of this class of methods, coupled with increasing emphasis on rigor and relevance in educational research, can help to solve the many riddles of educational technology. At the same time, Ross et al. (2010) indicate that despite a growing emphasis on increased rigor in educational research to identify and promote evidence-based practices, the quantity of experimental studies to assess educational interventions, including technology-based interventions, has declined.

As discussed above, meta-analyses provide helpful summaries of a large quantity of studies, providing general answers to large and important questions. But for the purposes of assessing costs, the application of meta-analysis is limited. Additionally, meta-analyses are only as good as the studies they analyze. In their meta-analysis of research on the effectiveness of various types of distance education, Bernard et al. (2009) raise concerns about the quality of the underlying research:

> We have learned … that the research methodologies typically used to assess this phenomenon are woefully inadequate and poorly reported. Fundamental confounds associated with different media, different pedagogies, different learning environments, and so forth, mean that causal inferences about the conditions of design, pedagogy, and technology use are nearly impossible to make with any certainty (p. 1245).

Another important consideration in estimating effects is the multilevel nature of education and learning. Technology effects may differ across students within a classroom, across students within schools, or across schools within districts, states, or nations. Russell (2010) argues that researchers must take account of these multiple levels through the use of multilevel modeling; failure to do so can result in inaccurate and/or misleading estimates of the impact of educational technology on teaching and learning.

As difficult as it is to estimate the effects of educational technology, estimation of costs may be even more of a challenge, and is much more rare. Several analyses of cost studies in education have noted methodological problems and errors in the estimation of the costs of educational interventions (Belfield & Levin, 2010; Harris, 2009; Levin & McEwan, 2001). In the case of distance education, Rumble (1999) argues that many previous studies use traditional management accounting systems, do not recognize the wide variations in course design and student readiness, and fail to identify the real drivers of the costs of distance education.

Finally, cost analysis generally assumes a common outcome across competing alternatives. In contrast, educational technology interventions can lead to many outcomes, both short- and long-term. While short-term outcomes may include improved attitudes and technological skills, long-term outcomes like improved test scores may take longer to achieve. As Ross et al. (2010) argue, "it is incumbent on researchers to understand the multiple purposes and outcomes of complex technology interventions" (p. 22). Evidence of even longer term effects, such as course completion and labor market success, is also extremely important but limited. For example, little research has examined the impact of online instruction on degree completion, success in the labor market, or wages. One exception is Carnoy, Rabling, Castano-Munoz, Duart Montoliu, and Sancho-Vinuesa's (2011) study of degree completion at the Open University of Catalonia. The authors find that while completion rates are generally low for the university's students, students taking shorter degree courses are much more likely to complete their degrees than students in longer programs. These results have important implications for the design of online degree programs, as well as the ultimate labor market success of graduates of online programs. Yet although it is important to consider multiple outcomes of educational technology and their temporal nature, such consideration makes the estimation of costs even more complex.

Areas for Future Research

This review suggests many fruitful areas for future research. To begin with, the field needs more rigorous research designed to assess the causal effects of technology interventions, coupled with serious assessment of the costs of various alternatives. There is also a need for more research that acknowledges and explores nuances in the purposes, provision, and use of educational technology. Educational technology should not be treated as dichotomous variable, either present or not. The research reviewed here has found differences in the effectiveness of technology interventions based on their purpose and use (Tamim et al., 2011; U.S. Department of Education, 2009), level of instruction (Tamim et al., 2011), type of media used (Jamison et al., 1978), and subject matter (Machin et al., 2007; Nielsen et al., 1991). Several studies also indicate that technology effects vary across different contexts or over time (Banerjee et al., 2007; Jamison et al., 1978; Nielsen et al., 1991).

Finally, rigorous cost-effectiveness research is particularly important (but limited) in developing nations, where the stakes of resource allocation decisions are higher. Although much of the early research on the costs of instructional radio and television was conducted in developing countries (e.g., Jamison et al., 1978), as lower income countries adopt newer technologies like online instruction, a new generation of cost-effectiveness studies is needed. Work by Banerjee et al. (2007) in urban Indian slums raises an intriguing question: Can investments in educational technology have a greater impact in lower income settings, where resources are more scarce and children are much less likely to have computers or Internet in their homes? Although a long line of inquiry in international comparative education has found some evidence that school resources have a greater impact on student learning in lower income countries (Chudgar & Luschei, 2009; Heyneman & Loxley, 1983), much less research has explored the possibility that investments in educational technology can reap greater rewards among the most disadvantaged.

Conclusion

Several core conclusions emerge from this review of the costs and benefits (or effects) of educational technology. First, instruction using educational technology may be as effective as traditional classroom instruction, but it is important to estimate *causal effects* and incorporate key information, such as the purposes and context of technology use. Second, although some economists have argued that investments in educational technology are inefficient (e.g., Angrist & Lavy, 2002), others have found that interventions like distance education of teachers can be more cost-effective than traditional face-to-face methods (Nielsen et al., 1991; Tsang, 1995). Key considerations in assessing cost-effectiveness include the ratio of fixed costs to variable costs, the number of users, and the opportunity costs to students.

Although a great deal of excellent and rigorous research has assessed the effects and effectiveness of educational technology in enhancing student outcomes, when it comes to costs, researchers have barely scratched the surface. For example, the subject index of the program of the 2012 annual meeting of the American Educational Research Association does not include the terms "costs," "cost-effectiveness," or "efficiency." A search of submission titles in the online program of the 2010 annual meeting of the Association for Educational Communications and Technology found two mentions of "efficiency" or "efficient" and none of "costs" or "cost-effectiveness." In their excellent review of educational technology research, Ross et al. (2010) do not mention the words "cost" or "costs." This omission from the research leaves such calculations to educational economists, who care deeply about efficiency, but may have less nuanced understandings of the purposes and uses of educational technology. Future research on the cost-effectiveness of educational technology requires cross-disciplinary collaboration of economists, instructional designers, experts in educational technology, and others with relevant interests and expertise. The ultimate result of such collaboration will be more complete information to help educational decision makers and educators make the most of precious resources as they apply educational technology to enhance student learning and other important outcomes.

Despite the importance of future research, educators and educational decision makers need not wait years for concrete lessons from research on the costs and benefits of educational technology. The information presented in this chapter provides at least four lessons that can be applied to the use of technology in classrooms. First, technology can and should enhance learning and other outcomes for students of all ages. Considerable evidence suggests that students who have access to educational technology outperform students without similar resources. However, the second lesson from this review is that the simple existence of technology is not enough; educational technology must be put to use effectively to have a positive effect on student learning. Third, how educators use technology matters. As an example, some evidence suggests that technology may be more effective when it is used directly to support learning, rather than simply to deliver content. Finally, educators and educational decision makers must consider and demand information on costs of educational technology interventions. Simply knowing that educational technology can help students learn is not enough to ensure that students learn as much as possible given the limited resources that are available to teachers and schools.

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Planning a Program Evaluation: Matching Methodology to Program Status

20

Jennifer Hamilton and Jill Feldman

Abstract

As Federal agencies have increasingly specified the methodology expected in the program evaluations that they fund, the long-standing debate about what constitutes scientifically based research has been resurrected. In fact, there are no simple answers to questions about how well programs work, nor is there a single analytic approach to evaluate the wide variety of possible programs and their complexities. Evaluators need to be familiar with a range of analytic methods, and it is often necessary to use several methods simultaneously, including both quantitative and qualitative approaches. Some evaluation approaches are particularly helpful in the early developmental stages of a program, whereas others are more suited to situations in which the program has become more routinized and broadly implemented. One of the key points that we stress in this chapter is that the evaluation design should utilize the most rigorous method possible to address the questions posed and should be appropriately matched to the program's developmental status. The warnings not to evaluate a developing program with an experimental design have been sounded for some time [Patton, M.Q. (2008). *Utilization focused evaluation* (4th ed). Thousand Oaks, CA: Sage; Lipsey, M. (2005). *Improving evaluation of anticrime programs*. Washington, DC: National Academies Press], but this is the first time to our knowledge that the developmental phases of program development have been specified in detail and linked to evaluation designs.

To guide design decisions, we present a framework that builds on the goal structure devised by the Department of Education's (DoE) Institute of Education Sciences (IES). It is important to note however that designing a program evaluation is often a complicated process, and the ultimate design rarely comes straight out of a textbook. Rather, design decisions require responsiveness and judgment particular to each setting, given the practical constraints of time and resources. Our intent is therefore not to be prescriptive, but rather to provide guidance, tools, and resources to help novice evaluators develop evaluation designs that are responsive to the needs of the client and appropriate to the developmental status of the program.

Keywords

Program evaluation • Formative evaluation • Summative evaluation • Fidelity • Experimental design • Quasi-experimental design

Over the last decade, Federal agencies have increasingly specified the methodology expected in the program evaluations that they fund, with a particular emphasis on randomized trials (e.g., US Department of Education, 2002, 2004, 2005, 2007; What Works Clearinghouse, 2011). This focus

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has resurrected the long-standing debate about the appropriateness of experimental designs in education with attendant criticism of the role of the legislature in defining what constitutes scientifically based research (Chatterji, 2004; Eisenhart & Towne, 2003; Erickson & Gutierrez, 2002; Julnes & Rog, 2007; Olson, 2004; Schoenfeld, 2006; Slavin, 2002, 2004; St. Pierre, 2002). Although much of the backlash around this debate has focused on the ascendancy of experimental designs as the gold standard of evaluation, they are not always the most appropriate design, nor does the DoE necessarily require them. Much depends on the audience for the evaluation. Decision makers at the national level tend to favor quantitative methods because they are accustomed to basing funding decisions on statistical indicators. In contrast, stakeholders at the local level can be skeptical about statistics and often prefer the richer data obtained through qualitative methods (National Science Foundation, 2010).

In fact, there are no simple answers to questions about how well programs work, nor is there a single analytic approach to evaluate the wide variety of possible programs and their complexities. As a result, evaluators need to be familiar with a range of analytic methods, and be able to use several methods simultaneously, including both quantitative and qualitative approaches. Some evaluation methods are particularly helpful in the early developmental stages of a program, whereas others are more suited to situations in which the program has become more routinized and broadly implemented. One of the key points that we stress in this chapter is that the evaluation design should utilize the most rigorous method possible to address the questions posed and should be appropriately matched to the programs' developmental status.

To guide these design decisions, we present a framework that builds on the goal structure devised by the DoE's IES Request for Applications. With more than $200 million in funding, the chief function of IES is to raise the capacity of education evaluators to conduct rigorous studies (IES, 2012a). Given this, we view the goal structure of IES solicitations as particularly relevant for aligning evaluation designs with programs at various stages of development. It is important to note, however, that designing a program evaluation is often a complicated process, and the ultimate design rarely comes straight out of a textbook. Rather, design decisions require responsiveness and judgment particular to each setting, given the practical constraints of time and resources. Our intent is therefore not to be prescriptive, but rather to provide guidance, tools, and resources to help novice evaluators develop evaluation designs that are responsive to the needs of the client and appropriate to the developmental status of the program.

For a detailed discussion of principles and standards undergirding best practices in evaluation, readers are referred to the standards issued by the Joint Committee on Standards for Educational Evaluation (2010) and those of the Evaluation Research Society (1982). The American Educational Research Association (AERA, 2008), American Evaluation Association (AEA, 2004, 2009), and What Works Clearinghouse (WWC, 2011) provide additional information about standards of evidence in studies of educational programs. For those more interested in a detailed discussion of various evaluation methodologies, there are many excellent resources available, including Hedrick, Bickman, and Rog (1993); Patton (1990); Shadish, Cook, and Campbell (2002); and Weiss (1972).

Distinguishing Between Evaluation and Research

Before we go much further, we need to take a moment to clarify how we are distinguishing between research and evaluation. Research is grounded firmly in the experimental method, and its goal is the creation of new scientific knowledge. Typically, research questions do not address the quality of a specific program, but instead focus on gaps in theory or in certain areas of knowledge. Evaluation uses similar methods and procedures but has different goals. Rather than identifying gaps in knowledge, program evaluations help stakeholders answer specific questions about a program and its components (Yarbrough, Shulha, Hopson, & Caruthers, 2011). Patton draws the distinction this way, "research seeks to prove, evaluation seeks to improve …" (Patton, 1990). Furthermore, research is typically self-initiated by scholars working in an academic environment. Researchers have more control over both the research topic and the research environment than does the evaluator who has to contend with more external intruding factors, such as those occurring within a school setting (Hedrick et al., 1993; Levin-Rozalis, 2003). Evaluation thus has more numerous and varied purposes, has a less controllable context, and is more complex than research (Bickman & Henchy, 1971).

The remainder of the chapter presents an organizing framework for planning program evaluations. It also describes typical elements of evaluations at each stage.

An Evaluation Planning Framework

In 1964, Kaplan issued a famous warning against "the law of the instrument." He warned that where a methodology is equated with a field of inquiry, it limits the field to only what can be answered by the method. Taking that warning to heart, this chapter stresses that there is a time and a place for experimental designs, but they should not necessarily define the field of program evaluation. Experimental designs provide the important causal mechanism that links program participation to the outcome of interest. Quasi-experimental designs (QEDs) can also make this causal connection, under

Table 20.1 Evaluation framework

IES evaluation category	Stage of program development	Research questions	Audience/evaluator	Evaluation design(s)/approaches	Evaluation products
Exploratory	Idea generation	Is my idea likely to work? What has already been tried? Is there a demand for my idea?	Program developer is the audience/evaluator is often internal	*Descriptive:* Needs assessment	*Informal and iterative:* Literature review, description of need
Development and innovation	Program being developed and implemented in limited number of sites	How is the program working? Have I got the right components? How can it be improved?	Program developer is the audience and possibly also funding agencies/evaluator can be internal or external	*Mostly descriptive:* Developmental evaluation, design-based research, pilot studies, evaluability assessment	*Informal and iterative:* Logic model, program description, implementation feedback, initial evidence of promise, evaluability findings
Efficacy and replication	Program is fully developed, not yet tested	Is the program effective under ideal conditions? Does it need further refinement? Is it ready for wider dissemination and testing?	Audience is broader. Often program developer; funding agencies; Federal, state, and local decision makers/evaluator is external	*Experimental/quasi-experimental:* Including implementation data fed back to program developers to improve performance	*Formal*: *some iterative:* Report on program impacts including identification of key active ingredients. Ongoing (iterative) reporting of implementation data
Scale-up	Program is fully developed with some indication of effectiveness	Is the program effective under real-world conditions?	Audience is broader. Often program developer; funding agencies; Federal state, and local decision makers/evaluator is external	*Experimental/quasi-experimental:* Implementation data used to help understand findings (is not fed back to program developers)	*Formal:* Report on program impacts including identifying for whom the program works, and under what conditions, and implementation information

the appropriate conditions. However, the field of program evaluation is broader than this, and causal inference is not the only thing evaluators are interested in (American Evaluation Association, 2009). As Patton (1987) states "evaluators need to know a variety of methodological approaches in order to be flexible and respond in matching methods to the nuances of a particular evaluation."

Table 20.1 provides a framework for matching evaluation methodologies to stage of program development. Programs typically (but not always) move through a series of stages sequentially, and evidence collected at each stage supports progression to the next. The first column of Table 20.1 uses IES categories (IES, 2012b) that divide program evaluations into four groups (exploratory, development and innovation, efficacy and replication, and scale-up). The second column links these evaluation categories to the programs' stage of development, while the third column provides some examples of the types of evaluation questions asked at that stage. The fourth column identifies the primary audience(s) for the evaluation and whether the evaluator tends to be internal or external. Next are the evaluation designs and approaches that are typically used during each developmental stage, and examples of the evaluation products created at each stage.

The framework presented in Table 20.1 can also be thought of in terms of formative versus summative evaluation. Formative evaluations are designed to answer questions about how a program works. Scriven (1991) describes formative evaluations as being conducted during the development of a program with the intent to improve. Thus, a major benefit of a formative evaluation is that it supports midcourse corrections and improves implementation. Summative evaluations, in contrast, provide information on the program's efficacy (outcomes when implemented under ideal conditions) or effectiveness (outcomes under routine conditions). Robert Stake is quoted as saying "When the cook tastes the soup, that's formative; when the guests taste the soup, that's summative" (Scriven, 1981). In practice, it is common for a program evaluation to have some questions that are formative in nature and others that are summative. Looking at the evaluation stages presented in Table 20.1, it is possible to envision a continuum moving from almost completely formative in the first row (exploratory) to almost completely summative in the last row (scale-up). A more in-depth treatment of formative and summative evaluation goes beyond the scope of this chapter. Interested readers are referred to Stufflebeam and Shinkfield (2007), Flagg (1990), and Reeves and Hedberg (2003) for more information.

Stage 1: Exploratory

IES defines the goal of this initial stage as "exploring relations between educational outcomes and malleable factors (i.e., factors that can be changed, such as teacher practices) as well as mediators or moderators of those relations. This type of study is intended to inform the development of interventions that can improve outcomes" (IES, 2012b). The efforts of the program developer are thus focused on identifying and understanding the problem, generating ideas or methods to overcome it, and investigating the efficacy of other methods that have been attempted in the past. The evaluator is usually internal to the development team, or may be the program developer herself. Although external evaluations are not typical at the exploratory stage, independent evaluators can serve as "critical friends" and are sometimes recruited to serve on advisory boards to provide guidance and advice.

The evaluation design at the exploratory stage is largely descriptive in nature, as the goals tend to be understanding of the nature of the problem—generating ideas and constructing a proof of concept. Therefore, this type of evaluation tends to be the least structured of designs and is frequently first in a series of studies on a topic (Hedrick et al., 1993; Lofland & Lofland, 1995).

A common design approach at this stage is to conduct a needs assessment. A needs assessment is a systematic process for determining "gaps" between current conditions and desired conditions. The discrepancy between the current condition and desired condition must be measured to appropriately identify the need. For more information on this topic see Altschuld and Kumar (2010).

Data collection methods used at the exploratory stage are largely qualitative because the evaluation questions typically solicit initial ideas about the feasibility of using a hypothesized approach. Quantitative (data in the form of numbers) and qualitative (data in the form of words) both have their advantages and disadvantages. Conventional wisdom holds that it is usually best to consider using both in ways that complement each other (Mark & Shotland, 1987). Usually, evaluators collect qualitative data to add depth and a fuller understanding of the complexities of a program or an idea. At this exploratory stage, the focus is usually on collecting qualitative information through reviews of existing literature, interviews, focus groups (Stewart & Shamdasani, 1990), observations, and case studies (US General Accounting Office, 1990). Quantitative approaches can also be useful at the exploration stage if, for instance, the objective is to conduct a meta- or cost–benefit analysis or to collect initial evidence that an approach is promising for improving outcomes.

Synthesizing the data collected into a format that is useful to the client is a critical activity in any evaluation. Evaluation products at the exploratory stage are more informal and iterative than deliverables produced during later stages of program development. One goal of exploratory studies is to initiate a continuous feedback loop between evaluator and developer that quickly translates data into program decisions. Unless required by the funder, open discussions and presentations are often the delivery method for sharing findings from an exploratory study, rather than a formal report. However, written deliverables can include a summary report that outlines the results of a literature review, and a description of need resulting from related analysis. If there is a determination of adequate need, and evidence indicates that the concept holds promise, then the program begins to be developed and we move on to the next stage, Development and Innovation.

Stage 2: Development and Innovation

The focus of the development and innovation phase is on the "development of interventions for use in authentic education delivery settings and the generation of pilot data showing the intervention's promise for generating beneficial student outcomes" (IES, 2012b, p. 44). During this phase, the program is being actively developed and implemented in a small number of pilot sites. The evaluator and developer are again in close contact, where evaluation findings are iteratively fed back to guide the design of program materials, which are field-tested, refined, and retested. As in the exploratory stage, the evaluator is usually internal to the development team, while the audience for the evaluation findings becomes slightly wider, with the possibility of various funding agencies and local decision makers becoming interested in the results.

There are a wide range of designs and approaches that are appropriate at this stage, and their selection largely depends on the needs of the client (in addition to practical constraints of time and funding). A handful of the most common are provided below.

Developmental evaluation is particularly well suited to this stage in the development of a new program. Its explicit purpose is to help develop an intervention and is particularly useful in situations where the outcomes are emergent and changing. Here, the evaluator becomes part of the program design team with the role of facilitating team decisions by "infusing evaluative questions, data, and logic, and supporting data-based decision making" (Patton, 2011, p. 20).

Design-based research (DBR) provides rich descriptions of the study context, implementation challenges, development and administrative processes, and the design principles that emerged (Anderson & Shattuck, 2012). Use of DBR involves using mixed methods to design and test an intervention through an iterative and collaborative partnership involving researchers and practitioners that results in actionable theories that directly relate to practice in a particular context. See Anderson and Shattuck (2012) and McKenney and Reeves (2012) for more information on this method.

Pilot studies are often conducted during a program's development phase to provide initial evidence that key program components can be implemented in an authentic classroom setting. Some additional advantages of conducting pilot studies include assessing whether the program components are feasible to implement; testing program materials, evaluation protocols, and analytic techniques; and using findings to convince funders that continued investment in the program is worthwhile. For a very practical guide on this subject, see Teijlingen and Hundley (2001).

Toward the end of this stage, an Evaluability Assessment (EA) can be conducted. An EA can help determine if a program is ready for a summative evaluation. The EA approach was developed in 1979 by Joseph Wholey, and can help ensure that precious evaluation resources are used at the most appropriate time. Lipsey (2005) provides an exhaustive list of factors considered at each stage of EA. For more information on EA, see the Office of Juvenile Justice and Delinquency Prevention (2003), Smith (1989), and Youtie, Bozeman, and Shapira (1999).

Evaluations conducted at the development and innovation stage produce deliverables aimed at (1) clearly describing the intervention, (2) refining and field-testing instructional resources and associated professional development, (3) operationally defining observable features of implementation, and (4) selecting methods and creating protocols to document the extent to which actual implementation matches the intended program model. A key deliverable produced at this stage is a logic model, which graphically represents the program processes hypothesized to improve the outcomes of interest. For more information on creating logic models see W.K. Kellogg Foundation (2004), National Science Foundation (2010), and Mayeske and Lambur (2001). The process of working with an evaluator at this stage is iterative and produces feedback to support program development and generate evidence about implementation of key program components. Findings from development and innovation studies provide the basis for conducting more rigorous summative evaluations at successive stages.

Stage 3: Efficacy and Replication

In the efficacy and replication stage the goal is to evaluate the effectiveness of a program under ideal conditions. It attempts to discover whether the program can have a positive impact on outcomes when significant implementation support is provided. Programs that are difficult to implement under these supported conditions are unlikely to be well implemented in real-world conditions where there is no (or very limited) implementation support. While efficacy and replication and scale-up studies tend to utilize very similar designs, an important distinction is that the implementation results are continuously fed back to the implementation team during an efficacy and replication study. Although implementation is measured at the scale-up stage, this information is not fed back to program staff.

The use of a comparison (or control) group and a focus on more quantitative study designs are key features distinguishing efficacy and replication studies from investigations conducted during earlier phases, and the goals have shifted from being mostly formative to being mostly summative. However, before embarking on a summative evaluation, there are four general conditions that need to be met (Lipsey, 2005):

1. The program is sufficiently developed and documented.
2. It is possible to collect relevant and reliable data.
3. The research design can distinguish program effects from other influences.
4. There are sufficient resources to adequately conduct the evaluation.

In summative evaluations, the objective is to provide evidence that a program's components resulted in the expected outcomes. The task is to demonstrate that not only those outcomes occurred but also the outcomes can be attributed to the program, and not to something else. Demonstrating causality is achieved by dividing the pool of potential participants into two groups—those who receive the program (the treatment group) and those who do not (the control or comparison group), and comparing outcomes for these two groups. How these groups are formed, either randomly or by some form of matching procedure, determines whether the study is considered experimental or quasi-experimental. In the Stage 4: Scale-Up section, we talk in more detail about the design methodology of experimental and quasi-experimental evaluations, but a key resource in this area is Shadish, Cook, and Campbell (2002).

The degree to which a program is practical to implement is determined through an assessment of implementation in general and through determining the fidelity of implementation in particular. It is useful to distinguish between measuring implementation generally and measuring fidelity of implementation more specifically. Broadly speaking, the measurement of implementation is qualitative and attempts to describe what transpired as the program was put into place. It describes the context of the study, and can help the evaluator to understand the extent to which outcomes may be unique to a given context (Cook, 2002). Fidelity is as a subset of implementation, defined as the extent to which the program as implemented is faithful to the pre-stated model (Cordray, 2007), and is increasingly being recognized as a necessary part of program evaluation (US Department of Education, 2003). Fidelity is a quantitative series of measures, usually made up of a score for each program component, which is then weighted and combined into an overall fidelity score. There are a number of well-defined steps for measuring fidelity, as described in O'Donnell (2008); Dane and Schneider (1998); Century, Rudnick, and Freeman (2010); Scheirer and Rezmovic (1983); and Resnick et al.

(2005). Measurement of implementation fidelity occurs at both the efficacy and replication and scale-up phases, although the findings are used differently. During the efficacy and replication phase, implementation findings continue to be fed back to developers to close gaps in the intended versus the enacted program model.

As the efficacy and replication stage moves out of the formative and into the summative realm, the audience for the evaluation also shifts. Federal and local funding agencies and policy makers are likely to have heightened interest in results from these studies, in addition to interest among program developers, and local decision makers. In addition, to generate independent evidence of a program's effects, the evaluator of programs in the last two phases is more likely to be independent and external to the implementation team.

Evaluation products resulting from efficacy and replication studies usually include a formal report of findings, including identification of any key active ingredients in the program. If the findings are promising, and implementation of the program is practical, then the next stage is to implement the program in more and increasingly diverse settings and evaluate it in the scale-up phase.

Stage 4: Scale-Up

The purpose of a scale-up study is to generate estimates of program impact when implemented under conditions of routine practice. That is, users implement the program without support from the developer or the evaluator (using only what is available to users who would purchase the program "off the shelf").

As in previous stages, the collection of implementation data is critical here too. Even though it is not being used to improve implementation, the information provides important contextual information about, and confidence in, the findings. At this stage, documenting fidelity provides evidence that helps to distinguish whether poor program outcomes are a result of a lack of implementation fidelity, or due to an ineffective program (WWC, 2011). In addition to providing a rich descriptive context for understanding how or why a program produces particular outcomes, implementation data can empirically link variations in fidelity and outcomes.

In addition to documenting implementation, evaluations at this stage must be able to attribute outcomes to the program, and no other cause. As described previously, this can be done using either an experimental or a quasi-experimental design. The main advantage of an experimental design is that it provides "strong methods for establishing relatively unequivocal causal relationships between treatment and student achievement variables" (Madaus, Scriven, & Stufflebeam, 1996). Carried out correctly, and with appropriate sample sizes, random assignment results in groups that are similar in both observable and *unobservable* characteristics. As a result, differences in outcomes between the two groups are attributable to the program alone, within a known degree of statistical precision. Correctly designing and implementing the randomization process is therefore a critical and essential element of an experimentally designed program evaluation. A very accessible resource on experimental designs is Kirk (1995).

While it is the strongest design to support causal inferences, an experimental design is not always appropriate, ethical, or feasible. Much has been written about the ethical concerns of depriving services to the participants who are randomly assigned to a control group. The importance of this issue cannot be overstated, and requires significant thought during the design stage. There are some strategies that may allay these concerns. One is to limit the experiment to programs with a waiting list of participants. In this case, the program cannot serve everyone, so even without the evaluation, not all individuals would be served. Selecting participants from the waiting list randomly (by lottery) is often felt to be fair. Another option is to provide the control group with the treatment after a delay.

A QED can be similar to an experimental design, but lacks the key ingredient of random assignment. The QED intervention group includes participants who were selected through another process (such as a school administrator or teacher determining which students receive the program), along with a matched comparison group of nonparticipants. As a result, a QED must demonstrate that the treatment and comparison groups are equivalent on observable characteristics at baseline. However, even with equivalence on observable characteristics, differences in unobservable characteristics may still exist. For instance, the comparison group might comprise individuals who had the option to receive the program but declined, resulting in two groups that are likely to differ systematically in their level of motivation or interest.

The method used to match the treatment to the comparison group members can improve group equivalence at baseline. Generally, it is best to match on variables that are highly correlated with the outcome, such as pretest scores. A relatively new and popular method of matching is the propensity score matching (PSM) approach (Rosenbaum & Rubin, 1983). Its basic idea is to find a group of nonparticipants who are similar to the treatment group participants in all relevant pretreatment characteristics. To do this, a propensity score (i.e., the probability of participating in a program given observed characteristics) is calculated using as many predictor variables as possible. However, PSM requires a large sample size, which can limit its applicability.

While in-depth treatment of the broad range of specific designs goes beyond the scope of this chapter, readers are encouraged to read Shadish, Cook, and Campbell (2002) who provide an authoritative and thorough review of experimental and several quasi-experimental designs. In addition, the WWC *Procedures and Standards Handbook* provides a detailed discussion of factors to keep in mind when designing a quasi-experimental or an experimental study so that it meets the highest standards for rigor (WWC, 2011).

An important factor to consider in any summative design is the power of the design to detect treatment effects, when they exist. The estimation of power is a critical component in the design of experiments, and is calculated to ensure that the sample size is sufficiently large (Cohen, 1988; Lipsey, 1990). Free software is readily available online that will calculate power for a variety of evaluation designs—the most common one is the Optimal Design Software available at the University of Michigan Web site http://sitemaker.umich.edu/group-based/optimal%20design%20software.

Conclusion

Using guidance provided by the IES as a foundation, readers are offered a framework to help guide the selection of an appropriate evaluation design that is consistent with the developmental status of the program. Evaluations conducted in the early phases of a program's development are geared toward describing the need for the program, providing information to guide the development of the program, and detailing how the program is implemented. In short, the initial stages are largely formative in nature, because their goal is program development and improvement.

Once a program has been fully developed and is stable, more summative evaluation methods are used. In the final two stages, the goal is to estimate the impact of the program under optimal conditions, and then under real-world conditions. The difference between these two conditions is that in the optimal condition, the implementation information is used by program staff throughout the evaluation to maintain high levels of program fidelity. In the real-world condition, the implementation information is used to help describe the context and to attempt to explain why the program works and under such conditions. To estimate program effects, either experimental or quasi-experimental designs are recommended, with random assignment distinguishing experimental from quasi-experimental designs.

Notice that at every stage, the collection of implementation information plays an important role in the evaluation. In all stages they are used to describe the context under which the program operated so that potential adopters of the program can determine the likelihood of finding similar results in their classrooms, schools, and districts. In earlier stages, these data are also used to improve performance and fidelity.

In addition to the framework provided, readers should familiarize themselves with established evaluation standards and the broad array of available literature on the subject. It is important to remember that there is no single approach to evaluation, and evaluators therefore need to be familiar with a range of designs including both quantitative and qualitative approaches. Design decisions also require responsiveness and judgment particular to each setting, given the practical constraints of time and resources. Our goal in writing this chapter is to provide guidance, tools, and resources to help novice evaluators develop evaluation designs that are responsive to the information needs of the client and appropriate to the developmental status of the program.

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Perspectives on Assessment of Educational Technologies for Informal Learning

21

Wilhelmina C. Savenye

Abstract

Informal learning is a complex area, yet one that increasingly involves educational technologists in practice and research. Informal learning includes many different settings, contexts and goals, and draws upon many fields. Two fields that have yielded considerable research literature are museum/free-choice learning and informal science education. While some have defined informal learning as nonschool learning, the nature of informal learning includes dimensions such as location, timing, structure, control, pacing, regulation and content, and so informal learning is not necessarily tied to space. This means that informal learning can and does occur frequently in museums, after-school clubs, botanical gardens, zoos, science centers, and community centers, but can also be engaged in at home and also be integrated within formal school or college settings. Informal science education, museum learning and workplace learning are designed for varied outcomes and have different frameworks. Reasons for assessing for informal learning include to provide formative feedback to participants and to provide evaluation data to improve the organization's learning goals. Methods for assessment for informal learning encompass both quantitative and qualitative approaches, including traditional tests and measures, but primarily rely on such methods as surveys, group and individual interviews, observations, artifact and product analysis, and sometimes ethnographic or case studies. Emerging educational technologies, such as social media, Web 2.0 tools, eLearning and online learning, provide fertile ground for continuing developments in informal learning and assessment.

Keywords

Informal learning • Informal science education • Assessment • Evaluation

Introduction

As we begin to review the perspectives, issues, approaches and a few of the methods involved in assessing learning in informal environments we face the reality that this is a complex area of practice and research. There are many factors operating in varied ways, numerous complex issues, a diversity of views and approaches, few easy answers, and even some possibly political and controversial concerns. However, one might contend that there is more freedom in working in informal environments than in more formal learning settings. This freedom does come with considerable professional responsibility.

In this review we draw upon theoretical views, approaches, methodologies, and findings from several seemingly disparate fields. These fields, not unexpectedly, include instructional design and development, technologies for learning, evaluation, and assessment. However, free-choice/museum

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learning and informal science education are two critical fields in which, arguably, the majority of the informal learning work to date has taken place. We also draw from work in qualitative research methods, workplace learning, eLearning, anthropology, social media/Web 2.0 tools, and other emerging technologies. These diverse fields contribute to a deep and productive understanding of how to assess educational technologies in informal learning contexts.

Our perspective as we begin, is that educational technology includes both processes and technologies, all forming systems designed to improve learning and performance in a wide variety of settings (Reiser, 2012). Like others in informal learning we hold a somewhat "pragmatic" or practical and mixed-methods perspective. Some would term this simply pragmatism (Smith & Ragan, 1999). We tend to agree with Reeves and Hedberg in their discussion of evaluation for technologies, that what they term "Eclectic-Mixed Methods-Pragmatic" is "…the one approach capable of handling the complexity (some would say chaos) that is the hallmark of contemporary society and technology" (2003, p. 34).

Our purpose in this short review is not to provide a manual or handbook on assessment for informal learning; our space is too limited to do that justice. Our purpose is instead to aid the educational technologist working in diverse informal learning contexts and environments by providing a broad overview of ways to approach and make decisions about assessment.

We begin our review by exploring what informal learning is, including definitions, models, frameworks and some arguments. We then explore the purposes and issues involved in assessing learning in informal environments. We examine a few of the key methodologies for assessing informal learning, especially those that involve new and emerging educational technologies. We conclude with recommendations for investigating the evidence of learning from the broad approach that informal learning provides. We close the chapter with a set of resources educational technologists may use to aid them as they endeavor to assess learning in informal environments.

What Is Informal Learning?

What Is Learning?

Falk and Dierking (2000), in their work on free-choice learning, particularly in museums, provide us with a note of caution with which to begin our examination of informal learning: "… learning is *common* but definitely not *straightforward*…" (p. 149). In school learning we often see the term achievement, while workplace learning frequently includes the terms competence and performance. In both settings learning often includes mastery. Defining learning itself may seem simple. However, learning has been defined many ways in the field of educational technology, education in general and in informal learning. Gagne, one of the early and seminal leaders of the field of educational technology, defines learning as a change in an individual that is persistent and that results, not just from growth, but from that person's interaction with his or her environment (Gagne, 1984).

A leading technology proponent of social media in her book for trainers adds to our views of learning by contending that most workplace learning occurs *between* formal training or educational events (Bozarth, 2010). Bingham and Conner (2010), in their review of social media, add that workplace learning provides an organization with a "competitive advantage," adding that, "Social learning is a fundamental shift in how people work—leveraging how they have always worked, but with new tools to accelerate and broaden individual and organizational reach" (p. 5). Cross (2007), too, focuses on informal workplace learning: "Learning used to focus on what was in an individual's head… The new learning focuses on what it takes to do the job right" (p. 5). And so we begin our discussion of the dimensions of informal learning by having already expanded our view of learning.

Definitions and Dimensions of Informal Learning

" …'informal learning' is a metaphor with a severe problem," according to Straka (2004, p.2). He describes a two-dimensional continuum from "explicit" to "implicit" and then from formal to informal "external conditions" surrounding the learner (p. 12). Straka concludes that formality is socioculturally determined and he prefers the term "non-formal education" (p. 13). Sefton-Green (2004) for the FutureLab in the UK concurs, adding that currently the term informal learning is used "quite loosely" (p. 6). He, too, sets up two dimensions related to informal learning, that is the degree of formality/informality of the "organization" of the learning, compared with the degree of formality/informality of the "setting" in which the learning occurs (p. 6). The Organization for Economic Co-operation and Development (n.d.), notably, does consider informal learning to be learning that is not organized in any way, and uses the term non-formal to mean learning activities that are out of school, but are organized and may have learning objectives.

Another aspect of this discussion is that learning activities may be "intentional" or "incidental". Clark (2010) defines "an intentional learning environment" as one designed to help learners accomplish certain objectives and goals, while incidental learning involves learners picking up skills or information on their own, without that necessarily having been the purpose of an environment. (It should be noted that learners themselves may have intentions to learn and seek out this learning.) Clark further contends that both informal and formal learning can include both incidental and intentional learning. He argues that the distinction between formal and informal learning rests in who is directing the development of the learning materials or programs. Clark, too, holds that formal and informal learning represent "part of a continuum" (p. 1).

For the purposes of this chapter, we include in our definition of informal learning activities that may be somewhat organized and planned, though that typically take place out of school, university, or formal training settings. This definition is in line with that of the National Science Teachers Association (2012) related to informal science education.

Hofstein and Rosenfeld (1996) have tackled "bridging the gap between formal and informal science learning" (p. 87), noting too, that there is little agreement about definitions. Informal learning activities can take place in formal/school settings and vice-versa, and informal settings, such as museums, can support "formal" learning activities, such as classes or courses. Hofstein and Rosenfeld term this a "hybrid" (p. 90) definition of informal learning.

Free-choice learning is the preferred term by several museum and informal educators and researchers (Falk, 2001; Falk & Dierking, 2002). They argue that the definition of learning should not depend upon a specific setting and that this term is more descriptive, more all-encompassing and more neutral. They reiterate the key dimensions of free-choice learning: "free-choice, non-sequential, self-paced and voluntary" (Falk, 2001, p. 7). Cross (2007) advocates for helping learners become much more self-directed, especially in our information and technology-rich world and he uses the term "free-range learners" (p. 175).

Rossett and Hoffman (2012) describe informal learning as defined by six factors, related to the type of outcomes and experiences desired and to be designed: the source of the informal learning and the roles of the learner, instructor and designer. One aspect of our discussion is that it is now clearer why these many terms tend to all be used interchangeably: informal learning settings, informal learning contexts, informal learning environments and informal learning experiences. Being comfortable now that the terms may vary and that there is little general agreement about the definitions, but considerable agreement on dimensions, we rely on the term "informal learning."

A Framework for Informal Learning

The US National Research Council (NRC) report (2009) on learning science in informal environments presents an "ecological framework for understanding learning across places and pursuits" (p. 31). The report also adds place and culture to the mix. We can see that some of the key differences between formal and informal learning make effects of informal learning hard to measure. For example, the NRC report notes that informal learning experiences are often short and spontaneous. What occurs cannot always be completely planned or predicted. Pleasure and fun are often important goals. Such informal learning experiences often result in "unexpected" and "emergent" outcomes (p. 63). In them, learners may choose to follow their own paths and develop their own goals.

Developing Outcomes, Goals and Objectives: Examples from Informal Science Learning

The key is to determine, "What is success?" in our particular informal learning situation. This is seldom easy. In the workplace, Allen's (2007) "success-based design" in eLearning is based on "measurable improved performance" (p. 51). In training and education, learning goals are developed, which lead to measurable and observable learning objectives. Cennamo and Kalk (2005) call the activities related to writing objectives and then assessments to measure learners' performance on them, "defining success" (p. 49).

Informal educators have long called for a broader view of indicators of success and effectiveness. It is common for museums, for example, to strive for deep impact on visitors in other forms. If learning is a change in the individual as a result of his or her experience and interaction with a (learning) environment, then educators in informal learning environments often look for a learner's increased interest and excitement about a topic, desire to learn more, change in conceptions, surprise about new learning, and even change in an individual's perceptions of identity with regard to a topic or field.

Science education is arguably at the leading edge of informal education. The US National Science Foundation includes an Informal Science Education program, currently under NSF's Division of Research on Learning in Formal and Informal Settings (NSF, 2011). The NSF has supported projects such as the National Partnerships for After-School Science (NPASS2), which provides science-learning resources for after-school educators (Education Development Center, 2012a). Many informal science learning projects and programs represent partnerships among after-school programs, and community organizations, science centers, museums, zoos, and botanical gardens. For example, Design It! Engineering in After School Programs represented projects developed by after-school programs in partnership with such organizations (Education Development Center, 2002).

The NRC report (2009), focused on informal science learning, notes that outcome statements are not only useful to stakeholders, but are often required by funding agencies. However, it notes that, "… traditional academic achievement outcomes are limited" (p. 3), in that they often do not include the range of goals and settings of informal learning and may in fact "… violate critical assumptions about these settings, such as their focus on leisure-based or voluntary experiences and non-standardized curriculum" (2009, p. 3).

The NRC report outlines six "Strands of Science Learning" which provide useful models for how those working in other settings might develop their learning goals and/or objectives (2009). The strands begin, notably, not with traditional learner achievement, but with attitudinal learning. They include deep, wide, and complex science learning goals and conclude with goals related to a learner's changed view of science and themselves as scientists.

Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.

Strand 2: Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.

Strand 3: Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.

Strand 4: Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own processes of learning about phenomena.

Strand 5: Participate in scientific activities and learning practices with others, using scientific language and tools.

Strand 6: Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science (p. 4).

Keeping in mind that the NRC report calls informal learning, "lifelong," "life-wide," and "life-deep" (2009, p. 28), we turn now to the range of purposes of assessing for informal learning.

Why Assess for Informal Learning?

Definitions of Assessment (and of Evaluation)

What is assessment? Assessment is typically defined as measuring learning. In their book on distance education, Simonson, Smaldino, Albright, and Zvacek (2012), for instance, define assessment as, "the process of measuring, documenting, and interpreting behaviors related to learning" (p. 262). What is measured is individual learning, both for their benefit and for use in improving instruction. Virtually all instructional design models and frameworks direct that learning must be measured in order for instruction to be evaluated and improved.

How does assessment relate to evaluation? Most educators and researchers make a distinction between evaluation and assessment. One way to look at this would be that there are two aspects to be examined, the learner's performance (assessment) and the instruction or learning environment (evaluation). Evaluation is usually focused on a program, course or organizational level. Evaluation does include assessing learning, but also the activities involved in making judgements and decisions about the quality of the program or initiative as a whole.

Evaluation includes what may be considered "types" or "phases". These begin with *front-end evaluation,* in some projects also called needs analysis, to gather data to aid in the later design and development processes. *Formative evaluation* is conducted to collect data to aid in improving a program, product or approach during development, ideally on an ongoing basis. *Summative evaluation* is done typically at the end of development for reporting purposes, or in order to make final determinations about retaining a program, or choosing another, etc. (Fenichel & Schweingruber, 2010; Reeves & Hedberg, 2003; Russ-Eft & Preskill, 2009.) In informal settings are added several others: "critical appraisal" and "remedial evaluation" (Bitgood, Shettel, & Williams, 1991, p. 27) typically are done after an exhibit or program is in place.

Though we find the clear distinction between *assessment* and *evaluation* to be very useful, as Simonson et al. note (2012), many authors use the terms synonymously. It is useful to bear in mind that many stakeholders also use the terms interchangeably.

Purposes of Assessment for Informal Learning

Many educators call for changes in the role of assessment for learning. We use the term assessment FOR, rather than assessment OF learning. This represents what Shermis and DiVesta (2011) describe as the "changing role of assessment" (p. 22). "Assessment *for* learning happens in the classroom and involves students in every aspect of their own assessment to build their confidence and maximize their achievement" (Stiggins & Chappuis, 2006, p. 11). With regard to digital technologies, Collins and Halverson (2009) and Gee (2007) are among those who advocate assessing learners using methods beyond standardized testing. This view of learners as active agents, using ongoing feedback to help them improve their learning performances, is particularly well suited to informal learning. Gee's work, focussed as it is on what students learn through video games and gaming, illustrates the value of examining learning in settings in which learners are engaging in very self-directed and enjoyable activities.

Falk and Dierking (2000) assert that one of the challenges to providing "compelling evidence for learning from museums…." is, "…not because the evidence does not exist, but because museum learning researchers, museum professionals, and the public alike have historically not asked the right questions. The result has been a search for inappropriate evidence of learning using flawed methodologies" (pp. 149–150). They suggest that we look at assessment purposes in two clear ways. One purpose is that assessment can aid learners, via feedback, in their progress toward their own learning goals. The second major purpose is to aid the institution in furthering its learning goals.

Formative assessment contributes information/data to use to further the learner's development on an ongoing basis. The idea is similar to that of formative evaluation, which contributes information/data for designers to use to further the improvement of a product or program on an ongoing basis, during development (Shepard, 2000). In our view an instructional designer could productively substitute the words "practice and feedback" for what classroom assessment specialists and teachers call "formative assessment and feedback." However, it may be more useful to keep the roles of these components of learning materials, programs and experiences separate.

While formative assessment is focused on improving individual learning, as Falk and Dierking (2000) note, another critical role of assessment is to improve the learning goals of an organization. This might be seen as a more traditional role for assessment in instructional design, development and evaluation, that is, to improve a program or course during development (formative evaluation). However, this is also a common role for assessment as part of reporting back to a funding agency, in a summative manner, about the final effectiveness of a program.

A Few Examples of Methodologies for Assessing Informal Learning and Educational Technologies

A multiple-method approach is most effective in assessment for informal learning. Many (or any) approaches, strategies, methodologies and tools may be adapted for your purposes, as long as the assessment purposes are clear. For instance, if one is developing the skills of after-school program leaders, funded by an agency requiring formative and summative reports, then pre–post learning quizzes might reasonably be used. However, for an after-school field trip one leader is designing, the individual might simply do quick group interviews after the experience. Those interviews could serve to provide those students with feedback about their learning (formative assessment), as well as to provide the educator with data for improving that field trip for the next group of learners. (See the work of the Center for Science Education and NPASS2 (Education Development Center, 2002, 2012b) as well as Yager & Falk, 2008, for many examples of mixed-methods studies of informal learning, particularly in projects representing partnerships such as among after-school programs, community organizations and museums, zoos, and science centers).

In this chapter we are not using the terms "quantitative" or "qualitative" methodologies for research quite purposely, as we advocate the value of mixed-methods approaches to assessment for informal learning. However, we have developed earlier guides to qualitative research that provide more technical specifics about how to use many of the more qualitative techniques we discuss here (cf. Savenye & Robinson, 2005; Savenye, Robinson, Niemczyk, & Atkinson, 2008).

We further suggest that one let go of the somewhat common evaluation idea that "learning" is measured using tests, and that "attitudes" are measured using surveys and interviews. A survey or a structured interview may, indeed, include "learning" questions, even formal or traditional "test" questions. Similarly "behaviors" or "performance" are not the only types of outcomes that can be measured using observations.

Assessment for informal learning may rely on traditional measures, such as tests and quizzes. However, typically more qualitative methods make up a good part of the mix of methodologies used to answer research and evaluation questions. These methods may include concept maps; classroom assessment techniques; self and peer reviews; performance assessment; analysis of learning products, discussions and conversations; surveys (administered in writing, via computer or orally); individual and group interviews, as well as many types of observations. We explore some of these measures below.

Traditional and Informal Learning Measures

Tests and quizzes. Other chapters in this volume discuss methods for measuring learning in more formal contexts, such as school and university, graded and standardized settings, so we will, in this review, only briefly review some of these types of more formal learning measures because they can easily be adapted for informal settings. Incidentally, we have found it less intimidating to call, in informal learning settings, such measures, "checks" or "starting at the beginning" or even including these items in a questionnaire, or structured interview. Also, learning measures may be administered as group measures at times in nonschool settings.

These more formal learning measures may include tests and quizzes, which in turn may include diagnostic tests, entry-level tests, pretests of prior learning, embedded or practice tests, and posttest measures. Most instructional design texts provide very effective introductions to these many types of more formal learning measures (cf. Dick, Carey, & Carey, 2009; Gagne, Briggs, & Wager, 1992; Smith & Ragan, 1999). In addition, many good texts on tests and measurement design are available (cf. Kubiszyn & Borich, 2009; Shermis & DiVesta, 2011) (For a more comprehensive overview of evaluation of training see Bassi & Russ-Eft, 1997; Brinkerhoff, 2006; Cennamo & Kalk, 2005; Reeves & Hedberg, 2003).

Concept mapping. Concept maps are increasingly being used to measure learning. These may be used both formally and informally. In more formal approaches, experts may be called upon to create concept maps of their mental models or of their conceptions of relations among concepts in a domain. Learners then also are tasked with creating concept maps and the maps of these more "novice" learners may be compared to those of the experts. Another approach is to have learners develop concept maps both before and after participating in the learning experience. A very promising area of research in concept mapping for measuring skills and knowledge is that of Spector, Shute and colleagues (cf. Pirnay-Dummer, Ifenthaler, & Spector, 2008; Shute, Jeong, Spector, Seel, & Johnson, 2009; Spector, 2006). These researchers have developed computer-based tools that are allowing researchers to have learners input their concept maps more easily. Then the computer tools themselves aid researchers in analyzing the learners' conceptions, thus somewhat automating the analysis process, which otherwise has been time-consuming and quite daunting to practitioners and researchers alike.

Classroom assessment techniques (CATs). Classroom assessment is a formative assessment approach that is designed to provide instructors with information on an ongoing basis about learner performance. Learner performance data are then rapidly analyzed and used to provide learners with feedback, again on an ongoing formative basis. Educational technologies, such as "clickers" are increasingly being used in classroom assessment, but these techniques may or may not rely on technologies. Angelo and Cross present many CATs for use by college instructors that may readily be adapted for informal learning (1993). Additional reference guides for developing classroom assessments are the works of Shermis and DiVesta (2011) and Shepard (2000).

Self and peer reviews. As part of a broad review of the research on formative assessment, Black and William (1998) note that many aspects of learners' perceptions may be assessed, including goal orientations, self-perceptions related to aspects of the learning content, or skills (Black & William, 1998). Shute (2009), in her argument for a revised perspective on assessment, includes self-assessment as a valued aspect of measuring learning. Peer assessment can also quite easily and productively be incorporated into informal learning.

Embedded assessment. Shute (2009) contends that assessment can be designed seamlessly into learning activities, particularly when using technologies. She has termed this "stealth assessment" (p. 7), adding that there is no need to interrupt learners' work, such as when they are engaged in learning in a technology-based environment or game. The system can collect student performance data continuously, and can respond and adapt to learners' choices, providing them learning assistance and support as they go.

Performance assessment. As noted earlier regarding "functions" or "purposes" it is useful to note that many of the same techniques developed for measuring on-the-job performance or competence in the workplace, and for measuring what visitors do in free-choice settings such as museums have much in common and could effectively be adapted for any setting.

Reflective Writing, Discussion and Media Creation

By using wikis, blogs and other social media tools, learners construct and share their own views of the world and of the content with which they are becoming more experienced. These tools are frequently used in online courses and eLearning (Paloff & Pratt, 2009), but they can easily be adapted for assessment for informal learning.

Blogs, vlogs, micrologs, and other types of journaling and reflective writing. In the spirit of formative assessment for the informal learner, blogs, vlogs (video logs), microblogs, like Twitter, and other types of journal and reflective writing can be used in informal assessment. Learners can use these artifacts to examine their own change over time. However, docents, mentors, coaches, and instructors can examine these learner creations and provide formative feedback to the creators as well. In addition, these blogs and journals can be examined as what would be termed artifactual data in more formal evaluations (Russ-Eft & Preskill, 2009). An increasingly common use of Twitter is for participants to develop backchat or backchannels as they engage in learning activities; a recent eLearning Guild conference provided these on monitors for all to view, and included a backchatter game (eLearning Guild, 2011).

Wikis. Wikis provide for a Web-based writing space that could be individual but is designed for collaboratively written pieces or set of pieces. One instructor (Bowman, 2010) has used wikis to allow students to share their critical analyses about various aspects of the criminal justice system in various cities in the USA. Learners not only conducted research online but, as the instructor says, they also called and wrote individuals and experts in the agencies in the cities to which they were assigned. In this way, students not only learned about aspects of criminal justice, but developed their own personal understandings of the topics, based on their own explorations, and in this way, the content "came to life" for the learners.

Discussions and online discussions. Programs both in and after school have long employed discussions to support learning and assessment. Online discussions are also regularly used in online courses. These discussions are frequently assessed for formative assessment and feedback on an ongoing basis in a course (Savenye, 2004). Online discussions can also be examined as data in evaluation studies and research. For instance, Thompson and Savenye (2007) examined the online discussions of learners enrolled in an online MBA program to determine participation rates and activities. Paloff and Pratt (2009), as well as Ko and Rossen (2010), provide guidance for assessing learners in online courses and discussions.

Learner-created media for formative assessment. While student-created portfolios and webfolios have been used in education (Kim, 2001), participants in informal learning environments are now able to develop their own videos, sets of photographs or photographic stories, their own Web sites, and their own (as compared with institutional) blogs and wikis. All these participant-created media could form the basis of rich formative assessments and evaluations. Gee (2007) in his book on gaming and literacies for learning would call this learner an " 'insider', 'teacher' and 'producer' (not just a 'consumer') able to customize the learning experience" (p. 227).

In our view informal learning now becomes not identified simply with museums or nonschool settings, but more clearly with *any* setting. Learners can now build and share their own photographs through sites such as Flickr or Picasa; videos, such as through YouTube; artwork, animations, writings—anything they wish to produce and share. They can set up their webcams to continuously stream videos, such as of birds, weather, natural phenomenon, city venues, etc, via UStreaming, and others can link to those sites and comment upon the videos. Informal learning is arguably truly ubiquitous in our world today and all of us, lifelong, are informal learners. (For an extensive overview of the many social media technologies and tools available for educators see Kim Peacock's site, Web 2.0 for Teachers (2011.) For more ideas about using social media in education see edsocialmedia.com site (2011)).

Use of rubrics. Rubrics are tools by which learner performances and products can be evaluated. "They set criteria for degrees of effective performance" according to Shermis and Di Vesta (2011, p. 133) who include in their review guidelines and examples for creating rubrics. Another useful introduction to rubrics is presented by the Illinois Online Network (2010) in their Web site on Assessment/Evaluation Topics under Online Education Resources. For younger learners, though these could be adapted for adults, Discovery Education's Kathy Schrock's Guide for Educators provides extensive Web-based resources for educators, including many aids for those who wish to develop and use rubrics (Schrock, 1995–2011). Her guide features, for instance, ready-made rubrics that can be used or adapted for evaluating student Web pages; subject-based rubrics; rubrics for Web 2.0 tools, such as blogs, wikis, Animoto, Skype, Glogster, Twitter, and Voicethread; as well as guides for building rubrics and articles about rubrics, performance assessment, and electronic portfolios.

Surveys

Most informal learning professionals rely quite heavily on questionnaires (the survey method) to measure aspects of learners' attitudes, and other affective variables, such as interest, excitement, intentions, and motivation. If designed with a mix of closed-ended questions, to capture considerable data that are not too difficult to analyze, and a few open-ended questions to capture broader or unanticipated views of the learners, they can be relatively efficient. Surveys are not easy to build effectively, so time will need to be spent to design and test the instruments. Though not the specific focus of this chapter, and likely to be covered in other areas in this volume, good references for survey development are numerous. For instance, Korn (1999) and others in the Borun and Korn (1999) volume on museum evaluation include guidance and many examples. For evaluation in general the Russ-Eft and Preskill (2009) text also provides many guidelines and examples of how to ask questions in organizational learning settings. Another excellent online source for survey development is Scheuren's (2004) "What is a Survey?", available free of charge from the American Statistical Association.

In informal learning, increased motivation may make up a major learning outcome to be assessed. John Keller has formulated his "model of motivational design" based on extensive reviews of the motivation literature and his own research. Keller and colleagues have developed and utilized instruments to measure learner motivation, based on his elements of motivation, that is: Attention, Relevance, Confidence and Satisfaction (ARCS) (cf. Keller, 2006; Kim & Keller, 2008). These approaches and measures could, with permission, be adapted for many informal learning environments.

Interviews

Interviews. It should be noted that surveys can easily be adapted and used as interview protocols in many informal learning situations, in which learners often prefer to answer questions verbally, rather than to fill out questionnaires. As an example, we used a survey in interviewing visitors to a free-admission botanical garden to determine their reasons for coming to enjoy the garden (and even in those early days some of the data were collected using PDAs) (Savenye, 1998). Doering (1999) provides guidance for how to develop and conduct interview techniques in survey research.

Interviews in informal learning are typically, however, not necessarily tied to questions with rating scales. They may be conducted individually or in groups (informally or using the specific "focus group" method), and may be structured or unstructured. A structured interview includes use of a somewhat standardized set of questions, or a protocol, that will be used with each respondent; probing questions that ask the learner for more detail can still be asked, but generally there is an attempt to be quite consistent in the questions that are asked of each learner. In contrast, unstructured interviews typically are conducted in a free-form manner, more like a conversation in which the interviewer begins with a very open-ended question and builds his or her next questions based on what the learner says. Interview data are typically analyzed for predominant themes in the learners' responses, though sometimes frequency counts are developed.

Read, think-aloud protocols. A special type of interview is a read, think-aloud protocol that is done in combination with observing a learner working through a program or experience. When these are computer-based programs, the observer asks the learner to talk aloud about how he or she is making decisions, choosing to navigate certain ways, choosing answers, etc.

Observations

Learners who participate in informal experiences for learning are particularly "free." What we learn about learners in these free-choice settings may in the future be applied in Web-based open learning communities and with free-choice technologies, such as Web 2.0 tools. Participation, for instance, can be tallied, via Web hits or attendance in a program or webinar. However, physically, informal learners often follow their own paths through the environment. When conducting formative evaluations in settings such as these, it is often important to observe learners to determine: how many use what, where they go, and what they do when experiencing learning programs or materials. Diamond, Luke, and Uttal (2009), for instance, show how individuals' paths may be observed and tracked and then analyses done of what aspects of a learning environment are, or are not, being used. They describe participant and nonparticipant observational methods for learning more about how learners access and use informal learning offerings.

Museum evaluators use specific observational techniques to measure attracting and holding power, as well as engagement. For example, in a desert botanical garden (outdoor museum) we used techniques adapted from Screven (1999), Bitgood et al. (1991) and colleagues, to determine the attracting and holding power of mock-ups, or rough prototype versions, of exhibits designed to help visitors understand and appreciate the ecology and plants of the Sonoran desert (Savenye, Socolofsky, Greenhouse, & Copeman, 1997).

After the prototype learning exhibits were working well to attract and hold visitors, the next step in the formative evaluation was a form of learning assessment. We interviewed visitors to ask them first a general, open-ended question like, "What do you think was the main message of this exhibit?" to determine first what message was getting across. In subsequent formative and summative evaluation phases we interviewed visitors before and after their visits with specific learning questions related to the main learning goals of the trail (Savenye et al., 1997).

Conclusions and Recommendations

We have come full circle. We have examined the issues and approaches involved in effectively assessing for informal learning. We have introduced a few methodologies that have proven useful in free-choice and informal learning settings. We have briefly toured a few ways that new educational technologies may impact informal learning and approaches to measuring learning.

We would recommend that educators use an informal-learning, free-choice perspective to develop their own goals and outcomes for the learner's experience. One suggestion would be to develop for their program or environment to be assessed "strands" or goals, such as those described earlier that are becoming widely accepted for informal science education (Fenichel & Schweingruber, 2010; NRC, 2009), and, for each of those identified, to develop assessment strategies, then methods, and then tools or instruments.

Another approach would be to adapt the evaluation framework widely used in training and workplace learning, that is, Kirkpatrick's Four Levels of Evaluation (1994): (1) Reactions, (2) Learning, (3) Behaviors, and (4) Results. It is our contention that most models or frameworks for assessment, thoughtfully adapted to the informal learning experience, program or environment at hand, with input from appropriate stakeholders, will ensure a successful evaluation.

Technologies such as eLearning and online learning, social learning media, other Web 2.0 media creation and writing tools, games and virtual worlds will all continue to impact learning in new ways. They will lend themselves well to informal learning techniques and approaches.

As Falk and Dierking (2002) recommend, consider the needs and desires of the learner for continuous, ongoing formative assessment and feedback. At the same time, consider the needs of the organization for evidence/data that can support the organization's learning goals, be those related to reporting to a funding agency or for the organization's decision-makers and community stakeholders alone. Develop your assessment plan, and the decision-making questions that require the evidence, together with relevant stakeholders. Select and build your assessment approaches, strategies, methods, and tools/instruments creatively. Use them efficiently to gather evidence. Report using strategies that address your and the stakeholders' needs. Finally, choose to engage in a continuous iterative cycle of improvement and excitement about your own, the organization's, and its learners' learning and enjoyment.

A Few Additional Web Resources for Assessment for Informal Learning

- AERA: Special Interest Group on Informal Learning Environments—http://informalscience.org/research/ilersig
- American Association of Museums: with a number of resources for evaluation—http://www.aam-us.org/
- Archives and Museum Informatics, including the Museums and the Web conferences and archives—http://www.archimuse.com/
- Center for Advancement of Informal Science Education (CAISE)—http://caise.insci.org/
- Conceptual Framework being developed for the Next Generation Science Standards—http://www7.nationalacademies.org/bose/Standards_Framework_Homepage.html & http://www.nsta.org/pdfs/Pratt_AnticipatingTheFramework.pdf
- Field-Tested Learning Assessment Guide: The University of Wisconsin-Madison's National Institute for Science Education: many CATs—http://www.flaguide.org/
- Frechtling, J.: The 2002 User Friendly Handbook for Project Evaluation (NSF)—http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf02057
- Illinois Online Network: Online Education Resources: Assessment/Evaluation Topics—http://www.ion.uillinois.edu/resources/tutorials/assessment/index.asp
- Informal Science: http://informalscience.org/
- Institute for Learning Innovation: http://www.ilinet.org
- Microsoft Corporation (2007). MSR Assessment Toolkit. At the Microsoft Faculty Connection. [Web Site]. Redmond, WA: Microsoft Research. (Developed by Savenye, W., Ozogul, G., & Cromack, J.) (https://www.facultyresourcecenter.com/curriculum/pfv.aspx?ID=6830&Login=)
- National Science (2011). Center for Education: Board on Science Education Retrieved June 11, 2011 from http://www7.nationalacademies.org/bose/.
- National Institute for Science Education http://archive.wceruw.org/nise/ at The University of Wisconsin-Madison.
- National Science Teachers Association (NSTA), Science Standards: http://www.nsta.org/about/standardsupdate.aspx
- National Science Foundation: NSF's Informal Science Education http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5361&org=EHR&sel_org=EHR&from=fund and *NSF's Division of Research on Learning in Formal and Informal Settings (DRL)*: http://www.nsf.gov/div/index.jsp?div=DRL
- The University of Maryland - Office of Evaluation & Assessment: Learner Assessment Resources—http://www.umuc.edu/outcomes/resources.shtml
- Visitor Studies Association: http://visitorstudies.org/ and it's "Evaluator Competencies for Professional Development": http://visitorstudies.org/professional-development
- W. K. Kellogg Foundation: http://www.wkkf.org:
- Evaluation Handbook http://www.wkkf.org/knowledge-center/resources/2010/W-K-Kellogg-Foundation-Evaluation-Handbook.aspx and Logic Model Development Guide http://www.wkkf.org/knowledge-center/resources/2006/02/WK-Kellogg-Foundation-Logic-Model-Development-Guide.aspx.

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Assessing Problem Solving

22

David H. Jonassen†

Abstract

Methods for assessing problem-solving learning outcomes vary with the nature of the problem. For simpler well-structured problems, answer correctness and process may be used along with assessments of comprehension of problem schemas, including problem classification, text editing, and analogical comparisons. For more complex and ill-structured problems that have no convergent answers, solution criteria, or solution methods, problem solving may be assessed by constructing and applying solution rubrics to assess mental simulations (scenarios), arguments in support of solutions, and student-constructed problems. Problem solving processes are normally assessed by coding schemes. In addition to assessing problem solutions, assessments of critical cognitive skills, including causal reasoning and student models, may be used to infer problem-solving skills.

Keywords

Problem solving • Problem types • Assessment methods • Rubrics

What Kinds of Problems Can Be Assessed?

An underlying assumption of instructional design is the congruence among goals/objectives, assessments, and instructional/learning strategies employed to meet those goals/objectives. That congruence applies to all levels and kinds of goals and objectives. However, problem solving too often has been conceived as a unitary process or activity. That is, all problems are alike and the normative processes used to solve all problems are similar. Based on that assumption, numerous models of problem solving have been suggested, most of which involve a sequence of steps, including:

1. Define the problem.
2. Analyze the problem (identify possible causes).
3. Investigate the problem (gather information).
4. Generate possible solutions.
5. Evaluate the alternative solutions.
6. Implement the solution(s).
7. Monitor the solution(s).

Jonassen (1997, 2000, 2011) has argued consistently that problems and the methods and strategies used by individuals and groups to solve them, both in the everyday and classroom worlds, vary dramatically. Smith (1991) categorized factors that influence problem solving as external and internal. External factors are those related to the nature of the problem as encountered in the world. Internal factors are related to the personal characteristics of the problem solver, such as prior experience, prior knowledge, or strategies used. Problem solving varies both externally (the problem as it exists in the world) and internally (how the individual or the group conceptualizes and resolves the problem). This chapter addresses internal factors related to understanding and solving different kinds of problems that differ in external factors. Next, I describe the ways in which problems vary externally and how they affect assessment of learner understanding and ability.

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Structuredness of Problems

The most significant difference among problems is structuredness. Problems vary along a continuum between well structured and ill structured (Arlin, 1989; Jonassen, 1997, 2000; Newell & Simon, 1972; Voss & Post, 1988). Most problems encountered in formal education are well-structured problems. Often found at the end of textbook chapters, well-structured problems present all of the information needed to solve the problems in the problem representation; they require the application of a limited number of regular and circumscribed rules and principles that are organized in a predictive and prescriptive way; they possess correct, convergent answers; and they have a preferred, prescribed solution process (Jonassen, 2000; Wood, 1983). These problems have also been referred to as transformation problems (Greeno, 1980) that consist of a well-defined initial state, a known goal state, and constrained set of logical operators.

Everyday problems (outside of formal education) are typically ill structured. Ill-structured problems are typically emergent and not self-contained. Because they are not constrained by the content domains being studied in classrooms, their solutions are not predictable or convergent. Ill-structured problems usually require the integration of several content domains, that is, they are usually interdisciplinary in nature. Workplace engineering problems, for example, are ill structured because they possess conflicting goals, multiple solution methods, nonengineering success standards, nonengineering constraints, unanticipated problems, distributed knowledge, collaborative activity systems, and multiple forms of problem representation (Jonassen, Strobel, & Lee, 2006). Ill-structured problems appear ill defined because one or more of the problem elements are unknown or not known with any degree of confidence (Wood, 1983); they possess multiple solutions, solution paths, or no solutions at all (Kitchner, 1983); they possess multiple criteria for evaluating solutions, so there is uncertainty about which concepts, rules, and principles are necessary for the solution and how they are organized; and they often require learners to make judgments and express personal opinions or beliefs about the problem.

Although information processing theories aver that “in general, the processes used to solve ill-structured problems are the same as those used to solve well structured problems” (Simon, 1978, p. 287), more recent research in situated and everyday problem solving makes clear distinctions between well-structured problems and ill-structured problems. Allaire and Marisiske (1999) found that measures that predict well-structured problem solving could not predict the quality of solutions to ill-structured, everyday problems among elderly people. Hong, Jonassen, and McGee (2003) found that solving ill-structured problems in an astronomy simulation called on different skills than well-structured problems, including metacognition and argumentation. Argumentation is a social and communicative activity that is an essential form of reasoning in solving ill-structured, everyday problems (Chapman & McBride, 1992) that is seldom used in solving well-structured problems. Jonassen and Kwon (2001) showed that communication patterns in teams differed when solving well-structured and ill-structured problems. Students solving ill-structured economics problems produced more extensive arguments than when solving well-structured problems because of the importance of generating and supporting alternative solutions when solving ill-structured problems (Cho & Jonassen, 2002). While the solution of well-structured and ill-structured problems requires some different processes, they are not mutually exclusive. Overlap in processing well-structured and ill-structured problems exists, although it varies by complexity and context.

Context of Problems

In everyday problems that tend to be more ill-structured, context plays a much more significant role in the cognitive activities engaged by the problem (Lave, 1988; Rogoff & Lave, 1984) because those problems are more embedded within a specific context. The context in which problems are embedded becomes a significant part of the problem and necessarily part of its solution (Wood, 1983). Well-structured problems, such as story problems, embed problems in shallow story contexts that have little meaning or relevance to learners. Workplace engineering problems, on the other hand, are more ill structured because the context often creates unanticipated problems (Jonassen et al., 2006). Very ill-structured problems, such as design problems, are so context dependent that the problems often have little meaning outside the context in which they occur.

The role of context defines the situatedness of problems. Is the situation predefined by the educator (preauthentication), or is it emergent in some real-world situation in which a problem occurs (emergent authenticity). Predefined problems (well structured and ill structured) refer to analyzing content or activity systems and attempting to simulate the problem in a learning environment that students work in. Almost all problems solved by students in formal education are predefined.

Emergent problems occur during practice within a disciplinary field (Barab & Duffy, 2000), where problems are embedded in authentic situations, allowing students to learn a skill by engaging in the activities germane to that field (Barab, Squire, & Dueber, 2000; Nicaise, Gibney, & Crane, 2000; Radinsky, Buillion, Lento, & Gomez, 2001). These problems tend to be much more ill structured because they are so ill defined.

What Is Complexity of Problems?

Problems also vary in complexity (Meacham & Emont, 1989). Complexity, like problems in general, is an interaction between internal and external factors. Problem solving complexity is a function of how the problem solver interacts with the problem, which is determined partially by the problem solvers' experience as they interact with the problem, importance (degree to which the problem is significant and meaningful to a problem solver), and urgency (how soon the problem should be solved). Ill-structured problems tend to be more difficult to solve, in part because they tend to be more complex (Jacobs, Dolmans, Wolfhagen, & Scherpbier, 2003).

Problem complexity is also a function of external factors, such as the number of issues, functions, or variables involved in the problem and the number of interactions among those issues, functions, or variables. Although complexity and structuredness invariably overlap, complexity is more concerned with how many components are represented implicitly or explicitly in the problem and how much they interact, and how much the learners understand those components. Complexity has direct implications for working memory requirements as well as comprehension. Complex problems impose more cognitive load on the problem solver. The more complex a problem, the more difficult it will be for the problem solver to actively process the components of the problem. Most well-structured problems, such as textbook math and science problems, are not very complex. They involve a constrained set of factors or variables. While ill-structured problems tend to be more complex, well-structured problems can be extremely complex and ill-structured problems fairly simple. For example, chess is a very complex, well-structured problem, and selecting what to wear to work or a social engagement is a simple ill-structured decision problem. Complexity is clearly related to structuredness, though it is a sufficiently independent factor to warrant consideration because of the working memory requirements. As problems become more complex, they make greater demands on working memory. Because most research with worked examples has been conducted with well-structured problems, the relationships between problem complexity and working memory demands remain questionable.

In a more recent analysis, Jonassen and Hung (2008) described problem complexity in terms of internal and external factors. Internal factors included the breadth of knowledge required to solve the problem, the attainment level of problem solver, and the level of domain knowledge. External factors include the intricacy of problem-solution procedures, the relational complexity among domain concepts, the level of intransparency (unknowns in the problem space), the heterogeneity of problem interpretations, and the interdisciplinarity, dynamicity, and legitimacy of alternative solutions. Ill-structured problems tend to be more complex; however, there exist a number of highly complex well-structured problems.

Assessing Problem Solving

Figure 22.1 illustrates the organization of the remainder of this chapter. In the next section, I describe methods for assessing well-structured problem solving, including answer correctness, problem classification, text editing, and analogical comparison. Then, I describe methods for assessing ill-structured problems, including solution rubrics, mental simulations, argumentation, and student-constructed problems. Then I describe methods for assessing underlying conceptual skills, including causal reasoning and students' models.

Finally, I describe how problem-solving processes are assessed using rubrics for assessing essays and coding schemes for assessing think-alouds or discussions.

Assessing Well-Structured Problems

Assessing Correct Answers

In scientific domains such as mathematics and physics, well-structured problems are most often used to represent and assess domain understanding. With those problems, judging student answers against the correct answer most often assesses problem solving. These problems are most often solved using the following procedure (Rich, 1960): (1) representation of unknowns by letters; (2) translation of relationships about unknowns into equations; (3) solution of equations to find the value of three unknowns; and (4) verification or check of values found to see if they fit the original problem. Student responses are therefore assessed by determining if the students selected the correct equation, inserted the correct values into the equations, and derived or solved the equation correctly to determine the correct answer. Instructors infer that if students obtain the correct answer to the problem, then they understand the problem and are able to transfer that skill to other problems. It should be noted that everyday and professional problems in scientific domains become very ill structured (Jonassen et al., 2006).

Summary

Assessing correct answers is the most reliable methods for assessing problem solving, because a correct answer and procedure are known, and student responses can be objectively compared to them. However, for well-structured problems, correct answers should be only one of the assessment methods used. Although correct answers have significant face validity, content and construct validity cannot be assured by correct answers alone. In order to assess conceptual understanding of the problems being solved (content validity), problem schemas should also be assessed.

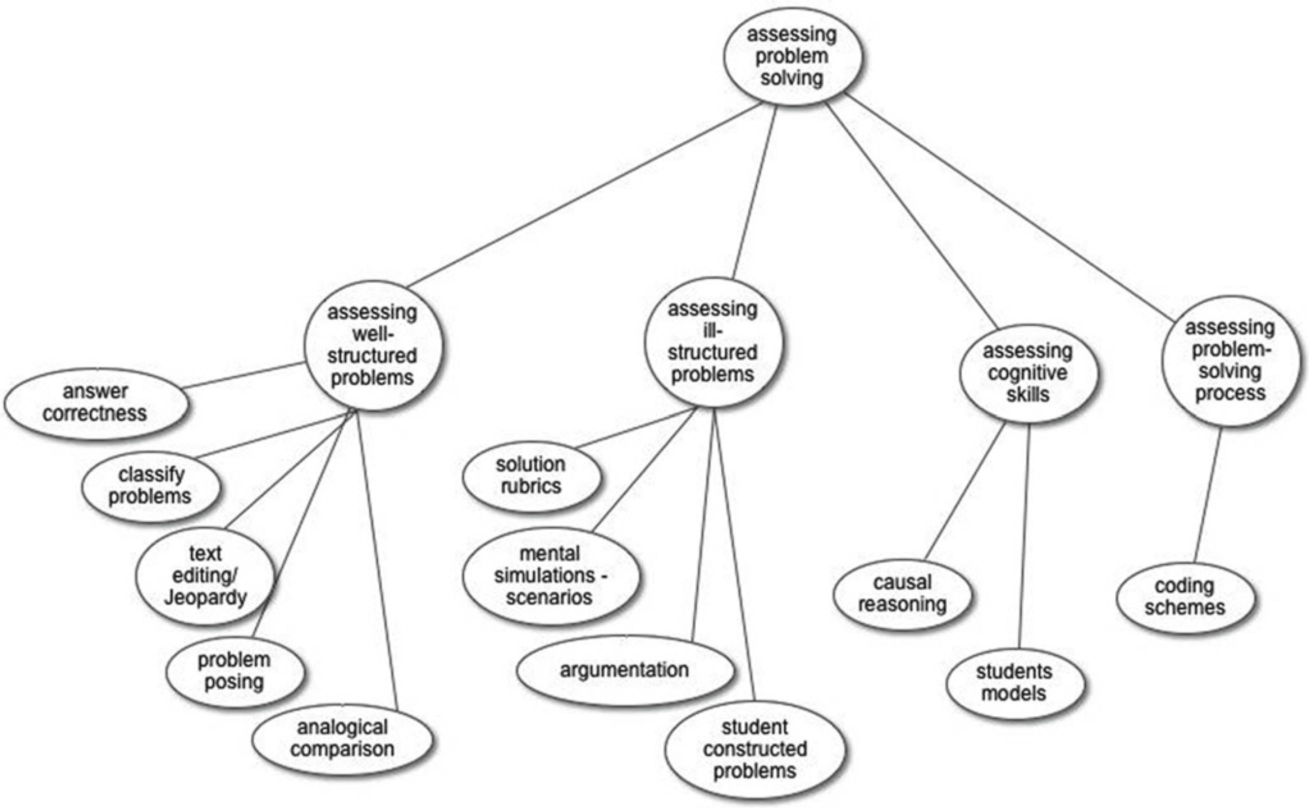


Fig. 22.1 Forms of problem-solving assessment

Assessing Problem Schemas

When problem solvers attempt to directly translate the key propositions in the problem statement into a set of computations (direct translation strategy), they frequently commit errors. Why? Because students have not constructed conceptual understanding of the problem, that is, they have not constructed a robust problem schema for the problem. Rumelhart and Ortony (1977) introduced the concept of problem schema as a form of knowledge structure used to identify the type of problem being solved. Problem schemas include semantic information about the nature of the problem, situational information about its occurrence in a problem situation, and procedural information about how to solve the problem. Typically, problem schemas for only well-structured problems can be adequately defined. Ill-structured problems may exhibit similarities, but the number of variable attributes makes them difficult to classify. Understanding problems requires more than the equations that express them. Conceptual understanding of the problem structure is essential. A robust problem schema enables learners to determine what kind of problem is being solved. Because a robust schema is essential to problem-solving transfer, the quality of a problem schema is predictive of problem-solving ability. In the remainder of this section, I describe alternative methods for assessing problem schemas.

Fig. 22.2 Physics problem used for problem classification

Assessing Problem Schemas with Problem Classification

If students have constructed robust problem schemas for the problems they are learning to solve, then they will be able to accurately classify the problems. For example, present a problem such as that in Fig. 22.2.

Rather than asking students to solve the problem, ask them to classify the type of problem, as, for example, kinematics, Newton's second law, work–energy, etc. (Chi, Feltovich, & Glaser, 1981). Science courses are normally taught as a sequence of problem types, so the first week in a physics course (typically kinematics), you would ask, "is this a kinematics problem or not". For week 2 (work–energy, for example), you would present problems and ask which of the two types (kinematics or work–energy) the problem exemplifies. Each week, you add another problem type to the list of possible classifications.

Fig. 22.3 Text editing question to support problem schema development

Jane, looking for Tarzan, is running at top speed (4.0 m/s) and grabs a vine hanging vertically from a tall tree in the jungle. How high can she swing upward?

For this problem,

a. There is insufficient data presented to solve the problem.

b. There is sufficient data presented to solve the problem.

c. There is more information presented than is needed to solve the problem.

Problem classification exercises are useful for helping students to construct more robust problem schemas, because students tend to generalize problem schemas based on surface-level similarities among problems rather than the physics principles used by experts (Chi et al., 1981; Dufresne, Gerace, Hardiman, & Mestre, 1992; Hardiman, Dufresne, & Mestre, 1989). Any efforts to help students to classify problems based on their structural characteristics will enhance students' problem schema development.

Another related method for assessing problem classification is the card sort or question sort. Rather than asking students to solve a set of problems, simply present a set of problems and ask students to sort them into conceptual piles. You should ask students to explain the reasoning behind their groupings, especially in terms of physics concepts and principles. Again, experts tend to group problems by laws of physics, and novices based on surface features (Chi et al., 1981).

Assessing Problem Schemas with Text Editing and Jeopardy Questions

Text editing is a method for assessing the quality of problem schemas. Text editing questions (Low & Over, 1989; Low, Over, Doolan, & Michell, 1994; Ngu, Lowe, & Sweller, 2002) present standard questions such as those in Fig. 22.2 to which a quantity has been added or deleted or left alone (see example in Fig. 22.3). Students are required to identify whether the problem contains sufficient, irrelevant, or missing information. Students cannot answer such questions unless they understand what kind of problem it is and what elements are appropriate for that kind of problem. While they appear fairly simple, these questions are difficult for students to answer, especially if the students are required to explain their answers. Because students are asked to complete the tasks without solving the problem, students need to understand the interrelationships between various physical quantities, not in terms of equations, but at a conceptual level to be able to successfully complete the task.

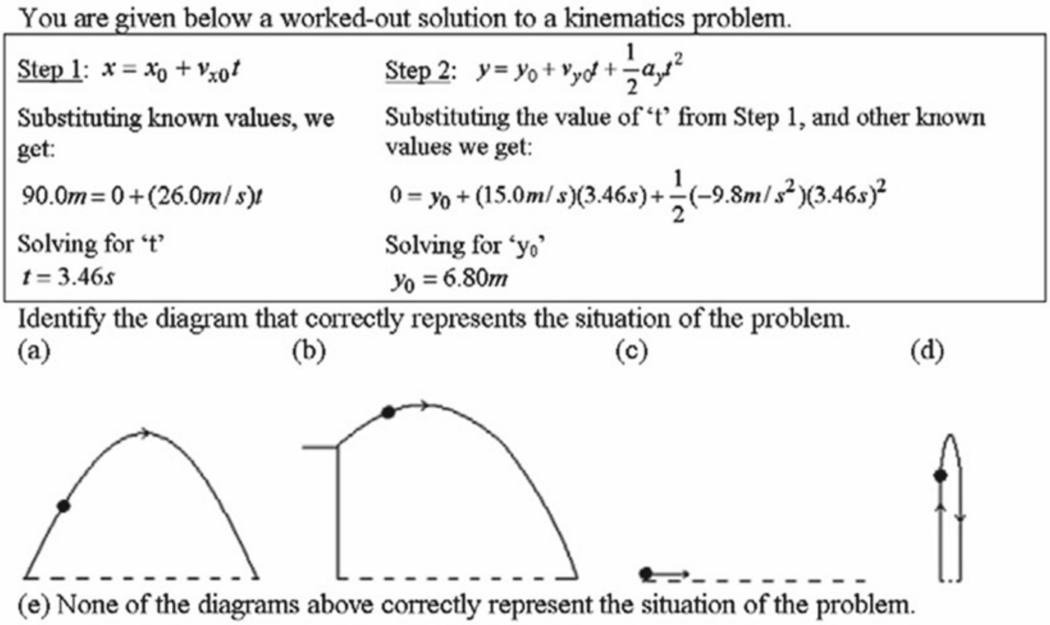
A variation on text editing is a Jeopardy problem, modeled after the popular television quiz show of the same name. Physics Jeopardy tasks were first developed by Van Heuvelen and Maloney (1999). As the game requires, these tasks require the students to work backward. Students are given a fragment of a solution to a problem and asked to identify the physical scenario that corresponds to the solution. The developers point out that these tasks require an effort to represent a physical process in a variety of ways. Because of these features, students are unable to use naïve problem solving strategies while solving Jeopardy problems. Figure 22.4 below shows an example of an adaptation of a Jeopardy problem that provides students with a few steps of a projectile motion. Students are asked to determine what trajectory shown corresponds to the problem. This task requires students to relate information given in the mathematical and symbolic representation to a visual or a pictorial representation.

How Do We Use Problem Posing to Assess Problem Schemas?

Problem-posing tasks were used by Mestre and others (Brown & Walter, 2005; Mestre, 2002; Silver & Cai, 1996) in the context of physics problems. In the tasks presented by Mestre, students were given a scenario, typically in the form of a picture and were asked to construct a problem around the scenario that was based on certain physical principles. Mestre points out that problem-posing tasks are aimed at probing students' understanding of concepts as well as assessing whether they transfer their understanding to a new context. Clearly such a task was rather open-ended with multiple possible answers.

Take a look at the picture below. Create your own physics problem based upon this situation. You may use anything that you have learned from General Physics (Fig. 22.5).

A variation on the problem-posing task is to give students a statement describing a situation and ask them to add a question that would turn it into a problem that uses specified principles or equations. It presents students with the first part of a problem statement that clearly describes a physical scenario (see Fig. 22.6). Students are then asked to select from a list of choices a question, which when added to the statement will create a solvable problem that requires the use of a set of given equations. Clearly, this adaptation differs significantly from the original problem-posing task. First, this task clearly does have a unique correct answer. Second, it requires specific conceptual knowledge, represented in the form of equations.



You are given below a worked-out solution to a kinematics problem.

Step 1: $x = x_0 + v_{x0}t$

Substituting known values, we get:

$90.0m = 0 + (26.0m/s)t$

Solving for 't'

$t = 3.46s$

Step 2: $y = y_0 + v_{y0}t + \frac{1}{2}a_y t^2$

Substituting the value of 't' from Step 1, and other known values we get:

$0 = y_0 + (15.0m/s)(3.46s) + \frac{1}{2}(-9.8m/s^2)(3.46s)^2$

Solving for 'y_0'

$y_0 = 6.80m$

Identify the diagram that correctly represents the situation of the problem.

(a) (b) (c) (d)

(e) None of the diagrams above correctly represent the situation of the problem.

Fig. 22.4 Physics Jeopardy problem

Fig. 22.5 Problem-posing stimulus

You are given the starting statement of a problem below.

A 500 kg cargo shipment, attached to a parachute, drops vertically out of a helicopter hovering 100 m above a large spring (k = 220,000 N/m). The cargo comes to rest when the spring compression is 0.50 m.

Which question, when added to the statement above, will make a solvable problem that *requires ALL of the following* equations to solve?

$W = Fd \quad W = \Delta KE + \Delta PE \quad PE_{spring} = \frac{1}{2}kx^2 \quad PE_{gravity} = mgy \quad KE = \frac{1}{2}mv^2$

(a) What is the speed of the cargo just before striking the spring?
(b) How much time does it takes for the cargo to make contact with the spring?
(c) What is the work done by air resistance acting on the parachute as it drops?
(d) What is the average force of air resistance acting on the parachute as it drops?
(e) None of the above.

Fig. 22.6 Alternative problem-posing question

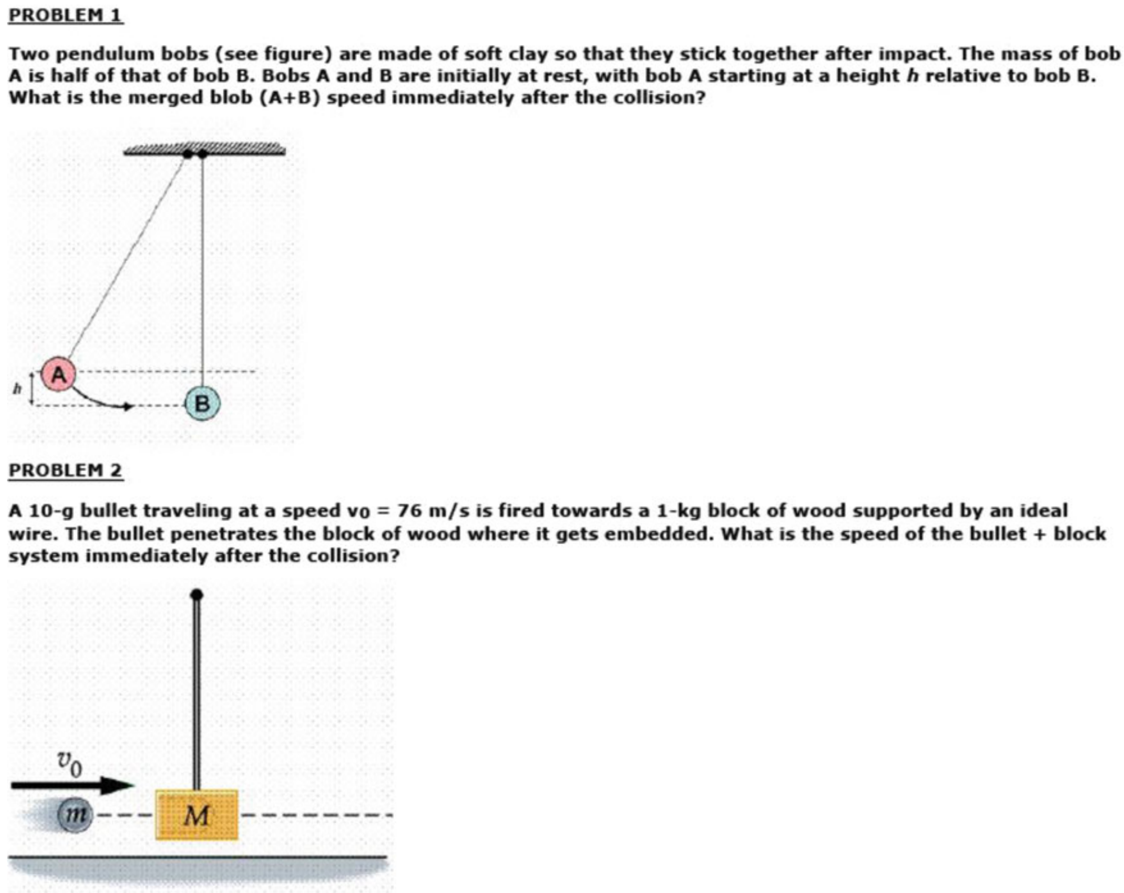


Fig. 22.7 Problem pair for comparison

Assessing Problems by Analogical Comparisons

Analogical comparison of problems requires that learners identify structural similarities and differences between pairs of problems. The simplest method for this comparison is to present pairs of problems and ask learners to identify on a scale how similar the problems are (Littlefield & Rieser, 1993; Low & Over, 1989, 1990, 1992). Hardiman et al. (1989) compared novices and experts on a similarity judgment task and found, like other studies, that experts relied on deep structure, while novices relied on surface similarities (Fig. 22.7).

Another form of analogical comparison question is to present a pair of problems and ask students to identify problem elements and similarities and differences between the problems. Those comparisons may be prompted with multiple-choice questions, such as the following:

In both problems, which of the following physical quantities change?

1. Gravitational potential energy
2. Kinetic energy
3. Mechanical energy
4. Linear momentum
5. None of the above

Summary

Assessing problem schemas generally requires a form of reasoning that most students have not encountered in their studies. Therefore, it will be necessary to provide practice and feedback on whatever kind of problem schema assessment that you select in order to support their performance. While these assessment methods possess content and especially construct validity, reliability will suffer in the absence of practice. Because of the validity of problem schema assessment, some form of this assessment should be required along with assessing correct answers to well-structured problems.

Assessing Ill-Structured Problems

Performance assessment should focus on "can the students perform the task?" not "do they remember how to solve problems?" or "do they remember the domain content required to solve problems?" Can the students solve problems similar to the ones they have been learned how to solve? In order to assess performance, it is necessary to ascertain how well the problem was solved? Performance assessment includes these elements (Elliott, 1995):

- Students must construct a response or a product, rather than simply select from a set of predefined alternatives or answers.
- Assessment consists of direct observation or assessment of student behavior on tasks or on the product that they produced.

To these, I add a third. Assessment also requires the assessment of the quality of the solution using some sort of description of desirable performance, called a rubric. Solving any kind of problem requires multiple operations or actions and different kinds of skills and knowledge.

Assessing Problem Solving with Rubrics

Many problems, well structured and ill structured, require students to generate and derive equations to determine the correct answer. In such problems, successful learners produce the correct answer and demonstrate the derivations of equations in the correct sequence to produce the correct answer. The criteria for assessing this kind of problem solving include the correct answer and the correct sequence of equations. The goal of assessment should be to more clearly articulate the requirements for an acceptable answer. The most common method is to construct performance rubrics that describe the levels of acceptable and unacceptable performance.

Assessing Problem-Solving Performance with Solution Rubrics

Writing and using rubrics is hard work. So why do it? The obvious answer is to communicate the parameters of a good solution to students. That is, rubrics play an important instructional function as well as an assessment function. Rubrics were not originally developed as summative assessment tools. Rather they were designed to provide feedback to students in a formative manner that would enhance the quality of their performance. However, they are often used to communicate final requirements and summatively assess student performance.

Another reason for writing rubrics is a bit more challenging. If you as a teacher, professor, designer, or trainer are unable to articulate the elements of some required performance, then you have no business assessing student performance. If you cannot even describe what proper performance is, how can you make informed, meaningful judgments about the quality of student performances? Most people recognize an excellent performance when they see it but often are unable to say why the performance was excellent. That is not adequate for assessment purposes. It is essential that designers articulate some of the elements of good performance. It is extremely difficult to anticipate every aspect of a complex problem-solving performance, but that should be the goal of any designer assessing problem-solving performance.

Rubrics can be constructed to assess any kind of problem solving. As indicated earlier in this chapter, most story problems require learners to select an appropriate formula to represent the problem, insert the values from the problem into the formula, and to solve the formula for a specific value. Most story problems are assessed based on whether the student produces the correct value for an answer. Rubrics may also be used to articulate the ability of students to understand the kind of problem being solved and also the nature of the structural relationships embedded in the problems. For example, for the problem:

> A policeman chases a master jewel thief across city rooftops. They are both running at 5 m/s when they come to a gap between the buildings that is 4 m wide and has a drop of 3 m. The thief, having studied a little physics, leaps at 5 m/s and at a 45° angle and clears the gap easily. The policeman did not study physics and thinks that he should maximize his horizontal velocity, so he leaps at 5 m/s horizontally. Does he clear the gap? By how much does the thief clear the gap? What type of problem is this? Show all actions, assumptions, and formulae used to answer these questions.

In this example, we may require that the student classify the problem type, identify initial conditions, set up the equation, estimate the answer, and solve the equation. Rubrics can be created for assessing the student's solution method because the students are required to show their work. These operations define the nature of the required rubrics. For story problems, the primary rubric focuses on the correctness of the answer. See Fig. 22.8 for some possible rubrics for assessing physics problem solving.

Needless to say, the nature of the rubrics will differ with the discipline and the structuredness and complexity of the problem. The rubrics must address the specific performances required by the problem. These can only be used when students' responses include some evidence of their thinking.

Accuracy of problem classification

Misclassified problem	Identified correct group, but misclassified specific problem type	Correctly classified the specific problem type

Identification of initial conditions

Unable to identify any initial or final conditions	Identified some initial or final conditions	Correctly identified all initial and final conditions in problem

Accuracy of equation

Used wrong equation or misplaced all values	Used correct equation by misplaced some values	Equation set up correctly with values in correct places

Accuracy of answer estimate

Estimate of answer the wrong order of magnitude	Estimate right order of magnitude but wrong sign or not close to final answer	Estimate of answer very close to final answer

Unit consistency

Units completely mismatched	Units mixed; some correct	Correct units used and cancelled

Accuracy of answer

Answer is quite different from correct	Answer is close to correct answer; arithmetic operation suspected	Answer is exactly correct, to the nearest hundredths

Fig. 22.8 Problem-solving rubrics for physics

For more complex and ill-structured problems that do not have universally accepted answers, the use of rubrics is more important in assessing student performance. We are implementing a problem-based curriculum in an introductory materials science course in the mechanical engineering curriculum. Students will learn by solving decision-making and troubleshooting problems. In the decision problem abstracted below, students must determine the performance problem, determine the material properties needed to meet performance requirements, calculate performance requirement, select and evaluate candidate materials, and construct an argument in support of their decision.

Improved Design of Cassette Plates—You have been asked to redesign X-ray film cassettes so that they are lighter but retain the same stiffness to bending loads. Compare various materials that are compatible with the application to produce an improved cassette.

For this kind of problem, we use the following rubrics (along with others) for assessing student reports. Note that their reports are not constructed during time-pressured examinations. Any kind of performance, including examination performance, can be assessed using rubrics. A corollary is that assessment of student knowledge and ability need not always occur in examinations.

Determination of performance problem:

3 All performance characteristics of problem (e.g., weight, speed, structural strength, thickness, stiffness, higher or lower temperature) identified; all characteristics relevant to problem.

2 Most performance characteristics identified; all relevant to problem.

1 Only a few performance characteristics identified; some not relevant to problem.

0 No performance characteristics identified.

Required performance characteristics:

4 All performance characteristics stated using appropriate descriptors (e.g., lighter, stronger, faster, bending stiffness, X-ray transmission).

3 Most performance characteristics stated, all with appropriate descriptors.

2 Most performance characteristics stated, some with appropriate descriptors.

Few performance descriptors stated.

0 No performance descriptors stated.

Material properties (*for each performance characteristic*):

3 All primary and secondary material properties identified for each performance characteristic.

2 Most primary and secondary material properties identified for each performance characteristic.

1 Some primary and secondary material properties identified for each performance characteristic.

0 No primary and secondary material properties identified for each performance characteristic.

Interactions among material properties on performance stated correctly:

3 All interactions among material properties on performance stated correctly (e.g., 2 increasing the thickness will increase the stiffness but may increase the weight).

Most interactions among material properties on performance stated correctly.

1 Some interactions among material properties on performance stated correctly.

0 No interactions among material properties on performance stated correctly.

3 All interactions among material properties and performance correctly quantified using appropriate equations.

2 All interactions among material properties stated but equations are not all accurate.

1 Some interactions among material properties and *performance* correctly quantified using appropriate equations.

0 No interactions among material properties correctly quantified using appropriate equations.

For specific material selected:

3 Correct calculation of changes from a baseline

2 Partially correct calculation of changes from a baseline

1 Inaccurate calculation of changes from a baseline

0 No calculation of changes from a baseline

For even more complex and ill-structured problems, writing rubrics can become even more difficult. For instance, consider the policy analysis problem:

Waterborne diseases: Most public water supplies are routinely monitored, but private supplies may not be subject to the same quality standards. In the Russian Federation, half the population uses water that fails to meet quality standards. In Latvia, 55 % of water samples from shallow wells fail to meet microbiological standards. Yet half the rural population relies on these wells as a source of drinking water. In Albania, 25 people died of cholera in 1994 after drinking contaminated water. In Latvia, several hundred cases of hepatitis A and bacterial dysentery are attributed to contaminated drinking water each year. In Tajikistan, some 4,000 cases of typhoid fever were reported in 1996 following heavy rainfall. In the past decade there have been some 190 outbreaks of bacterial dysentery, 70 outbreaks of hepatitis A, and 45 outbreaks of typhoid fever associated with drinking water and recreational water in Europe and central Asia. More than five million people, most of them children, die every year from illnesses caused by drinking poor-quality water.

Advise the Secretary General of the United Nations what actions should be taken by the UN.

It is likely that your students would individually or collaboratively write position papers to deliver at the UN council as well as white papers that advise the Secretary General. Because of the complex nature of the problem, the nature of the assessment for such a problem will depend on the nature of the specific problem that you posed to the students. The nature of the rubrics will depend on the nature of the task. If students were to write a policy paper for the United Nations Secretary General, some rubrics for assessing the paper might include the following:

Quality of information sources cited		
Sources of information in report unknown	Sources of information in report were questionable and not well established	Sources of information in report were internationally recognized
Constraint analysis		
Solution considered few, if any, social, political, and economic constraints	Many constraints identified; unequal balance among sources	All known social, political, and economic constraints identified in report
Economic feasibility		
Solution recommendations are economically impossible	Solution recommendations have unclear economic implications	Solution recommendations are feasible within current economic constraints
Relevance of political implications		
Few, if any, political implications identified	Political implications identified but unclear how they affect situation	Political implications are clear and feasible within current political context

Of course, many, many other rubrics could be constructed to describe such a complex performance, including all of the quality issues surrounding the writing of the report. The nature of the rubrics that you construct to assess any activity should emphasize the aspects of the performance that you deem most important. It is difficult to identify all of the rubrics that are relevant to problem-solving performance. While applying rubrics during assessments, I frequently identify other aspects of performance for which rubrics could be written and applied. At some point, however, the number of rubrics can become so numerous and complex that their meaning may get lost.

Assessing Mental Simulations (Solution Scenarios)

Mental simulations, also known as scenarios, are hypothetical sequences of events that may result from alternative decisions (Kahn, 1965). Policy analysts and strategic planners construct scenarios when assessing long-range economic, political, and societal developments. For example, scenarios were used to inform important military and political decisions such as the following:

- Should the United States invade Iraq to depose Hussein?
- Should we increase troop strength in Afghanistan?
- Should we grant marriage benefits to same-sex partners?

According to Kahn (1965), a scenario is:

- Hypothetical, representing a possible future.
- Selective, representing one possible state of complex, interdependent, and dynamic affairs.
- Bounded, consisting of number of states, events, actions, and consequences.
- Connected by causally related elements and events.
- Assessable, providing a judgment based on probability.

Most scenarios are exploratory or anticipatory where the scenario constructor starts with some states and anticipates future consequences (making predictions), although some are normative, where scenarios describe futures as they should be. Scenarios present a chain of causally related events resulting from implementation of some option and leading to some outcome (Tversky & Kahneman, 1980). The network of causally related events in the scenario can take on various states depending on which actions are taken. Scenario generation is a kind of mental simulation of future events.

For purposes of designing problem-solving learning environments (PSLEs), scenario construction can be used to assess the ability to make meaningful decisions and predictions about their outcomes. Although unsupported by empirical research, scenarios that are constructed by learners can be assessed using criteria, such as:

- All beginning factors, states, and conditions identified.
- Assumptions about factors, states, and conditions supported by evidence.
- All predictions plausible (probable).
- Predictions based on interdependent, dynamic relationships among changes in factors, states, and conditions.
- Influences among factors supported by evidence.
- Intermediate events, actions, and consequences plausible.
- Interfering events, probabilities, and impacts plausible.
- Causal map (influence diagram) included.

Assess Problem Solving with Argumentation

Because argumentation is an implied component in every kind of problem solving, students' argumentation about how and why they solved problems as they did provides perhaps the most powerful form of problem-solving assessment. If students can argue effectively about their solutions to problems, how they solved the problem, or why they did what they did, they provide confirmatory evidence about their problem-solving ability.

Student arguments can be collected using a variety of methods, although essays are the most common method. In those essays, educators try to get students to support their own position as well as anticipate and rebut different counterarguments, which is the hallmark of effective argumentation (Jonassen & Kim, 2010). For example, Nussbaum and Kardash (2005) conducted two experiments where they provided directions for different kinds of student essays.

Persuasion Condition: *Please write an essay expressing your opinion on the following question: "Does watching TV cause children to become more violent?" Provide as many reasons as you can to justify your position, and try to provide evidence that supports your reasons.*

Counterargue/Rebut Condition: *Please write an essay expressing your opinion on the following question: "Does watching TV cause children to become more violent?" Provide as many reasons as you can to justify your position, and try to provide evidence that supports your reasons. Then discuss two or three reasons why others might disagree with you, and why those reasons are wrong.*

As expected, Nussbaum and Kardash (2005) found that persuasion instructions reduced the number of counterarguments generated by students, which was consistent with a study by Stein and Bernas (1999) that showed that arguers better support their own position than they do opponent's position because they perceive more benefits accruing from their own position vs. another's. The students in the Nussbaum and Kardash study actually believed that identifying counter-

Quality of conclusions (claims)			
Conclusions unrelated to problem needs or solution	Few conclusions relate to problem needs or solutions; inconsistent relationships	Conclusions relate to problem generally, but some unclear; usually support stated solution	All conclusions relevant to problem; support solutions; related to needs
Premises are sound			
Premises not related to conclusions	Relationship of premises to conclusions is inconsistent; not related well with other premises	Most premises support conclusion	All premises support specific conclusion; add strength to the conclusion; consistent with other premises
Adequacy of premises			
No premises stated; only unsupported conclusions	Few premises stated; most unclear	Most premises stated explicitly; most clear	All premises stated explicitly and clearly
Assumptions related			
Completely unstated and unknown	Few stated but not associated with premises or conclusions; mostly unreasonable or invalid	Most assumptions stated; not all connected to conclusions or premises; some invalid	Clearly stated; consistent with claims and premises; reasonable and valid
Credibility of premises			
Sources of evidence are weak, filled with unsupportable evidence and propaganda	Sources of evidence are questionable or origin is unknown	Sources of evidence mostly valid with limited amounts of unknown data	Sources of evidence (personal, written, etc.) are unimpeachable; accepted as fact
Counterarguments accommodated			
No counterarguments acknowledged	Only one or two counterarguments acknowledged; none argued or rejected	Most counterarguments addressed; refutation not premise based	All counterarguments identified and refuted using valid, supportable premises
Organization of arguments			
Arguments are indistinguishable; unorganized; do not support each other	Arguments identified; relationships to each other not obvious	Arguments articulated but partially integrated; relationships to each other usually positive	Each argument separated; sequenced logically to support solution to problem

arguments would make their own arguments less persuasive. Argumentation is a powerful yet neglected skill that may also provide useful assessment data for problem solving.

Assessing those essays requires the construction and application of argumentation rubrics. This method requires reading and evaluating students' argumentative essays using those rubrics, which are based on the strength of relationships between premises, conclusions, assumptions, and counterarguments (Halpern, 2003). Norris and Ennis (1989) suggested the following criteria for evaluating argumentative essays:

- Do you clearly state the conclusion and define the necessary terms?
- Are the materials that you included relevant to the conclusion?
- Is the argument sound? Do the premises support the conclusion?
- Have you considered the credibility of your experts?
- Is the essay well organized with each argument laid out separately?
- Have you fairly represented opposing points of view and counterarguments?
- Have you used good grammar and a clear style of writing?

Below, I synthesize a series of assessment rubrics for assessing the quality of students' argumentative reports or essays based on Halpern's (2003) conception of arguments. When students construct arguments as part of the problem solution or as an addendum to their solutions, you might use these rubrics, along with discipline-specific rubrics to assess the quality of their arguments.

Student essays or individual verbal or written accounts of problem solving may also be assessed using rubrics based on Toulmin's conception of argumentation, which focuses on claims, supported by warrants, supported by backing or evidence. Cho and Jonassen (2002) scored individual reports of how problems were solved using the scoring rubric below in order to determine the quality of argumentation based on Toulmin's (1958) model of argument. Individual scores were achieved by summing the number of points achieved in each argumentation category (claims, grounds, warrants, backings, and rebuttal).

Claims			
No claim related to the proposition or unclear assertions	The writer makes generalizations that are related to the proposition, but the assertions lack specificity or offer unclear referents. The writer leaves much for the reader to infer in order to determine the impact of the claim	The writer states generalizations that are related to the propositions, but the assertions are not complete. Enough information is available to figure out the writer's intent, but much is left to the reader to determine	The writer states generalizations which are related to the proposition and which are clear and complete
Grounds			
No supporting data are offered or the data are not related to the claim	The data or evidence are weak, inaccurate, or incomplete. For example, (a) an attempt at using a general principle without establishing the truth of the principle; (b) the use of examples from personal experience that are not generalizable; (c) the citation of data when no source is identified; and (d) the use of obviously biased or outdated material	The data offered are relevant but not complete. The writer leaves much for the reader to infer from the data. The writer may have offered the data without the complete citation, which would allow the reader to determine the reliability of the data as evidence. The writer may offer data, which are not complete enough to allow the reader to determine their significance	The supporting data are compete, accurate, and relevant to the claim
Warrants			
No rules and principles are offered	The writer recognizes a need to connect the data to the claim and states some elaboration of data, but the writer fails to make the connection. Or most rules and principles are not valid or relevant	The writer explains the data in some way, but the explanation is not linked specifically to the claim	The writer explains the data in such a way that it is clear how they support the claim
Backings			
No sources of warrants are given	The writer states incorrect, irrelevant sources of warrants	The writer states correct, relevant sources of warrants but the sources are very general, not specific	The writer states correct, relevant, and specific sources of warrants
Rebuttals			
No recognition of constraints of solutions	The writer offers few constraints of solutions but the constraints are not elaborated	The writer identifies constraints of solutions but the constraints are not sufficient	The writer states complete and systematic identification of constraints of solutions

Coding Student Arguments

When students are engaged in an argumentative discussion, either face to face or online, their arguments can also be assessed. If the discussion is face to face, it is necessary to transcribe the discussion in order to later assess it. When assessing online discussions, most bulletin board software allows you to save each student's message as a separate record in a database. The messages that students posted that are stored in the database can be counted and qualitatively analyzed for which components of argumentation used are present in each posting. Cho and Jonassen (2002) also analyzed student online discussion while solving problems by using a coding scheme adapted from Toulmin's (1958) model of argument (described before). Each message was classified by two coders into one of those five categories without knowing the identity of the group. After classifying all of the messages, we counted the number of each category used during the discussion. Analysis showed that students using an argumentation scaffold, Belvedere, produced significantly more argument components during group discussions than subjects in the discussion groups that did not have access to the scaffold. Specifically, groups using the scaffold produced significantly more claims and grounds than groups who did not have access to the scaffold. The analysis also showed that groups solving ill-structured problems produced more arguments during group discussions than students solving well-structured problems, especially in stating rebuttals. Groups solving ill-structured tasks produced more rebuttals than those solving well-structured problems because this kind of reasoning is more important to that kind of problem solving.

Summary

In order to assess problem-solving performance, scenarios, or argumentation as a proxy for problem-solving performance, it is necessary to identify the requisite skills and activities and use those in the form of rubrics to assess performance because rubrics provide the best evidence of content validity. However, using rubrics to assess performance is a difficult work that often lacks reliability. Strategies like blind reviewing and assessing similar elements from student performances at the same time may increase reliability; however, application of rubrics tends not to be very reliable. It is likely that certain rubrics may prove to be more reliable; however, some aspects of subjectivity necessarily enters the process. Coding student interaction suffers the same lack of reliability. In some of our research (Jonassen & Cho, 2011; Jonassen et al., 2009), we used multiple coders to assess different performances. Even after training, inter-rater reliability was often 60 %, requiring reconciliation of code through debate. Despite these difficulties, the generation and application of rubrics is probably the single most important method for assessing problem solving.

Objective Forms of Argumentation

Argumentation skills can also be assessed using objective forms of assessment, such as multiple-choice tests. Questions requiring argumentative reasoning can form the stem of a test item. For example:

Students who work harder in school will make a better living after school. Which is the most appropriate assumption on which this premise and conclusion are based?

1. *Attitude is the most important difference; those who work harder get more.*
2. *What your teachers think of you is the strongest predictor of success.*
3. *Skills acquired in school better prepare you to function in the real world.*
4. *The harder you work, the more you know.*

Which conclusion logically follows from the following premise: the stock market has fallen 200 points in the last week.

1. *Buy more stock; it's a bargain.*
2. *Sell all of my stock; the economy is broken.*
3. *The economy is inflationary.*
4. *Consumer confidence is down.*

These questions focus on the evidence to support the claims stated in the question stem. Similar questions can also be developed to specifically assess the arguments required to solve a particular kind of problem. There is no research on the use of this form of assessment and its relationship to problem solving. With practice, students can develop this skill, at which point assessment may be more reliable. It is most probable that this kind of question would have predictive validity.

Assessing Student-Constructed Problems

Jonassen, Strobel, & Ionas (2008) conducted a 3-year, design-based research study on case-based learning. Beginning with a cognitive flexibility hypertext (see Chap. 13), they found that students slowly adapted to the nonlinear interconnections among the different content-types; however, students experienced difficulties in making comparisons, because the environments did not provide space for student construction of their own ideas. Flexibility hypertexts are static, providing a definitive body of material that is difficult for users to elaborate. Users of the system were unable to contribute their own perspectives, links, or connections, so they were passive consumers of information stored in the environment.

Therefore, in the second and third iterations, the system shifted from a content-navigation environment to a student-authoring environment, because authoring hypertext requires deeper understanding of the domain; identification of core concepts, cases, and themes; and careful selection of new cases to represent the content (Jacobson & Archodidou, 2000; Jonassen, Strobel, & Ionas, 2008). We incorporated authoring functions that gave students more control of the environment so that the focus of designing the hypertext system shifts from content and relationship development to providing support structures and guidance to the end users as the instructional designer of their own learning experience. When students construct and elaborate their own cases, they are more deeply engaged in learning than when interpreting someone else's cases.

A potentially powerful yet empirically unexamined form of problem-solving assessment is the construction of PSLEs by students. Student construction of problems is a transfer task. After engaging in problem-solving activities in instructor-provided PSLEs, we have informally investigated the construction of problems by students. Using simple Web-construction tools, students construct their own problem situations and supports. Their environments may be assessed by asking questions such as the following:

- Are users required to solve a real problem?
- Are the problems authentic? Situated in meaningful context?
- Are supports appropriate for problem type?
- Are meaningful perspectives provided?
- Are analogous cases provided? Prior experiences?
- Do users have to articulate causal model of problem-solution?
- Are questions used to scaffold performance?
- Do users have to construct arguments in support of solution?

Assessing student productions requires the construction and application of relevant rubrics. The use of rubrics to assess student-constructed problems encounters the same validity and reliability issues as described before.

Assessing Cognitive Skills in Problem Solving

There are a number of cognitive skills that are involved in learning to solve problems. Each skill, by itself, is insufficient for learning to solve problems. Whether each skill is necessary for solving each kind of problem depends upon the kind of problem being solved. The most important cognitive skills that are necessary for solving each and every kind of problem are analogical reasoning and causal reasoning. Analogical reasoning is necessary for inducing robust problem schemas (described before). In addition to assessing the quality of problem schemas, problem-solving ability can be predicted by assessing student understanding of the causal relationships between problem elements.

Assess Causal Reasoning

Causal reasoning is central to all problem solving. From a cognitive processing perspective, problem solving is largely a process of understanding the causal relationships among the problem elements and making inferences about what caused a certain state or predicting what state will be the result from a set of conditions (Jonassen & Ionas, 2008). That is, problem solutions are causes that will produce the effect—problem solved. Those solutions are based on the causal conditions used to represent the problem. Asking questions about those causal relationships will focus students' attention on conceptual, qualitative understanding of the problem elements.

In order to ask causal questions, it is necessary to present a scenario and ask students to make an inference or a prediction based on that scenario. That is, it is necessary to ask students to apply the causal relationship in a new situation. It is much easier to ask students about the relationship. In order to elicit causal reasoning, students must apply the relationship. For example the following question (in multiple-choice format) requires an inference (what was the cause of a specific effect).

You have just received a shipment of three boxes, each containing one of the isotope sources for the three nuclear thickness gauges described above. Each box has a radioactive material label affixed. The sources all weigh the same amount. The boxes are the same size but have different weights. What is the likely reason for the different box weights?

(a) *The sources each emit radiation of different energy, so they each weigh differently because of the different shielding needed.*

(b) *The sources each emit radiation of different penetrating ability, so they each weigh differently because of the different shielding needed to attenuate the radiation from each source.*

(c) *The sources each have a different amount of radioactivity, so they each need a different amount/weight of shielding depending on the amount of radioactive material.*

(d) *The sources each have a different half-life, so they each need different shielding depending on the half-life.*

Likewise, in order to assess prediction (what will be the effect of a specific cause) performance provide a scenario and ask students to respond:

Suppose that a sample of 238U is allowed to come to equilibrium with all of its daughters in its decay chain and then the 226Ra is chemically removed from the sample. What will happen to the activities of the isotopes in the decay chain starting with 226Ra and its daughters as time increases? Check the one best answer.

(a) *They will all decrease because the 226Ra has been removed.*

(b) *They will increase because the decay of the parent of 226Ra (e.g., 222Rn) will decay producing more 226Ra and all of its daughters.*

(c) *The activity of 226Ra will increase due to the decay of its parent, 222Rn, but there will be no increase in the activities of the daughters of 226Ra.*

(d) *There will be no increase in the activity of any of the isotopes in the decay chain following 226Ra.*

If students are unable to answer questions such as these, it is unlikely that they will be able to solve problems involving uranium. Note that these examples of causal questions are multiple choice. They could also be presented as open-ended questions that require students to construct and answer, a process that would require more mental effort. With practice in answering this kind of questions, student can develop reliable skills. In addition to constructing validity related to the ideas embedded in any problem, causal-reasoning questions will likely have significant predictive validity. The relationships between causal reasoning and problem-solving performance deserve research.

Assessing Student Models

Although equations are the most common form of problem representation in mathematics and science problems, there are many other ways that students can construct models of problems, such as free body diagrams in physics. Two very powerful methods for modeling problems that require the explication of causal relationships are expert systems and system dynamics models. Modeling is fundamental to human cognition and scientific inquiry. Modeling helps learners to express and externalize their thinking; visualize and test components of their theories; and make materials more interesting. These are all essential skills in problem solving. Models function as epistemic resources (Morrison & Morgan, 1999). When students directly represent problem entities, they are representing the problem space. Constructing a model of a problem requires constructing a different form of problem repre-

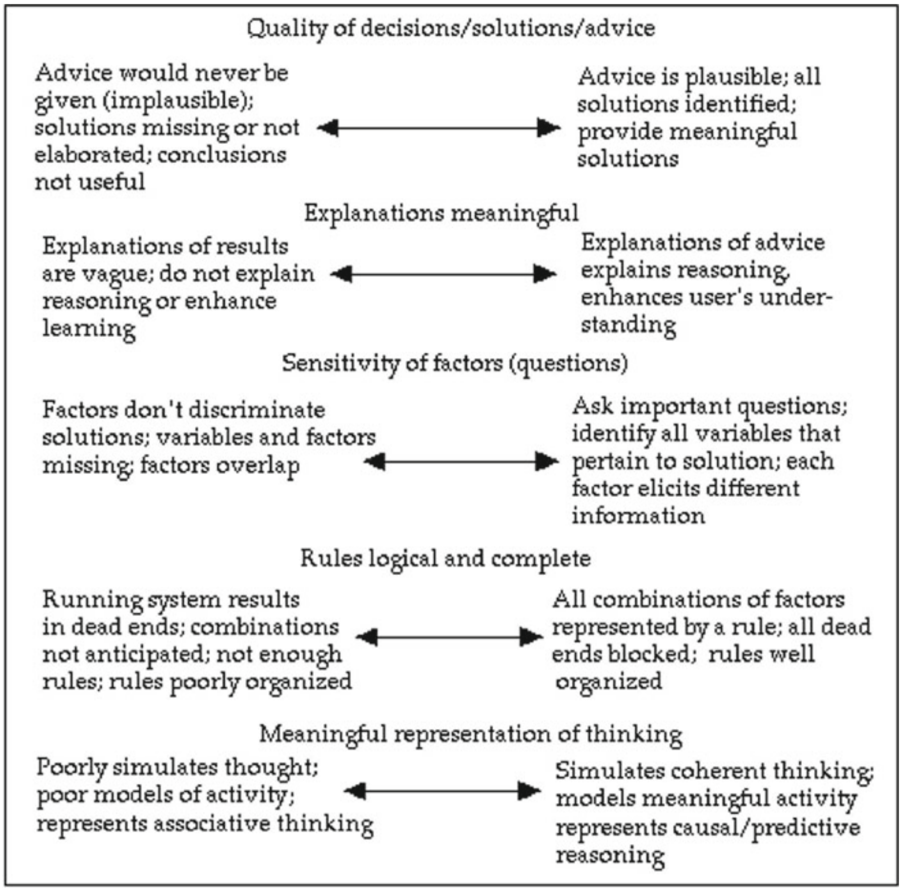


Fig. 22.9 Criteria for assessing student-constructed expert systems

sentation which guides further interpretation of information about the problem, simulates the behavior of the system based on knowledge about the properties of the system, and triggers a particular solution schema (Savelsbergh, de Jong, & Ferguson-Hessler, 1998).

Although models define the structure of most learning systems, "we do not learn much from looking at a model—we learn a lot more from building the model and from manipulating it" (Morrison & Morgan, 1999, pp. 11–12). If students are unable to construct models of systems or problems, then they simply do not understand the problem.

Expert Systems

An expert system is a computer program that attempts to simulate the way human experts solve problems—an artificial decision maker. Expert systems include a knowledge base of facts about objects and IF–THEN rules about the relationships among those objects that can qualitatively represent covariational and mechanistic information about causal relationships. The rule base is searched by the inference engine to provide advice that may be rendered by a human expert in order to reach a decision. Rules state that IF a set of conditions exists, THEN some conclusion is reached. For example, IF temperature increases, THEN pressure increases. Conditions can be combined using conjunctions (condition 1 AND condition 2 must exist), disjunctions (condition 1 OR condition 2 must exist), and negations (condition 1 but NOT condition 2 must exist) in order to reach a conclusion about a set of causal relationships. That conclusion may be an action or it may state another condition, which is then combined with other conditions to reach another decision.

Expert systems are most easily constructed using an expert system editor that provides rule editors and an inference engine for testing the rule base. These editors enable learners to construct and test a qualitative model of a set of causal relationships. Building expert systems better supports understanding the underlying mechanisms of the causal relationships. It is not sufficient to know how much the cause affects something, but also why it does. Necessity and sufficiency of causal effects (very hard concepts for students) are also effectively represented by rules. Criteria for assessing the quality of the rule base constructed by students are presented next (Fig. 22.9).

System Dynamics Models

System dynamics tools, including Stella, VenSim, and PowerSim, help learners to build dynamic simulation models of systems that elaborate causal loops. These tools use

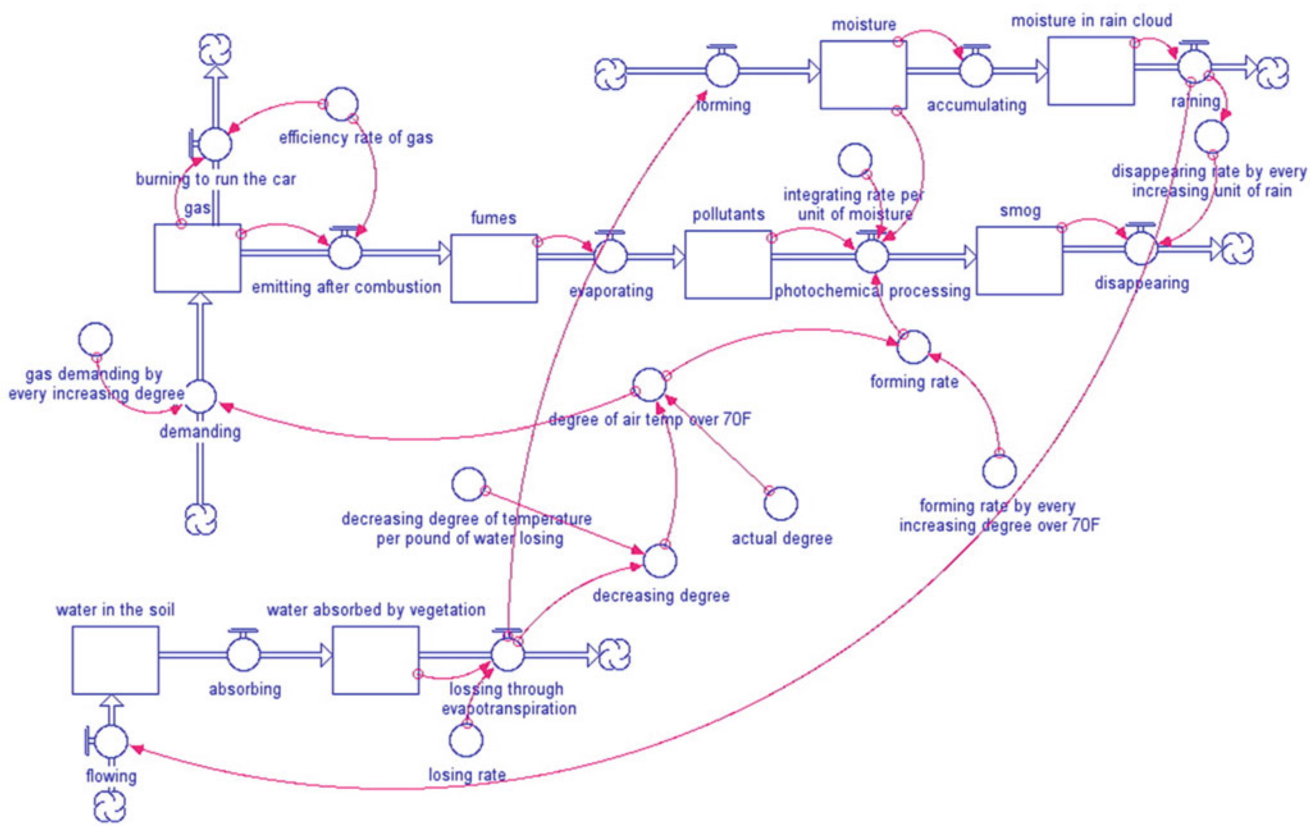


Fig. 22.10 System dynamics models of smog formation

accumulations and flows as the primary modeling tools. For example, the systems model in Fig. 22.10 was built using Stella and represents the factors that contribute the formation of smog. The models use simple algebra to convey the strength of relationships between each other. When the model is run, it becomes a simulation that is driven by an engine based on differential equations, which emphasizes change over time. Running simulations and adjusting the model to contrast alternate solutions are among the most cognitively engaging tasks that students can perform. Figure 22.11 presents possible criteria for assessing the quality of student-constructed systems models. Although empirical research on the relationships of systems modeling and problem solving does not exist, the quality of the model produced by students very likely has the greatest predictive validity of any data source.

Assess Problem-Solving Processes Using Coding Schemes

All of the rubrics described before are used to assess the products of student performance (papers, exams). Rubrics can also be used to assess problem-solving processes as well as products. Another way to assess policy analysis problem solving is to observe and assess the problem-solving process. Audiotaping or videotaping the problem solvers while they are solving problems and transcribing those tapes leave you with a verbal protocol to analyze. Atman and Turns (2001) described a series of verbal protocol studies where they observed engineering students engaged in design tasks. Students would think aloud (Ericsson & Simon, 1993) while solving the problem. They developed a coding scheme including identification of need, problem definition, gathering information, generating ideas, feasibility analysis, evaluation, decision, communication, and implementation. Each thought uttered by students as they solved design problems aloud was classified according to one of these codes. The codes that Atman and Turns used were meant to characterize the cognitive activities engaged by design problem solving. Different kinds of problem solving would require different codes. Atman and Turns (2001) found that older students (seniors) identified more criteria, had significantly more transitions between design steps, and gathered more information than younger students (freshmen). Verbal protocol analysis is a more difficult kind of analysis, but it exposes student reasoning better than most other forms of assessment. After coding protocols, you really understand the students.

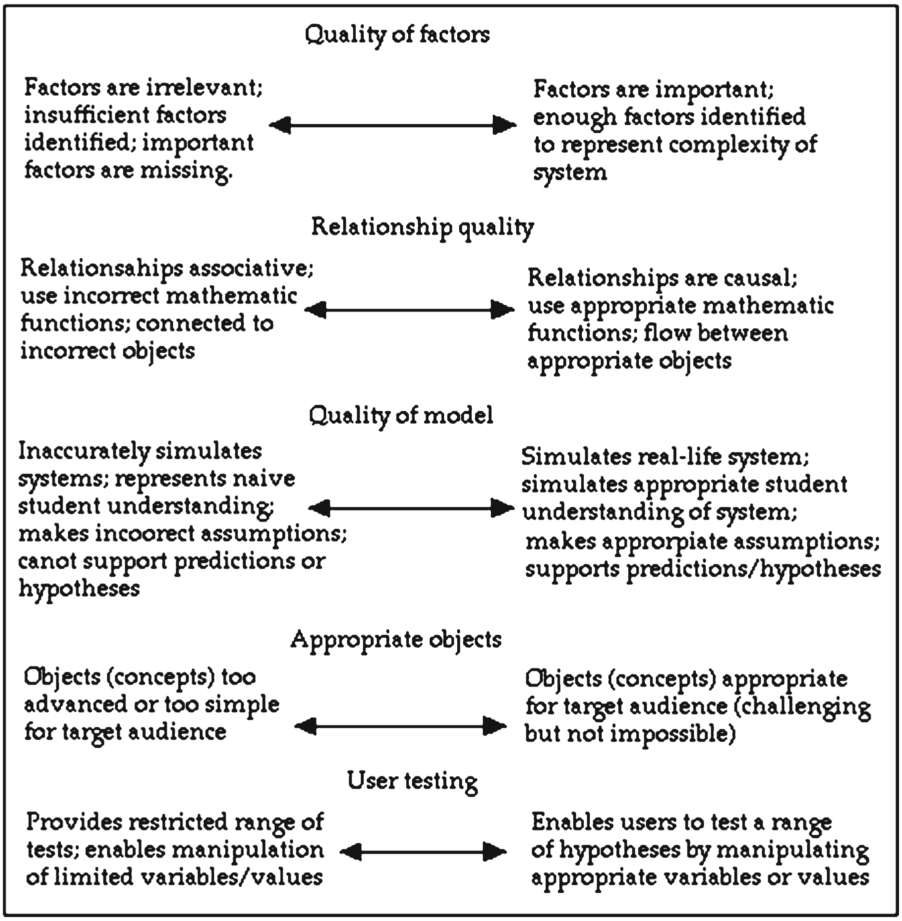


Fig. 22.11 Criteria for assessing the quality of systems models

The verbal protocol analysis process is made easier when the discussions are online, because each message and its producer are already identified, and the contents of the discussion forum can be saved in a database. Cho and Jonassen (2002) analyzed each of the messages posted during problem-solving sessions by classifying each message based on a problem-solving coding scheme, the Decision Function Coding System (DFCS) adapted from Pool and Holmes's (1995). The DFCS consists of seven categories, including problem definition (PD), orientation (OT), criteria development (CD), solution development (SD), solution approval (SA), solution critique (SC), and non-task statement (NS). That is, we classified the purpose of each message according to this scheme. We found that providing a constraint-based argumentation scaffold during group problem-solving activities increased the generation of coherent arguments, and that groups who solved ill-structured problems produced more extensive arguments. The nature of the coding scheme could be changed to focus on the required elements of the problem. For instance, we could have used constraint analysis, political implications, or any other element required in the solution. These codes, in effect, represent rubric, so you as the teacher are coding student responses in terms of desired behavior.

Jonassen and Kwon (2001) used a similar coding scheme to compare problem-solving processes used in computer-mediated communication vs. face-to-face communication. We found greater use of non-task, simple agreement (corresponding to solution approval), and simple disagreement (corresponding to solution critique) categories for both well-structured and ill-structured tasks in the computer-mediated group, relative to the face-to-face group. That is, the nature of the task did not have a significant effect on the problem-solving processes used by students. That is why Cho and Jonassen (2003) scaffolded problem-solving skills. Coding messages or interactions observed while students are problem solving provides valuable information about the nature of problem solving that students performed. Again, the emphasis in all of these methods is to analyze performance.

Coding collaborative communication during the problem-solving process provides perhaps the best evidence of socially co-constructed knowledge. Coding student interaction suffers the same lack of reliability with using rubrics to assess complex performances. As described before, inter-rater reliability among coders is frequently low. Validity of this form of assessment depends on the quality of the coding scheme that is used. As with rubrics, identifying every relevant code is difficult, so important aspects of performance may be missed.

Use Multiple Assessments

In this chapter, I have described multiple methods for assessing students' abilities to solve different kinds of problems, including problem-solving accuracy, comprehension of problem schemas, analogical comparison of problems, solution processes, mental simulations, causal reasoning, student models, and problem-solving processes. The kind of assessment required depends on the kind of problem and whether problem solving is an individual or a collaborative process. Research is needed to compare and contrast assessment methods with problem-solving types.

What has become obvious is the premise that in order to adequately assess problem-solving skills and abilities, it is necessary to use more than one form of assessment. The ability to solve problems and the cognitive residue of that experience cannot be adequately assessed in using any single assessment. Each kind of assessment requires different cognitive skills. In order to understand how learners are solving problems and the cognitive prerequisites and residue from the process, it is imperative to use multiple forms of assessment, especially for research (Jonassen & Grabowski, 1993). If you want your students to learn to solve different kinds of problems, you must learn to teach them to solve different problems and then assess their different abilities to solve the kinds of problems that they practiced. So much research is needed to empirically validate relationships among these different assessment methods and the problem-solving activities they represent.

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23 Model-Based Tools for Knowledge Assessment

Dirk Ifenthaler and Pablo Pirnay-Dummer

Abstract

This chapter introduces the functions of knowledge representation and presents a critical review of the model-based tools for assessment: Pathfinder, ALA-Reader, jMAP, HIMATT, AKOVIA. For each model-based tool, foundations and applications are discussed. Next, the tools are compared in order to illustrate their advantages and disadvantages, strengths, and limitations. The latter part postulates that there is no easy and no complete way to integrate any of the model-based tools. However, the strength of good research lies in a best possible integration: Multiple perspectives on the same construct are usually needed. Thus, the further development of existing tools as well as of new ones is necessary to explore human knowledge, its change, decision-making, performance, and problem-solving as our understanding of those complex human potentials evolves.

Keywords

Mental representation • AKOVIA • HIMATT • Pathfinder

Introduction

The rapid advancement of information and communication technologies (ICT) has important implications for learning and instruction. Remarkable repertoires of hypermedia systems, cognitive tools, learning management systems, and computer-based applications have been developed for almost every subject domain during the past decades (Ifenthaler, 2008; Pirnay-Dummer & Ifenthaler, 2010; Spector, 2010). However, these important changes in teaching and learning through emerging technologies require new perspectives for the design and development of learning environments (see Hannafin, 1992; Ifenthaler, 2010b; Kirschner, 2004; Spector, 2009). Closely linked to the demand of new approaches for designing and developing up-to-date learning environments is the necessity of enhancing the design and delivery of assessment systems and automated computer-based diagnostics (Almond, Steinberg, & Mislevy, 2002; Ifenthaler, 2008; Spector, 2010). These systems need to accomplish specific requirements, such as (1) adaptability to different subject domains, (2) flexibility for experimental and instructional settings, (3) management of huge amounts of data, (4) rapid analysis of specific data, (5) immediate feedback for learners and educators, and (6) generation of automated reports of results (Pirnay-Dummer, Ifenthaler, & Seel, 2012a).

Recently, promising methodologies have been developed which provide a strong basis for applications in research and instruction in order to follow up with the demands that come with better theoretical understanding of the phenomena that are a prerequisite or an integral part or go along with the learning process. This chapter introduces the functions of knowledge representation and present a critical review of the following model-based tools for assessment: Pathfinder

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Networks (Schvaneveldt, 1990), ALA-Reader (Clariana, 2010), jMAP (Shute et al., 2010), HIMATT (Pirnay-Dummer, Ifenthaler, & Spector, 2010), and AKOVIA (Pirnay-Dummer & Ifenthaler, 2010). On the basis of the reviews, we provide a taxonomy for model-based assessment and analysis where current and future developments can be positioned by developers and researchers as regards to the expected validity, feasibility, range of application, ease of integration (with other instruments), strength of assessment, and scope of analysis.

Knowledge Representation

Knowledge is internal and its representations are internal (Ifenthaler, 2010d; Seel, 1991). Accordingly, it is not possible to measure these internal representations of knowledge directly (Ifenthaler, 2008; Seel, 1999a). Additionally, it is argued that different types of knowledge require different types of representations (Minsky, 1981). Therefore, it is necessary to identify economic, fast, reliable, and valid techniques to elicit and analyze knowledge representations (Ifenthaler, 2008, 2010d). In order to identify such techniques, one must be aware of the complex processes and interrelationships between internal and external representations of knowledge. Seel (1991, p. 17) describes the function of internal representation of knowledge by distinguishing three zones—the object zone **W** as part of the world, the knowledge zone **K**, and the zone of internal knowledge representation **R**. As shown in Fig. 23.1, there are two classes of functions: (1) fi_n as the function for the internal representation of the objects of the world (internalization), and (2) f_{out} as the function for the external re-representation back to the world (externalization). Neither class of functions is directly observable. Hence, a measurement of knowledge representation is always biased as we are not able to more precisely define the above described functions of internalization and externalization (Ifenthaler, 2008, 2010d; Seel, 1991; Strasser, 2010). Additionally, the possibilities of externalization are limited to a few sets of sign and symbol systems (Seel, 1999b)—characterized as *graphical* and *language-based approaches*.

Lee and Nelson (2004) report various graphical forms of external knowledge representations for instructional uses and provide a conceptual framework for external representations of knowledge. Graphical forms of externalization include (1) knowledge maps, (2) diagrams, (3) pictures, (4) graphs, (5) charts, (6) matrices, (7) flowcharts, (8) organizers, and (9) trees. However, not all of these forms of externalization have been utilized for instruction and educational assessment (Ifenthaler, 2008; Scaife & Rogers, 1996; Seel, 1999a). Other forms of graphical approaches are the structure formation technique (Scheele & Groeben, 1984), pathfinder networks (Schvaneveldt, 1990), mind tools (Jonassen, 2009; Jonassen & Cho, 2008), and causal diagrams (Al-Diban & Ifenthaler, 2011; Spector & Koszalka, 2004). Language-based approaches include thinking-aloud protocols (Ericsson & Simon, 1993), teach-back procedures (Mandl, Gruber, & Renkl, 1995), cognitive task analysis (Kirwan & Ainsworth, 1992), and computer linguistic techniques (Pirnay-Dummer & Ifenthaler, 2011a; Pirnay-Dummer, Ifenthaler, & Spector, 2010).

With regard to cognitive psychology and its focus on human knowledge representation the most important result of research consists in the observation that learners are able to use different forms of representation of memorized

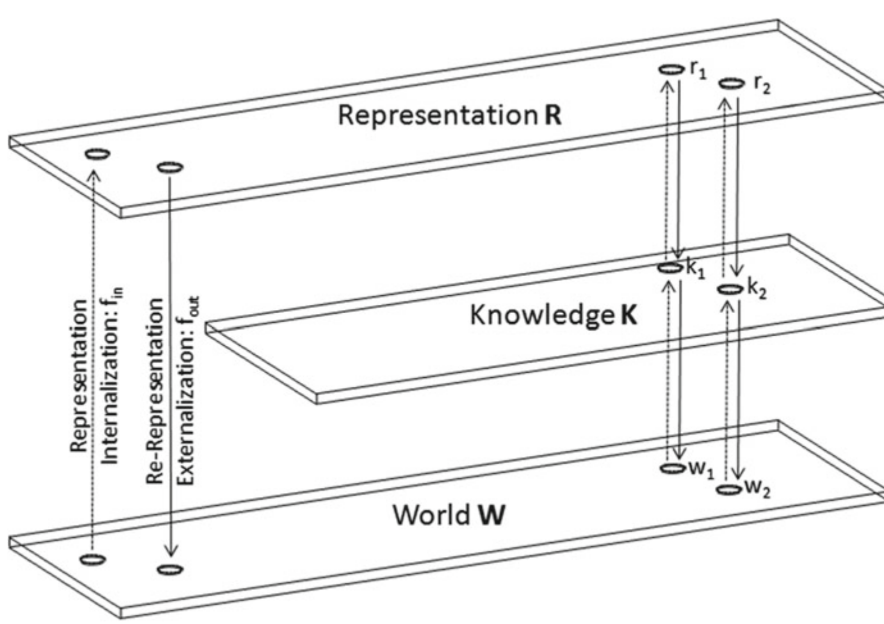

Fig. 23.1 Functions of representation and re-representation (Ifenthaler, 2010d)

information. Learners can either recall an appropriate form of representation from memory or transform memorized information in an appropriate form of representation in dependence on situational demands. However, because it is not possible to assess directly internal representations of knowledge one of the most important issues of research on knowledge representation is concerned with reliable and valid measurements of declarative and procedural knowledge (Galbraith, 1999; Ifenthaler, 2008; Pirnay-Dummer, Ifenthaler, & Seel, 2012b; Seel, 1999a; Stachowiak, 1973; Wygotski, 1969).

To sum up, externalizations are the only available artifacts for empirical investigations of knowledge representation. An externalization is always made by means of interpretation. But the externalization also needs interpretation for its analysis. These are two different kinds of interpretation. All kinds of features may be clustered for a description and aggregation of the artifact. Some of the interpretation is done by the learner and some of it is carried out by humans and technology (Ifenthaler & Pirnay-Dummer, 2010). In most cases a mixture of all three interpreters will be part of the assessment. This mixture and the complexity of the construct both make it specifically difficult to trace the steps and bits of knowledge. Recently, promising tools have been developed which provide a strong basis for applications in research and instruction.

Tools

The latest hardware and software technology provides great potential not only for the design and development of learning environments but also for the enhancement of automated assessment and analysis. Advanced databases and network technologies contribute an especially wide variety of applications for an efficient assessment of individual and group data (Koper & Tattersall, 2004). However, numerous capabilities remain unused because standard assessment tools do not facilitate these technological features (Janetzko, 1999). Foundations and applications of the following model-based tools for knowledge assessment are discussed next: Pathfinder (Schvaneveldt, 1990), ALA-Reader (Clariana, 2010), jMAP (Shute et al., 2010), HIMATT (Pirnay-Dummer et al., 2010), and AKOVIA (Pirnay-Dummer & Ifenthaler, 2010).

Pathfinder

Foundation

Pathfinder is a well-established system for deriving and representing the organization of knowledge structure (Schvaneveldt, 1990; Schvaneveldt, Durso, & Dearholt, 1989). Pathfinder is implemented in the Knowledge Network Organizing Tool (KNOT; http://interlinkinc.net). KNOT includes utilities to facilitate the Pathfinder analysis. KNOT produces graphical representations of the solutions and additional information in the form of text files which can be used for further analysis. Pathfinder transforms estimates of relatedness of propositions (pairs of terms) into a network representation—the Pathfinder Network (PFnet).

The Pathfinder analysis includes three steps: (1) Learners rate the relatedness between a set of concepts (terms) on a scale from low (e.g., one) to high (e.g., nine). The total of pairwise comparisons is calculated as $(n^2-n)/2$ (where n is equal to the total number of concepts). The first step results in a proximity data set. (2) KNOT is used to transform the proximity data into a PFnet. Such a network representation consists of a least-weighted path which links all included concepts. (3) Comparison between different PFnets is calculated in the KNOT software (Goldsmith & Davenport, 1990). As a result, the Configural Similarity of two PFnets indicates how many links between concept pairs they have in common (Goldsmith & Davenport, 1990). KNOT also includes a group average feature which calculates an average of multiple proximity files and represents a group average PFnet representation (Goldsmith & Davenport, 1990).

Application

Pathfinder has a well-established research base. For the past 20 years, numerous empirical studies in several domains have been conducted and proven the utility of PFnets. PFnets have been applied to study multidimensional spaces (Branaghan, 1990; Gillan, Breedin, & Cooke, 1992), conceptual structures of experts (Gammack, 1990), similarity between expert representations (Acton, Johnson, & Goldsmith, 1994), knowledge structures in training programs (Davis & Yi, 2004) as well as knowledge and problem elicitation (Gomez, Hadfield, & Housner, 1996; Gomez, Schvaneveldt, & Staudenmayer, 1996; Gonzalvo, Canas, & Bajo, 1994; Johnson, Goldsmith, & Teague, 1994; Rowe, Cooke, Hall, & Halgren, 1996; Trumpower, Sharara, & Goldsmith, 2010). Finally, new tools have been developed on the basis of the Pathfinder algorithm, e.g., the KU-Mapper (Clariana & Wallace, 2009) and ALA-Reader text analysis software (Clariana, 2010).

ALA-Reader

Foundation

ALA-Reader text analysis software (Clariana, 2010) was modeled on ALA-Mapper software for analyzing network representations (Taricani & Clariana, 2006). ALA-Mapper converts the links between terms (propositions) and the distance between terms (associations) in network representations into proximity array files that can then be analyzed by Pathfinder analysis (Schvaneveldt, 1990). The advantage of this approach is that proximity array files can be compared, combined, and analyzed in many different ways and especially, Pathfinder analysis is proving to be a powerful data reduction approach that can reveal important or salient aspects of the original data set.

ALA-Reader is based on a connectionist knowledge representation approach view that is strongly influenced by Kintsch (1988). Thus, to covert text into proximity arrays, ALA-Reader finds and associates preselected key terms (primarily nouns). The analysis of text is realized sentence by sentence, or linearly within and across sentences. First, the text is preprocessed, i.e., synonyms and metonyms of key terms are replaced with the appropriate key term. In order to validate this process, key terms and their corresponding synonyms and metonyms are determined by content experts.

In the sentence level approach, the key terms that co-occur in the same sentence are entered into a proximity array. A "1" entered in the array indicates that two key terms co-occurred in the same sentence and a "0" means those two key terms did not occur in the same sentence. Each sentence is processed in turn until done. Note that key term co-occurrences are aggregated not summed, so the final proximity array contains only ones and zeroes. In the linear approach, the software searches through the text from the beginning to the end sequentially, adding a "1" in the proximity array to indicate a link between consecutive key terms. Each succeeding key term is "linked" to the next key term found. The software continues to aggregate linearly into the proximity array until all of the text is processed (Clariana, 2010).

Application

ALA-Reader has been applied as a tool for scoring essays and for measuring participant's knowledge structure (Clariana, 2010; Clariana & Wallace, 2007). Reliability of ALA-Reader is regarded as $r = 1.00$, as the software produces exactly the same proximity array for a text every time. Additionally, the researcher may use different key words and different referents, obtaining different proximity arrays for the same text. Validity has been tested for texts with a high frequency of technical vocabulary. Correlations between ALA-Reader and multiple raters' validity scores have been reported as $r = 0.70$ (Clariana & Koul, 2004). For essays with less technical vocabulary, validity scores range from $r = 0.20$ to $r = 0.60$ (Clariana & Wallace, 2007). Probably any instruction or assessment task that involves text or network representations could utilize ALA-Reader. The results for ALA-Reader so far are sufficient to justify further extending the research in this approach.

jMAP

Foundation

jMAP is implemented as an MS Excel application which enables learners to elicit causal understanding of a phenomenon in question, visualize changes of learners' representations, and determine the degree of match between learners and experts (Jeong, 2010). Learners construct their causal representation using MS Excel's autoshape tools. The strength of the causal relations (links) between two concepts is designated by varying the densities of the relations as well as evidentiary support (Shute et al., 2010). jMAP codes the causal representation into a transitional frequency matrix based on the causal strength (1 = weak, 2 = moderate, 3 = strong) and the evidentiary support (0 = none, 1 = weak, 2 = moderate, 3 = strong). If multiple causal representations (e.g., from several students and/or experts; different time points; collective group representation) are available, they can be aggregated. Each individual causal representation can be superimposed over other causal representations. As a result, jMAP produces visual comparisons between the available causal representations, highlighting similarities and difference between time points and/or different causal representations (Shute et al., 2010). In addition, raw scores can be generated from the transitional frequency matrix for further analysis.

Application

The only recently developed jMAP tool provides a good basis for potential instructional applications. For example, using jMAP for solving complex ill-structured problems and assessing students' concept maps, goals, as well as skills in instructional settings. Open research questions, which may be addressed with jMAP, include the change of causal representations over time, variables affecting the way specific relations change, and to what extent do novices converge towards experts based on varying instructional interventions.

HIMATT

Foundation

HIMATT (Highly Integrated Model Assessment Technology and Tools) is a combined toolset which was developed to convey the benefits of various methodological approaches to one environment (Pirnay-Dummer et al., 2010). It integrates the features of DEEP (Dynamic Enhanced Evaluation of Problem Solving; Spector & Koszalka, 2004), MITOCAR (Model Inspection Trace of Concepts and Relations; Pirnay-Dummer & Ifenthaler, 2010), T-MITOCAR (Text-MITOCAR; Pirnay-Dummer & Ifenthaler, 2011a), and SMD Technology (Structure, Matching, Deep Structure; Ifenthaler, 2010c).

The architecture consists of two major platforms: (a) HIMATT Research Engine and (b) HIMATT Subject Environment. Functions for conducting and analyzing experiments are implemented within the HIMATT Research Engine. These functions include: (1) experiment management, (2) researcher management, (3) subject management, (4) view function, and (5) analysis and compare function. The HIMATT Subject Environment provides assigned experiments to individual subjects dynamically.

HIMATT was implemented and run on a Web server using Apache, MySQL (MY Structured Query Language), and PERL (Practical Extraction and Report Language), plus additional packages such as GraphViz (Ellson, Gansner, Koutsofios, North, & Woodhull, 2003).

The core unit in HIMATT is the experiment, which can be laid out flexibly by the researcher. Experiments in HIMATT consist of two assessment modules: (1) DEEP and (2) T-MITOCAR, as well as an INSTRUCTION module which is used to give the subject instructions and explanations. The instructions are texts which may contain HTML code (e.g., to link pictures, videos, or other objects). The subject management function includes multiple options. First, a researcher can add subjects to the HIMATT database. Subject information includes at least a username and a password. If a researcher wants to add a large number of subjects, HIMATT can automatically generate a specified number of subjects with individual usernames and passwords. Additionally, the user can add a prefix to all usernames or passwords in order to more easily identify them later on during experimentation and analysis procedures. Once an experiment has been laid out completely and subjects have been added to the database, researchers can assign subjects to experiments.

The view function presents the knowledge graph as a picture to the researcher. This function allows the researcher to choose from specific experiments and knowledge graphs, which are then available as Portable Network Graphics (PNG) images for download. Depending on the underlying module (DEEP, T-MITOCAR), the graphs will have different features: annotations for DEEP concept maps and associative strengths at the links for T-MITOCAR. Essentially, the standardized re-representation is done in the same way for all modules using the pairwise stored information from the database and GraphViz (Ellson et al., 2003).

The analysis function consists of descriptive measures to account for specific features of the knowledge structure, like interconnectedness and ruggedness. Using the compare function, researchers may compare any kind of knowledge model with standardized similarity measures (Pirnay-Dummer et al., 2010). These measures range from surface oriented structural comparisons to integrated semantic similarity measures (see Table 23.1). The similarity indices range from 0 to 1 for better in-between comparability. Matrices of multiple models can be compared simultaneously. All of the data, regardless of how it is assessed, can be analyzed quantitatively with the same comparison functions for all built-in tools without further manual effort or recoding.

Table 23.1 Description of the seven HIMATT/AKOVIA measures (Ifenthaler, 2011a)

Measure (abbreviation) and type	Short description
Surface matching (SFM) Structural indicator	The surface matching (Ifenthaler, 2010c) compares the number of vertices within two graphs. It is a simple and easy way to calculate values for surface complexity
Graphical matching (GRM) Structural indicator	The graphical matching (Ifenthaler, 2010c) compares the diameters of the spanning trees of the graphs, which is an indicator for the range of conceptual knowledge. It corresponds to structural matching as it is also a measure for structural complexity only
Structural matching (STM) Structural indicator	The structural matching (Pirnay-Dummer & Ifenthaler, 2010) compares the complete structures of two graphs without regard to their content. This measure is necessary for all hypotheses which make assumptions about general features of structure (e.g., assumptions which state that expert knowledge is structured differently from novice knowledge)
Gamma matching (GAM) Structural indicator	The gamma or density of vertices (Pirnay-Dummer & Ifenthaler, 2010) describes the quotient of terms per vertex within a graph. Since both graphs which connect every term with each other term (everything with everything) and graphs which only connect pairs of terms can be considered weak models, a medium density is expected for most good working models
Concept matching (CCM) Semantic indicator	Concept matching (Pirnay-Dummer & Ifenthaler, 2010) compares the sets of concepts (vertices) within a graph to determine the use of terms. This measure is especially important for different groups which operate in the same domain (e.g., use the same textbook). It determines differences in language use between the models
Propositional matching (PPM) Semantic indicator	The propositional matching (Ifenthaler, 2010c) value compares only fully identical propositions between two graphs. It is a good measure for quantifying semantic similarity between two graphs
Balanced propositional matching (BPM) Semantic indicator	The balanced propositional matching (Pirnay-Dummer & Ifenthaler, 2010) is the quotient of propositional matching and concept matching. Especially when both indices are being interpreted, balanced propositional matching should be preferred over propositional matching

Application

Every single measure integrated into HIMATT is tested for reliability and validity. The reliability scores range from $r=0.79$ to $r=0.94$ and are tested for the structural and semantic measures separately and across different knowledge domains (Pirnay-Dummer et al., 2010). Convergent and divergent validity has been tested using several criteria. Ifenthaler (2010c) reports a validity study using a declarative knowledge test as an outside criterion. The study demonstrates convergent (declarative knowledge correlates significantly with the semantic measure, $r=0.355$) and divergent validity

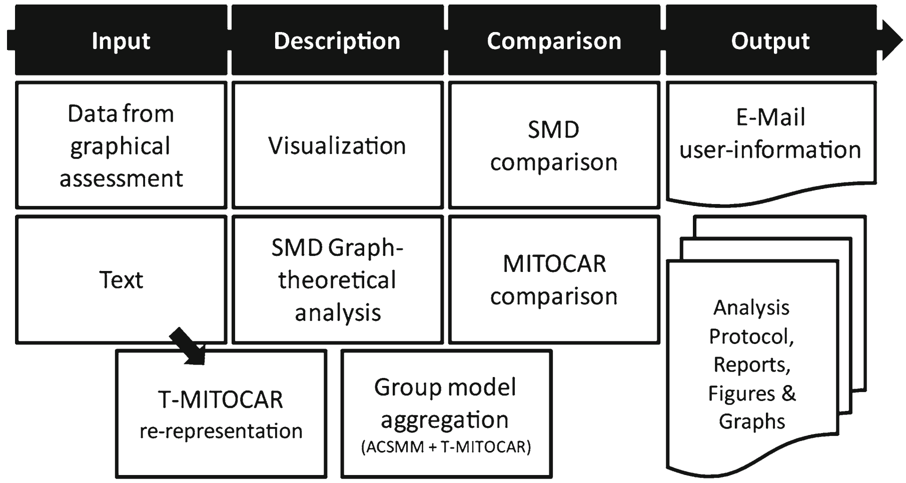

Fig. 23.2 AKOVIA framework (Pirnay-Dummer & Ifenthaler, 2010)

(no significant correlation between declarative knowledge and structural measures). Another validation study showed convergent validity among structural (e.g., SFM and GRM, $r=.79$; SFM and STM, $r=.63$; all correlations are significant) and among semantic (e.g., CCM and PPM, $r=.68$, PPM and BPM, $r=.91$; all correlations are significant) measures (Pirnay-Dummer et al., 2010).

HIMATT and its tools have been successfully applied within classical experimental settings (Ifenthaler, 2010a, 2011a, 2012; Ifenthaler & Pirnay-Dummer, 2009; Spector, 2010) and fields of applications within the domains of instructional planning, medical diagnosis, and geology (see Kim, 2008; Lachner & Pirnay-Dummer, 2010; Lee, 2009; McKeown, 2009; Smith, 2009; Spector & Koszalka, 2004). Further, empirical studies showed that HIMATT measures (e.g., GAM, CCM) helped to distinguish inexperienced from highly experienced problem solvers in all domains examined so far (J. Lee, 2009; McKeown, 2009). Finally, a usability test showed that HIMATT is widely accepted among the users and the usage is easy to learn (Pirnay-Dummer et al., 2010).

AKOVIA

Foundation

AKOVIA (Automated Knowledge Visualization and Assessment) is based on the HIMATT framework, however, concentrates on the model-based analysis methods (Pirnay-Dummer & Ifenthaler, 2010). Instead of limiting the framework to a narrow set of data collection procedures, AKOVIA was development to integrate a large number of interfaces to different methods. The core analysis in AKOVIA is a comprehensive blend of MITOCAR, T-MITOCAR, and the SMD Technology. Thus, it is also based strictly on mental model theory (Johnson-Laird, 1983; Seel, 1991, 2003). In contrast to HIMATT, the input formats and outputs have been changed to better accommodate the needs of researchers, thus allowing more applications as in the original technologies and HIMATT.

Figure 23.2 provides an overview on the modules of AKOVIA. There are two general input formats (text and graph). Thus, the software can be used to analyze many currently available assessment methods. A standard interface may be used for graphical methods. This interface is derived from SMD and HIMATT and uses the list form. Specific interfaces are under construction. The software can visualize, aggregate, describe in detail, and compare the models. The measures from SMD and MITOCAR are embedded and available for use (see Table 23.1), as are the text to graph algorithms from T-MITOCAR. In the following paragraphs we introduce the process from input to output in more detail. There are also examples for the AKOVIA scripting technology, which helps handle large data.

Application

AKOVIA places no explicit limits on the size of data which can be investigated and analyzed. Large concurrent analyses used to slow HIMATT servers down to the point where the browser experienced time outs. Therefore, the topology of the small analysis grid has been separated into the *upload server*, which takes in the files, and the *analysis servers*. The latter access the upload server and process the tickets offline. Afterwards, the results are uploaded to the upload server and the user is notified via email. Depending on the number and size of concurrent jobs, a response may take hours or sometimes even days (Pirnay-Dummer & Ifenthaler, 2010). When users upload data, they only receive an initial confirmation email with either a list of errors (if the data is not formatted correctly) or a short note confirming that their data is being processed. If the data is correct, an available analysis server downloads the files as soon as it has finished previous analyses. After completing a script, the analysis server packs and uploads the results and a protocol to the upload server, which sends an email to the user. The email contains abbreviated information on the progress of the analysis and a protected download link with which the user can access the package for a limited time. Afterwards, the package is deleted from the server as is the download link (Pirnay-Dummer & Ifenthaler, 2010).

The main applications of AKOVIA are clearly in analysis and comparison, whereas the assessment step itself is left to the tools and experimental setups of the researchers. AKOVIA is designed to complement various kinds of technologies as it uses interfaces which allow many forms of data to be analyzed. The visualizations of the models have shown to have an especially positive effect on learning within tasks which involve writing (Pirnay-Dummer & Ifenthaler, 2011a, 2011b). Thus, the possible applications reach beyond the structural and semantic analysis and comparison of knowledge (Ifenthaler & Pirnay-Dummer, 2011). In addition, AKOVIA allows the development of self-assessment technologies, such as automated model-based feedback. In this case, specifically formatted and interpreted outputs of the analysis and comparison are embedded into feedback (Ifenthaler, 2009, 2010a, 2011b).

Comparison of Model-Based Assessment Tools

Several possible solutions to the assessment and analysis problems of knowledge representations have been discussed (e.g., Al-Diban & Ifenthaler, 2011; Clariana & Wallace, 2007; Ifenthaler, 2008, 2010d; Shute, Jeong, Spector, Seel, & Johnson, 2009). Therefore, it is worthwhile to compare the above described model-based assessment and analysis approaches in order to illustrate their advantages and disadvantages, strengths and limitations (see Table 23.2). Yet, there is no ideal solution for the automated assessment of knowledge. However, within the last 5 years strong progress has been made in the development of model-based tools for knowledge assessment. Still, Table 23.2 highlights necessary further development of the available tools, especially for everyday classroom application.

Conclusions

Not all types of knowledge representations have the same types of properties and strengths, e.g., *written language* is always sequenced and has multiple dimensions at the same time, *concept maps* are not semantic webs most of the time due to underspecification problems and a lack of homogeneity, *association networks* do not have directions and propositions, *causality networks* cannot deal with dynamics, and representations of dynamic systems are almost impossible to aggregate—nor are they supposed to be aggregable in the first place. The list is not even complete. There is no easy and no complete way to integrate any of them, and the strength of good research therefore lies, maybe more than in other research domains, in a fitting integration: Multiple perspectives on the same construct are usually needed (Ifenthaler, 2010d; Ifenthaler & Pirnay-Dummer, 2010). The only way to make better decisions about the kind of knowledge representation as well as the type of tool to be used on it is to know the strengths and weaknesses of the tools. It is worth the effort to acquaint oneself with at least a representative selection of the available tools (Ifenthaler & Pirnay-Dummer, 2010; Mislevy et al., 2010). As long as mental constructs are not observable directly, there will be a need for different perspectives on the states and changes of knowledge. Every methodology at our current disposal is only a heuristic to narrow down the gap of the unknown functions between what is considered to be mental (internal) and behavior. In research about knowledge models we rely on the analysis of the artifacts being constructed by this behavior—be it text, graphs, tracks of problem solving or any other observable aspect of the object world.

Aside from automating the processes of elicitation and analysis, another important aspect of the recent developments is that the methodology becomes more and more fine-grained, thus allowing a whole new set of research questions to be ready for investigation. Research on knowledge has become less about how much there is and how complex it looks if it is derived from expertise. With new tools and developments at hand, we can say by far more about how things are structured and build from the inside (Pirnay-Dummer, 2010). This has allowed research to ask more specific questions on what really changes during learning. And it will allow even more specific questions if the researchers who are currently working on the methodologies and tools advance both in integrating and converging the analysis of knowledge structures and in finding more specifics to the artifacts of elicitation.

Scientific Quality Criteria

As discussed above, there are numerous approaches for eliciting knowledge for various diagnostic purposes. However, most approaches have not been tested for reliability and validity (Ifenthaler, 2008; Seel, 1999a). Additionally, they are almost only applicable to single or small sets of data (Al-Diban & Ifenthaler, 2011; Ifenthaler, 2010c). Hence, new approaches are required which have not only been

Table 23.2 Comparison of model-based assessment tools

	Pathfinder	ALA-Reader	jMAP	HIMATT	AKOVIA
Description	Converting estimates of relatedness of pairs of concepts into a network representation	Scoring open-ended concept maps and essays	Workbench to map concepts onto a predefined structure	Experimental toolset to elicit and analyze graphical or text-based artifacts	Automated researcher tool to analyze existing graphical or text-based artifacts
Measures	Graph theory-based measures Network representation	Graph theory-based measures Scoring algorithm	Adjacency matrix of links	Quantitative structural measures Semantic measures Graphical representation as qualitative measure	Quantitative structural Semantic measures Graphical representation as qualitative measure
Objectivity	Model building process depends on the interpretation by the subjects	Model building process depends on observers	Model building process depends on observers	Automated analysis	Automated analysis
Reliability	Tested (Schvaneveldt, 1990)	Tested (Clariana, 2010)	Not tested	Tested (Ifenthaler & Pirnay-Dummer, 2010)	Tested (Ifenthaler & Pirnay-Dummer, 2010)
Validity	Tested (Schvaneveldt, 1990)	Tested (Clariana, 2010)	Not tested	Tested (Ifenthaler & Pirnay-Dummer, 2010)	Tested (Ifenthaler & Pirnay-Dummer, 2010)
Automatization	Partly	Partly	Analysis only	Elicitation and analysis	Model-elicitation (text) and analysis
Strength	Well established research approach	Instant analysis	Off-line availability Instant analysis	Complete experimental setup Server-based for both the elicitation and the analysis	Large datasets Fast analysis Scripting server and online access Data can be assessed by any means outside of the system
Limitations	Connectivity to other learning environments is rather weak	Connectivity to other learning environments is rather weak	Model construction objectivity	Connectivity to other learning environments is rather weak	No elicitation module available

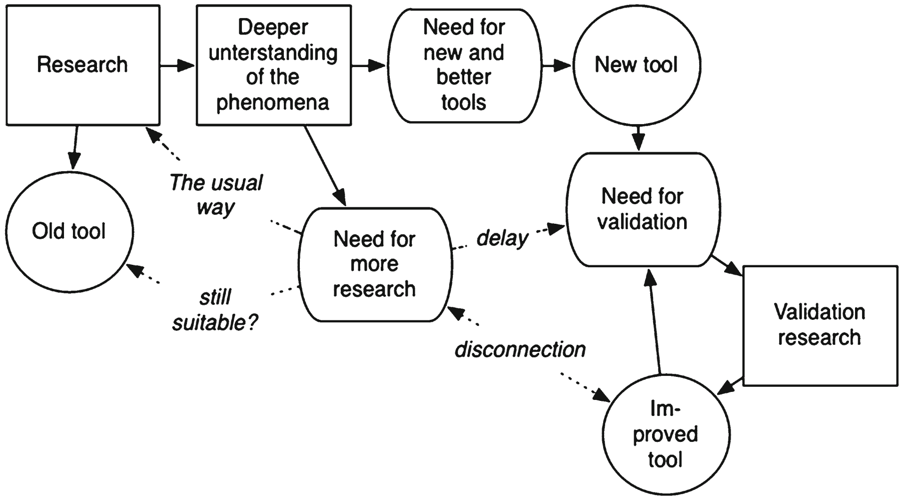

Fig. 23.3 Current disconnection and delay of research and methodology (tools) development

tested for reliability and validity but also provide a fast and economic way of analyzing larger sets of data. Additionally, approaches for educational diagnostics also need to move beyond the perspective of correct and incorrect solutions. As we move into the twenty-first century, we argue that the application of alternative assessment and analysis strategies is inevitable for current educational diagnostics. To do so, there must be a wider discussion that is more innovation-friendly at the same time.

Figure 23.3 shows the disconnection and avoidable delays in common methodology and tools development. To circumvent the disconnection, two competing assumptions need to be addressed in order to properly match the tools to the implicit or explicit demands in research:

First, we cannot afford to use outdated tools just because new ones are not properly tested. No matter how standardized they may be. As theories evolve so will new technologies to keep up with the newly discovered phenomena. Thus, tools which are based on an outdated theory will expire for their use to a deeper understanding of newer developments. If yet the outdated tools are used, research may run into a high risk of producing everlasting circles of the same results and insights, probably renaming the theories to cover for the lack of innovation. Thus, the use of innovative tools for assessment should be considered a scientific standard on its own.

Second, we cannot afford not to test new tools. Tools must be tested in- and outside the community of its developers (Al-Diban & Ifenthaler, 2011). To even make that possible, decisions on funds need to take into consideration the researchers' willingness and ability to triangulate knowledge data and to apply new methodologies in their research even if that research is not directly about new methodologies. Thus, the test of new methodologies alongside already existing ones should become a scientific standard, too. Cross-validation and first large-sample tests should of course still remain a key focus of the developers. But after a series of such studies, a wider analysis and evaluation of feasibility is needed: There will never be resources to widely apply every new tool to a proper set of studies. And we believe, we often saw good developments in the loop and their developers going on a life-quest to run sufficient studies on just everything only to make a point towards the methodology. But this would be a waste of resources and time—since the innovations are already there.

Figure 23.4 shows a way to integrate common research and the innovation of research tools in general by just using innovations along with the standards. This simple application can inform both the innovation process (validation research) and improve the research at the same time without widening the risk for the research results: As a "plan B" the standard tools are still used at that point. The triangulation will give interesting additional insight into the research problem, i.e., by means of post hoc analyses. An integration of methodological innovation alongside with research standards and common research will shorten the time for implementation by years if not decades without harming the research process itself.

Automation of Tools

In many settings manual and therefore labor-intensive methods have limits, e.g., when the groups under investigation are large or practical applications do not have the resources which prototypes may have. Also, from a methodological viewpoint the automation helps in raising the objectivity of studies. Another important focus of our work is to make the applicability of the tools as broad as possible while retaining a very specific set of well-tested algorithms and methods which have shown to be reliable both in technical and empirical

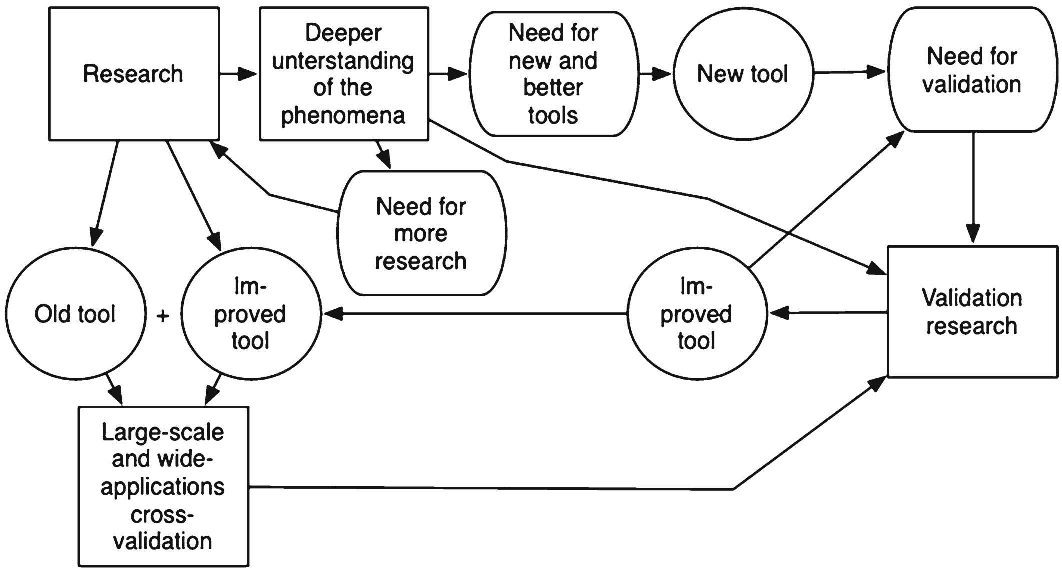

Fig. 23.4 Possible workaround to circumvent the disconnection between research and tools development

respects. Thus, automation does not only make things easier and less expensive. It also allows for a whole set of small and medium research projects to gain access to a reliable means of measurement and analysis. In a way, without automation, many research projects would not be possible from the start. This does not contradict the fact that labor-intense qualitative work will have its own rewards in allowing much deeper insight to questions and aspects of knowledge where automated tools cannot yet look at. But especially in cases, where the resources are not available to go through and analyze a larger set of artifacts by hand, the automated tools will help to explore new boundaries of learning.

Full automation as opposed to part-manual approaches also open up another class of technologies. If the assessment and analysis can be carried out automatically and in real time, then its results can be used to inform both the decision-makers (e.g., teachers) and the learners during an ongoing learning process. Outcomes and results of these assessments can then be aggregated, transformed, and thus utilized to create feedback-panels or even written feedback based on the current learner model. Feedback into the ongoing learning can be explicit by using the results of the analysis, e.g., graphs, change indicators, as well as convergence towards an expert solution (Ifenthaler, 2010a, 2011b). The feedback can also be transformed for a more implicit use of the aggregations by using algorithms to create written feedback based on numerical indicators (Ifenthaler, 2011b; Pirnay-Dummer & Ifenthaler, 2011a, 2011b). Only with the complete automation of the assessment and analysis process an assessment-based feedback to inform the ongoing learning process is possible (Ifenthaler, 2009).

Future Research

Since many new tools focus on how knowledge is structured and it is less and less about how much there is, the gap between qualitative and quantitative approaches will be narrowed down substantially. But narrowing that gap is not only about developing new tools. The process will need an open cross-validation from both perspectives with an emphasis of what can be done (and in what way) that was not possible yesterday.

Future research will change the theories of knowledge and thought substantially. With the finer grain of exploration at hand, those theories will inevitably become more complex because we are now more able to see differences and nuances as well as their effects within learners and problem solvers. Because we find new phenomena, they will be a need for thorough explanation, preferably not quick-shots but deeply reflected theories that explain the new variety of phenomena.

None of the existing tools are finished and complete at the moment. Based on their potential they may be improved in several ways, e.g., a better integration, extended automation, or even finer grain of measurements. Hence, the tools need to be challenged on both empirical and technological ground. This process needs to be conducted in front of and for the research audience that uses the tools. It is imperative that there will not be a parallel universe of methodologists raising the quality of tools to a high orbit if either nobody will understand and use them or they become less feasible.

The latter requirement also comes with an important goal for further development and a very important distinction as regards simplicity: Essentially, implementing the tools and subsets of them in practice needs to be simple and as less invasive to the common processes as possible. The tools need to be simple so that every practitioner has the time to implement them if necessary. This means, that the tools need to be highly usable and easy to apply, which is the easier goal. The second goal is not that simple. There is almost no way around the proper interpretation of the outcome, i.e., of measures or aggregations made by the tools. In order to work properly in practice, this also means, that practitioners as well as researchers will need training on how to interpret the outcomes of the tools, especially when they might look very much alike at the surface. Any decision maker who uses the tools needs to know what the output of the tools is about and what are the heuristic limitations of the output are, e.g., distinguishing an association net from a knowledge map although they look very much alike.

To triangulate the use, usability, and feasibility of the tools, we would suggest to apply them to a large dataset of national and international magnitude. The process can be repeated for validation and comparability should new tools be built or every some years if the existing tools changed significantly. The following aspects should be considered in such a triangulation:

1. The convergent and divergent validities between the tools as compared to available standard measures (e.g., grades, performance indicators)
2. Objectivity measures—if parts of the observation depend on human interpretation
3. The limitations of the tools for any of the investigated target groups
4. The total cost of the implementation per sample
5. The variety of outputs and outcomes per single application of each tool
6. The quality and use of the output as perceived by
   - Researchers
   - Target group
   - Group of the decision-makers (e.g., teachers, policy makers)
7. The possibility of tool- or part-tool reduction if the outputs measure or assess the same (by convergent validity)—in this case the tool that is easier to implement (without any loss of information) prevails. This aspect will also encourage researchers to converge their technologies where possible.

A large scale triangulation study will continuously help to improve and converge the innovations in the methodology of knowledge- and model-assessment. It can also control for the benefits of the existing tool while researchers who built the tools will have a predictable motivation to put their tools to the test. However, the effect of the convergence should not reach out to reduce the diversity in tool initial development. Even already dismissed approaches must be available for reinvestigation. The results of a triangulation study cannot be a shortcut to decide on funding and resources. The development of the existing tools as well as of new ones is necessary to explore human knowledge, its change, decision-making, performance, and problem-solving as our understanding of those complex human potentials evolves.

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Performance Assessment: Something Old, Something New

24

Dee H. Andrews and Wallace H. Wulfeck II

Abstract

Education, industry, and the military rely on relevant and effective performance assessment to make key decisions. Qualification, promotion, advancement, hiring, firing, and training decisions are just some of the functions that rely on good performance assessment. This chapter explores issues, tools, and techniques for ensuring that performance assessment meets the goals of decision makers. Important considerations include the following: the task environment in which assessment takes place, the validity of the measures selected, the diversity and scope of the measures, and often the local political environment in which assessments are made. Unfortunately, primarily in education, assessment policy is a matter of intense political debate, and the debate is sustained by misinformation. For example, traditional paper and pencil assessment techniques have come under fire from those who do not feel they have the relevance they once did. Simulation-based training technologies in industry and the military have put more emphasis on performance assessment systems that show real-world work relevance. The chapter examines these topics.

Keywords

Authentic assessment • Alternative assessment • Portfolio assessment • Performance appraisal • Performance evaluation • Performance task

Introduction

In education, performance assessment refers to testing methods that require students to create an answer or product, or execute a process, that demonstrates their knowledge or skills. Performance assessment, in education and work settings, can take many different forms including writing short answers, doing mathematical computations, writing an extended essay, conducting an experiment, presenting an oral argument, executing a series of tasks, or assembling a portfolio of representative work (US Congress, Office of Technology Assessment, 1992). More broadly, performance assessment refers to the measurement of a system or process with respect to goals or benchmarks set for it.

Assessment in one form or another has a history going back at least 2000 years. In early China, prospective civil servants were examined not only on recitation, but on productive originality (Madaus & O'Dwyer, 1999). Later, the focus turned away from production toward reproductive thinking "because government officials became worried that the scoring of these questions would be too subjective; thus, they reverted back to questions that required more rote answers" (Madaus & O'Dwyer, 1999). Twelve hundred years later, universities in France and Italy began the practice of

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oral examinations, and written examinations in Latin composition appeared by the sixteenth century (Madaus & O'Dwyer, 1999). Guild membership led to professional certification based on proven skills and knowledge. The industrial revolution brought a focus on quantification in measurement, and by the twentieth century industrial task analysis and "scientific management" had given rise to the invention of multiple-choice testing by Frederick Kelly in 1914 and its large-scale use in the Army Alpha test in World War I. The College Board's Scholastic Aptitude Test used multiple-choice items beginning in 1926. By the 1950s, the invention of data processing systems and optical scanners, as well as taxonomies of educational outcomes (Bloom, 1956) and the behavioral objectives movement, led to the predominance of machine-scorable tests, particularly in the USA.

Since at least the 1950s, there has been a continuing societal debate about the use, fairness, and appropriateness of various forms of assessment. Robert Glaser (1963) focused on the *purpose* of testing and distinguished between norm-referenced and criterion-referenced testing. Performance assessments are usually criterion-referenced because they refer to defined performances, but can be norm-referenced, for example in sales or sports. More recently there has been ongoing controversy concerning the proper role of testing in schooling, and this has tracked larger societal debates concerning the "constructivist" and "situated learning" movements (Anderson, Reder, & Simon, 2000), and most recently, standards-based education policy with so-called "high-stakes" testing.

Definitions

Authentic Assessment: Engaging and worthy problems or questions of importance, in which students must use knowledge to fashion performances effectively and creatively. The tasks are either replicas of or analogous to the kinds of problems faced by adult citizens and consumers or professionals in the field. (Wiggins, 1993, p. 229).

Alternative Assessment: The term alternative assessment is broadly defined as any assessment method that is an alternative to traditional paper-and-pencil tests. Alternative assessment requires students to demonstrate the skills and knowledge that are difficult to assess using a timed multiple-choice or true-false test. It seeks to reveal students' critical-thinking and evaluation skills by asking students to complete open-ended tasks that often take more than one class period to complete. While fact-based knowledge is still a component of the learning that is assessed, its measurement is not the sole purpose of the assessment.

Alternative assessment is almost always teacher-created (rather than created by other test developers) and is inextricably tied to the curriculum studied in class. The form of assessment is usually customized to the students and to the subject matter itself. (Teaching Today. McGraw-Hill Retrieved from http://teachingtoday.glencoe.com/howtoarticles/alternative-assessment-primer.)

Portfolio Assessment: A portfolio is a collection of student work that can exhibit a student's efforts, progress, and achievements in various areas of the curriculum. A portfolio assessment can be an examination of student-selected samples of work experiences and documents related to outcomes being assessed, and it can address and support progress toward achieving academic goals, including student efficacy. Portfolio assessments have been used for large-scale assessment and accountability purposes (e.g., the Vermont and Kentucky statewide assessment systems), for purposes of school-to-work transitions, and for purposes of certification. For example, portfolio assessments are used as part of the National Board for Professional Teaching Standards assessment of expert teachers. (Retrieved from answers.com http://www.answers.com/topic/portfolio-assessment.)

Performance Appraisal: Performance appraisal is the procuring, analyzing and documenting of facts and information about an employee's net worth to the organization. It aims at measuring and constantly improving the employee's present performance and tapping the future potential.

Performance Evaluation: Performance evaluations are prepared by company management on a periodic basis to determine if employees are working up to, or beyond, the minimum standards of their job description. Critical areas are graded by supervisors or department managers in either a written or checklist format, or a combination of both. Decisions ranging from salary increases to possible termination can result from performance evaluations.

Performance Task: A performance task is a goal-directed assessment exercise. It consists of an activity or assignment that is completed by the student and then judged by the teacher or other evaluator on the basis of specific performance criteria.

Current Status

Extensive work on performance testing has been going on since at least the 1960s (e.g., Glaser, 1963; Glaser & Klaus, 1962). Perhaps the best overview of the state of research and practice in educational assessment was given in a recent report on educational assessment by the National Research Council (Pellegrino, Chudowsky, & Glaser, 2001).

In addition there are modern standards for the practice of assessment. The Joint Committee on Standards for Educational Evaluation was formed in 1975 by major professional associations in social, psychological, and education science and practice. Three sets of standards have been published: Personnel Evaluation (Joint Committee, 1988, revised 2009), Program Evaluation (Yarbrough, Shulha, Hopson, & Caruthers, 2011), and Student Evaluation (Joint Committee on Standards for Educational Evaluation, 2003). In addition, the American Educational Research Association, American Psychological Association, and the National Council on Measurement in Education (1999) have produced standards for educational and psychological testing that cover validity, reliability and error, test development, scoring, score comparability, fairness, and testing applications.

Today there is continuing interest in the role and purpose of testing, and performance-based assessments are in vogue. The US Department of Education's *Race to the Top* assessment program provides "funding for the development of new assessment systems that measure student knowledge and skills against a common set of college and career-ready standards … in mathematics and English language arts in a way that covers the full range of those standards, elicits complex student demonstrations or applications of knowledge and skills as appropriate, and provides an accurate measure of student achievement across the full performance continuum and an accurate measure of student growth over a full academic year or course." (Department of Education, 2010).

Performance assessments often appeal to those who are uncomfortable with large-scale, high-stakes, standardized, normative testing. However, performance assessments have obvious shortcomings. These include: difficulty and expense of administration, unreliability of scoring because of human rater error or bias, and poorer validity or generalizability due to limited time and opportunity to sample extensively from a broad universe of knowledge and skill.

Many performance assessments used in classrooms are teacher designed. This has both advantages and disadvantages. Teachers can adapt their assessments more rapidly to individuals, and can therefore diagnose and remediate more effectively. But this flexibility comes at the price of standardization and reliability, because teachers are often not trained or expert in the design of reliable and valid assessments, and because adaptation necessarily involves alteration of the assessment situation from individual to individual. In addition, teachers may have more difficulty interpreting results that are not expected.

There are more subtle problems in the design of reliable and valid performance assessments. Most performance assessments have associated "rubrics" or scoring keys, which are necessary to provide some standardization and reliability in scoring. Many examples are online at, for example http://www.rcampus.com/indexrubric.cfm or http://www.rubrics4teachers.com/. But in reality, most of these are nothing more than checklists for critical events, and "behaviorally anchored rating scales" from 50 years ago (Smith & Kendall, 1963). At the time these rating techniques were originally developed, such checklists and behavioral anchors depended on reasonably extensive critical-incident and behavioral task analyses. Such analyses have their own difficulties: they are expensive and time consuming to conduct; they depend on deep subject-matter or content knowledge on the part of the analyst; they may be incomplete or inaccurate; they often lead to oversimplification of content (and therefore, for performance measurement, to assessment at too rudimentary a level); and to an overemphasis on procedural skill (rather than underlying cognition) (Bell, Andrews, & Wulfeck, 2010). Ironically, without deep task analysis, performance assessment may be just as behaviorally trivial as poorly designed machine-scored objective tests.

In the end, performance assessments, by definition, rely on some observation of behavior, with inferences about underlying knowledge and cognition. The same is true of any objective assessment which relies on the same sort of behavioral and cognitive task analyses. Therefore, claims concerning the supposed superiority of performance assessment (compared to objective tests) in contemporary education advocacy must be taken with a large dose of skepticism. Indeed, we often find recommendations and practices that, at best, show little awareness of decades of development, and at worst, are simply wrong. This is true not only in the popular press, where policies and practices of education and assessment are often the subject of inflammatory but ill-informed political debate, but also in professional guidance for educators. For example, a publication from a state office of education giving recommendations for science teachers about development of performance assessments says: "…objectively scored tests are not valid measures of what is important to learn in school. Objectively scored tests—multiple choice, completion, short answer—emphasize the acquisition of and the memorization of information. They cannot be appropriately used to measure many higher level thinking abilities nor can they be used to measure some other important goals of schooling." (Baird, 1997).

Leaving aside the bizarre implication that acquisition and memorization of information are not important outcomes of schooling, we concentrate on the claim that objectively scored tests cannot appropriately measure higher-level thinking: While it is true that poorly designed tests might not assess very well, it is certainly not true that assessments cannot be designed to provide objective scoring of many kinds of complex performances, including those that depend on reasoning and problem solving. We have known for decades how to do it, when the tasks for which performance is to be assessed are deeply and explicitly analyzed (e.g., Ellis & Wulfeck, 1982; Glaser & Klaus, 1962; Merrill, 1994; Stevens & Collins, 1977).

We are indebted to a reviewer of this chapter for noting that various forms of assessment cover a broad range of alternatives, such as the nature of the contextual setting for response or performance, process vs. product measurement, response modes, types of "items" (or instances of response observation), and methods of scoring. Different combinations of alternatives on these dimensions may be more or less appropriate depending on the specific task(s) to be assessed but there should be no *a priori* claim of superior reliability or validity for any particular combination, assuming, of course, that the assessment is competently designed. Further, however, the choice of different combinations may have substantial implications for the cost and practicality of development, administration, scoring, reporting, and utilization of assessment results. For example, "paper" simulations with "multiple-choice" responses can be designed for many types of mechanical or electronic troubleshooting tasks: they can test logical reasoning and problem solving and can provide diagnostic information concerning misconceptions (cf. Ellis & Wulfeck, 1982). They are much cheaper to administer and score than an actual hands-on troubleshooting event that requires live test equipment and individual administration and scoring by a human observer.

Simulation-Based Performance Assessment

Even before the large-scale development of computer-based simulations, case-based and role-based simulations were used in education, such as "moot courts" in legal training, or wargaming in the military. Non-computer-based simulators are heavily used in many fields, for example, in medical education (cf. www.simulation.com for examples of commercially available human patient simulators), or in firefighting training (cf. www.mobilefireunits.com for examples of commercially available simulators).

In simulation-based training, the simulation is used to provide the context in which human performance may occur and be observed, recorded and measured. The most important ingredients for successful simulation-based training and assessment are the design of the scenarios, since these prescribe the conditions under which performance will be elicited, the physical fidelity of the simulation (for example in medical devices), and (as in any performance assessment) the scoring criteria against which performance will be evaluated. In simulations which are not computer based, observation and measurement generally use the same techniques as in other performance assessments, namely checklists, rating scales, and occasionally time-to-solution measures. These, of course, suffer from the same limitations as most other performance assessments. For example, a review of assessments used in anesthesia simulation in medical training found few which addressed questions of validity or reliability (Byrne & Greaves, 2001).

So, What's New in Assessment?

In recent years, with the development of computing technologies, it has become possible to build detailed, highly veridical simulations of complex phenomena (cf. Baker, Dickieson, Wulfeck, & O'Neil, 2008). Computer-based simulations are now used in many fields of endeavor, such as medicine and surgery, engineering, economics, geology, vehicle piloting, and many others. Simulations are used for system design, system performance analysis, prediction of outcomes, analysis of alternative courses of action, and of course for training and performance assessment.

Computer-based simulations have some properties which may contribute to effective performance measurement. First, the process of constructing the simulation essentially involves a very fine-grained task analysis, since almost every aspect of the user's interaction with the simulation must be taken into account in its design (Wulfeck, Wetzel-Smith, & Dickieson, 2004). Thus, unlike performance assessments where variations in performance can be handled (or missed) by a human rater's observational skill, such variation must be explicitly accounted for in the simulation. Second, the simulation can be designed to collect performance data automatically, and use it for scoring and evaluation, as well as for control and adaptation in the simulation itself. Third, the simulation is, by definition, situated in a task environment, so criticisms concerning the unreality of common standardized multiple-choice testing are avoided.

Simulation-Based Performance Assessment for Aviation

Before we discuss simulation-based performance assessment for aviation it is important to discuss simulation fidelity in its various forms. There are a number of different types of simulation fidelity (Hays & Singer, 1989; Swezey & Andrews, 2001). Physical fidelity refers to the physical characteristics of the simulation or simulator ("does it look right?"). Functional fidelity refers to the way the simulation or simulator behaves ("does it act right?"). Psychological fidelity, which is much more difficult to assess, refers to how an experienced real-world operator of a system believes the simulation or simulator subjectively meets their expectations in terms of its "feel" to them ("does it feel right?"). For example, an aircraft simulator may look and act like the real thing, but an operator may still not get an authentic feeling when they fly the simulator. "Cognitive fidelity" is a construct similar to psychological fidelity.

A simulation or simulator might have different levels (low to high) of each type of fidelity. The training developer and/or assessment developer must decide about the optimal mix of fidelity levels for the simulation's intended purpose. The cost to achieve higher levels of fidelity and the technical challenges in reaching higher levels both enter into the decision. The authors have seen many instances where large amounts of money have been invested to achieve high levels of physical and functional fidelity and yet the operational experts still did not feel that the simulation felt like the real thing. It did not reach a high level of cognitive fidelity. Yet, we have also seen example where physical/cognitive fidelity was achieved with relatively modest investments in physical/functional fidelity. The key is determining as precisely as possible what salient characteristics of the real-world system must be represented in the simulation in order for learning to occur, or in order for the trainee to be able demonstrate competence to an assessor.

A key example of the use of simulation to enable assessment comes to us from years of research and practice in the pilot assessment arena. From the beginning of pilot training, concern has been given to how best to measure pilot performance (Meister, 1999). Assessment of this type is used both in training and in assessing readiness for job performance. Pilots must make rapid decisions in highly dynamic and complex environments. Since the time of the Wright Brothers, the main method for assessing pilot trainee and pilot performance has been via rating sheets, typically with five or seven point rating scales. The instructor pilot, flying with the trainee, determines the pilot's performance for each of the scale dimensions (e.g., mission planning, preflight check, taxi, takeoff, aerial maneuvers, stall recovery, instrument flight, situational awareness, etc.). Once a military pilot progresses beyond their initial undergraduate training and is ready for combat training, the instructor pilot assesses their performance on various phases of tactical flying. This happens not only in their initial aircraft specific training but also periodically throughout their flying career.

This approach for assessing trainee and pilot performance is a tried and true method. Although ultimately subjective in nature, it has proven to be generally valid and reliable. Instructor pilots have come up through this type of assessment system as they gained expertise and are quite used to making judgments on the rating scales after observing trainee/pilot performance.

Andrews, Nullmeyer, Good, and Fitzgerald (2008) provide an overview of the progress made in performance measurement in the aviation field. They note two advancements that deserve highlighting. The first is the advent and use of digital performance recording as described above. This has led to new approaches to automated performance assessment, as well as giving instructors new tools to make subjective assessment decisions. The second advancement is the use of behaviorally anchored rating scales coupled with automated performance assessment tools to develop a more robust total measurement system.

Aircraft simulators have opened up a broad new horizon for performance assessment in pilot training. Digital simulators can record every aspect of the simulated aircraft on a micro-second basis. Every button push, toggle switch movement, image display, radar mode, etc. can be recorded for eventual analysis by instructors and raters. This data can be aggregated both for individual trainee evaluation and across trainees to spot gross trends that can lead to training program improvements. In addition, all audio communication can be recorded and replayed.

In many cases, measurement done in a simulator can be more valid and reliable than measurement done by an instructor pilot. That is especially true in the early phases of training. If the simulator possesses both high physical and functional fidelity it is a relatively straight forward task to measure each button push and control movement. The validity and reliability become more difficult to maintain as the pilot moves into phases of flight that demand more cognitive skill (e.g., understanding how to synthesize the information from various displays, decision making, etc.). In those cases the automated performance measurement system can aid the instructor, but normally can't provide all of the measurement capability required.

One potential advantage of simulator-based assessment systems is that they may give the trainee the feeling that they are not constantly being watched by their human instructor. A number of researchers (Diaper, 1990; Shivers, 1998; Staal, 2004) have shown that performance is altered when it is done in the presence of others. Performers who were unaware that they were under observation typically performed better than a control group on complex tasks. One might then conclude that having an automated performance system do the assessing improves performance if the instructor is not directly involved with observing the trainee's performance.

Lane (1986), in a report examining the performance measurement issue in aviation, cites "seven" criteria that can be used in evaluating aviation performance measurement. They are as follows:

Reliability—"Reliability ... is in the metric sense the most basic issue. If the measures are not dependably replicable over the required time period, other criteria are of little or no importance." p. 36

Validity—Lane provides a cogent quotation from Wallace (1965) that explains the importance of true validity, "... it is possible to develop extremely plausible measure sets, with high apparent relevance, which are in reality mostly irrelevant and provide no evidence of any sort germane to the purpose of the evaluation."

Sensitivity—"The sensitivity of a measure reflects the extent to which the measure behaves 'appropriately' in response to changes in conditions under which the task is performed or to differences in individual capability to do the task." p. 80

Completeness (*Dimensionality*, *Comprehensiveness*)—"… basic, advanced and operational flying, evaluators made consistent and reliable distinctions between such aspects of proficiency as basic airwork, instrument flying and ability to use weapons." p. 81

Seperability of Operator from Measurement Context Contributions—"If comprehensiveness is the inclusion of all the relevant components of performance, then the concern for seperability is for the omission or exclusion of irrelevant components." p. 91

Diagnosticity (*Specificity*)—"To be effective in … diagnostic use, variables must satisfy three general requirements: a) they must provide a level of detail which allows differentiation among skill and knowledge components, b) they must be sufficiently distinct in the content they measure, and c) the measures must be capable of being mapped with a reasonable degree of correspondence into those specific components." p. 93

Utility and Cost Benefit (*Value against Alternatives*)—"A measurement system may be reliable and valid and possess all the other properties required of performance measures and still be of limited utility … To be 'useful', a method must produce results that represent 'true' performance more closely than any other available and affordable way of achieving that objective." p. 94.

Lane's (1986) comments concerning performance assessment in aviation apply well to most new applications of performance assessment technology. While some progress has been made in recent years in applying more modern statistical approaches to questions concerning reliability, validity, and generalizability of performance measurements (cf. Webb, Shavelson, & Haertel, 2006), much remains to be done to build an engineering science using modern computer-based simulations for performance assessment.

Non-aviation Example of Simulation-Based Performance Assessment

An example might help the reader to understand how a simulation-based approach might be of use in K-16 schooling and in higher education. In a history course a teacher wants students to develop more complex decision making capacity. They wish to have the students exercise their abilities to define a problem, describe the key elements of a decision and solution requirements in order to frame their solution alternatives, pick a solution strategy and apply it, evaluate the results of the decision and make revisions where necessary or reject that alternative and choose a different solution strategy. They could use an off-the-shelf game that re-creates a financial emergency such as the great depression. It is not likely that an off-the-shelf game would have the kinds of assessment characteristics that a teacher would likely desire, so they would need to conduct the assessment of student skills manually, but the main point is that the students would be developing decision making skills in a real-world simulation with the types of variability that would expect to be found in the actual historical settings. The huge success enjoyed by decision making games using real-world simulation, (e.g., SimCity and Age of Empires) shows that schoolchildren enjoy such games. We highly encourage educational game makers (i.e., serious games) to build in the types of assessment characteristics discussed in this chapter.

Assessment of medical skills is another area that is benefitting from simulation-based education and training. Past medical specialty certifications by national boards for that discipline consisted primarily of written exams and interviews between the applicant and experts in that field. The expert would ask various questions about the specialty and often pose relevant questions about best treatment paths using verbal scenarios. While that approach is still in use in some cases, the certification boards are turning more and more to simulation-based assessment approaches that can supplement the other elements of the assessment process. These computer based assessment systems allow the certifying assessors to test the medical specialist applicants' hands-on skills. This trend will continue to gain momentum.

Future Research Needs

A fruitful area of research involves extending simulation design to the measurement and assessment of high-level cognition. An entire volume on assessing problem solving using simulations explicitly treated issues and examples in the design of simulations for assessment (Baker et al., 2008).

A second area of research and development would extend the progress made in the use of simulation for assessment for broader application, particularly in education at the preschool through college levels. Here the need is primarily for diagnosis of progress and prescription of curricular and instructional alternatives that maximize the progress of individual students (cf. Lesgold, 2008). These areas of research have been seriously neglected in education and psychology in recent years, due to intense pressure from politicians and others who apparently think that a focus on scores on standardized tests will somehow improve competitiveness in a world economy. While a quick search of the Internet will locate hundreds of computer-based simulations or environments for K-12 tasks, few have mechanisms for recording student interaction to permit significant assessment or diagnosis. This is due in part to the relative infancy of computer applications in education, and in part to the difficult problems of practical management of such systems in today's classrooms.

A third related area of research involves performance assessment for high-level tasks which are complex and ill-structured. These are often the highest-value tasks/skills at any level of work, in any kind of organization. Wulfeck and Wetzel-Smith (2008) described these "Incredibly Complex Tasks" as those that are almost unbelievably complicated, in that they required deep expertise obtained through years of highly contextualized study, practice, and experience for successful performance. In later work, Wulfeck and Wetzel-Smith (2010) described training strategies for incredibly complex tasks. These involve using computer modeling, visualization, and careful design of instruction to deal with task characteristics that contribute to difficulty and complexity, such as multiple sources of variation, interaction, dynamism, continuity, nonlinearity, simultaneity, uncertainty, and ambiguity. These design strategies can also inform the design of performance assessments. Unfortunately, however, developing training and performance assessments for incredibly complex tasks requires at least as high a level of expertise as performance of the tasks themselves, and so such tasks are often considered by non-experts (such as policy-makers) to be impossible to teach or to assess. On the contrary, it is entirely possible to design good assessments for incredibly complex tasks: it merely requires decades of work by task experts and millions of dollars. However, efforts on such a scale, even in education and training, are common. Standardized testing programs for *No Child Left Behind* or college entrance examinations have already consumed much larger amounts of resources.

Conclusions

After a combined 80 years as practicing instructional psychologists, we welcomed the opportunity to examine current developments in the area of performance assessment. In the past 20 years there has been tremendous progress in the application of technology to performance assessment, particularly in developing and applying simulation systems for both individual and team training. Much of this progress has come in the military in the development of simulation-based training systems, and in some professions for certification.

Performance assessment has become more important over time. In our litigious society, the capability to accurately determine who can do what not only makes good educational and economic sense but it also can protect organizations from being sued for hiring, promotion and termination decisions. As a scientific community and community of practice, our performance-assessment standards and tools continue to evolve. We are considerably more likely to make the right judgments about personnel and student performances now than we were, say, 50 years ago. Not only have the accuracy and reliability of our assessments improved, but also the standards and tools we possess make us better able to anticipate and react to, and in some cases mitigate, both individual and societal differences. In addition, our assessments better help our community to make sound prescriptions to improve performance for students and employees.

Despite the progress in assessment over the last few decades considerable work remains to be completed. Research into performance assessment techniques that translate from tests to real-world performance is still inadequately funded. At least some of the considerable public debate about the place of testing in schools stems from a general misunderstanding, and in some cases mistrust, of validity of the assessment process at measuring true educational progress. While there is a general sense that the standardized tests used to measure that progress are not complete, in some cases there is the feeling that the tests are biased in one way or another. Researchers in the educational measurement community have work to do in establishing validated methods for identifying key concepts and principles required in the various academic subjects that can be translated into effective tests.

We generally believe it is a more straightforward, although by no means simple, task for measurement specialists in business, industrial and military settings to develop quality measurement approaches than it might be in formal education. Proximity of their assessment development activities to real-world work places gives them an advantage over their formal education counterparts. Having completed a number of task analyses, from which flow metrics for assessment, your authors know the advantage that comes from being able to observe and interview incumbent workers as they perform their jobs. Formal education assessment developers have access to subject matter experts, but seldom get to watch them use their expertise to accomplish real-world tasks, whether that is performing cognitive or manual work tasks.

However, the task of workplace performance assessment is made difficult because of the increasing complexity of many jobs. While automation has simplified many workplace tasks it has also forced decisions about the allocation of job functions that have resulted in humans taking on more executive control functions. These are almost always more difficult to assess than jobs where the human is doing more procedural work. While the mundane parts of jobs are performed by sophisticated software, the human is left to monitor the job activity and decide when to intervene in the process. These control decision tasks were usually left to senior, more experienced, and better trained employees, but they have been often pushed down to newer and less trained employees. Designing performance measurement systems can help in assessing the preparation of employees who will make these decisions. Since in some cases there may not be only one right answer in a workplace setting, performance assessment systems will have to increase in flexibility.

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25 Formative and Stealth Assessment

Valerie J. Shute and Yoon Jeon Kim

Abstract

Assessing generally refers to the process of gathering information about a person relative to specific competencies and other attributes, in formal or informal learning contexts. This should lead to valid and reliable inferences about competency levels, which in turn may be used for diagnostic and/or predictive purposes. Too often, classroom and other high-stakes assessments are used for purposes of grading, promotion, and placement, but not to enhance learning. In this chapter, we focus on formative assessment which posits that assessment should (a) encourage and support, not undermine, the learning process for learners and teachers; (b) provide formative information whenever possible (i.e., give useful feedback during the learning process instead of a single judgment at the end); and (c) be responsive to what is known about how people learn, generally and developmentally. This type of assessment has as its primary goal improvement of learning, which is critical to support the kinds of learning outcomes and processes necessary for students to succeed in the twenty-first century. It is referred to as "formative assessment," or assessment *for* learning, in contrast to "summative assessment" (or assessment *of* learning). This chapter overviews the role of formative assessment in education generally, and also touches on stealth assessment specifically—an evidence-based approach to weaving assessments directly into learning environments (Shute, Computer games and instruction. Charlotte, NC: Information Age Publishers, 2011).

Keywords

Competency • Evidence-centered design (ECD) • Formative assessment • Stealth assessment

Introduction

> Assessment should not merely be done to students; rather, it should also be done for students, to guide and enhance their learning. NCTM (2000).

In the United States, assessment currently plays a significant (and often heavy-handed) role in educational systems. A prevalent form of assessment in education today is the standardized test. The primary goal of standardized tests is to ensure accountability of schools and teachers. Our nation's usage of standardized tests has increased considerably since the No Child Left Behind (NCLB) Act was signed into law in 2001 (Chappius & Chappius, 2008). For example, before NCLB, 19 states required annual reading and mathematics tests in grades 3–8, and one test administered in high school. By 2006, every state required standardized testing (Jennings & Rentner, 2006).

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Although there is a little evidence supporting positive effects of the NCLB Act, there is extensive criticism about the hidden costs of NCLB. For instance, Stiggins (2002) argued, "*We are a nation obsessed with the belief that the path to school improvement is paved with better, more frequent, and more intense standardized testing. The problem is that such tests, ostensibly developed to 'leave no student behind,' are in fact causing major segments of our student population to be left behind because the tests cause many to give up in hopelessness—just the opposite effect from that which politicians intended.*" (p. 2).

The primary problem with current assessment practices is that the information from the assessment currently is not being used, as it could and should, to support teaching and learning (e.g., Shute, 2007; Symonds, 2004; Wiliam & Thompson, 2007). Typically, classroom assessments are only administered at the end of some major chunk of time with assessment results arriving too late for teachers to effectively act on them. Symonds (2004) highlighted this problem as she explored policies and practices in dozens of schools that were classified into two groups: successful and unsuccessful in closing the achievement gap. The report showed clear, striking differences between the gap-closing versus non-gap-closing groups—particularly with regard to the use of data. Gap-closing schools assessed students often and used the results to make changes in their instructional program. Non-gap-closing schools assessed students infrequently and did not use the data to effect instructional changes. Two recommendations that emerged from the Symonds study (and which have been endorsed by the Council of Chief State School Officers (2004)) are the following: (1) schools need frequent, reliable data, and (2) teachers need support to use data effectively.

Broadly speaking, the type of assessment that uses test information to support learning is called formative assessment. Despite growing evidence that this type of assessment supports student learning, we don't see wide application of formative assessment in classrooms. Two explanations for the limited adoption of formative assessment in the classroom are the following: (a) it's hard to do, and (b) it's often misconstrued as yet another test. But as James Popham notes, formative assessment is a test-supported *process* rather than a test (Popham, 2009).

The goal of this chapter is to describe formative assessment fully and also present a special approach to formative assessment called *stealth assessment*. Therefore, we discuss (a) measurement and assessment, (b) summative and formative assessment, and (c) formative and stealth assessment. Within each of these sections, we provide definitions, examples, and relevant research. We conclude this chapter with recommendations to help bring formative assessment into the classroom and a discussion about how stealth assessments fit well with a systematic approach to instructional design.

Measurement and Assessment

Different models of educational measurement are associated with different instructional practices in the classroom and thus have different effects on student learning. Historically, the main aim of measuring students' educational progress was to identify differences among students in order to rank order them by achievement. This type of measurement model makes heavy use of summative assessment, which is useful for accountability purposes but only marginally useful for guiding day-to-day instruction and supporting student learning. In contrast, student-centered measurement models rely mostly on formative assessment, which is associated with meaningful feedback that can be very useful in guiding instruction and supporting student learning.

Assessment is a general term that typically applies to individuals and may include testing, observation, and so forth. Progress toward educational goals is usually assessed through testing of some type. Assessment can refer to both an instrument and a process by which information is obtained relative to a known objective or goal (Shute, 2009). Since inferences are made about what a person knows on the basis of responses to a limited number of assessment tasks or items, there is always some uncertainty in inferences made on the basis of assessments. The goal in educational measurement is to minimize uncertainty or error; thus key aspects of assessment quality are validity and reliability. Reliability refers to the consistency of assessment results—the degree to which they rank order students in the same way. Validity refers to the extent to which the assessment accurately measures what it is supposed to measure, and the accuracy of the inferences made from task or test results to underlying competencies.

The focus of this chapter concerns not only measuring students' existing and emergent competencies accurately and reliably but also using that information to render diagnoses and instructional support. Consequently, the focus is on formative assessment (FA) rather than summative assessment. Later, we describe stealth assessment which involves embedding formative assessment into the learning environment such that it is invisible and hence does not disrupt learning and engagement.

Summative and Formative Assessment

> When the cook tastes the soup, that's formative; when the guests taste the soup, that's summative. Robert Stake

The choice and use of a particular type of assessment depend on the educational purpose. As mentioned earlier, schools in the United States today generally make heavy use of summative assessment (also known as assessment *of* learning), which is useful for accountability purposes (e.g., unidimensional assessment for grading and promotion purposes) but only marginally, if at all, useful for supporting personal learning. In contrast, learner-centered measurement models rely mostly on formative assessment, also known as assessment *for* learning, which can be very useful in guiding instruction and supporting individual learning, but may not be particularly consistent or valid. That is, one current downside of the assessment-for-learning model is that it is often implemented in a non-standardized and hence less rigorous manner than summative assessment, and thus can hamper the validity and consistency of the assessment tools and data (Shute & Zapata-Rivera, 2010).

Summative Assessment

Summative assessment reflects the so-called traditional approach used to assess educational outcomes. This involves using assessment information for high-stakes, cumulative purposes, such as for grades, promotion, certification, and so on. It is usually administered after some major event, like the end of the school year or marking period, or before a big event, like college entry. Benefits of this approach include the following: (a) it allows for comparing learner performances across diverse populations on clearly defined educational objectives and standards; (b) it provides reliable data (e.g., scores) that can be used for accountability purposes at various levels (e.g., classroom, school, district, state, and national) and for various stakeholders (e.g., learners, teachers, and administrators); and (c) it can inform educational policy (e.g., curriculum or funding decisions).

Formative Assessment

Formative assessment reflects a more progressive approach in education. This involves using assessments to support teaching and learning. Formative assessment is incorporated directly into the classroom curriculum and uses results from students' activities as the basis on which to adjust instruction to promote learning in a timely manner. A simple example would be a teacher giving a "pop quiz" to his or her students on some current event, immediately analyzing their scores, and then refocusing his or her lesson to straighten out a prevalent misconception shared by the majority of students in the class. This type of assessment is intended to be administered more frequently than summative assessment, and has shown great potential for harnessing the power of assessments to support learning in different content areas and for diverse audiences (e.g., Black & Wiliam, 1998; Hindo, Rose, & Gomez, 2004; Schwartz, Bransford, & Sears, 2005). In addition to providing teachers with evidence about how their class is learning so that they can revise instruction appropriately, formative assessment directly involves students in the process, such as by providing feedback that will help them gain insight about how to improve, and by suggesting (or implementing) instructional adjustments based on assessment results.

While the scope of what comprises an assessment for formative purposes is quite broad (e.g., informal data, test responses, homework, observations), what is key in the definition is that the information or the evidence is used as feedback—by teachers (or systems) and students to improve teaching and learning, respectively. It is essential that an FA system includes support tools to help teachers learn to implement the full range of assessment types, gather evidence, make sense of the data, and adjust instruction accordingly. Such support tools may reside within a professional development strand related to the FA system. An FA system should also provide support for learners to help them improve motivation, volition, self-efficacy, problem-solving skills, and so on.

Finally, notice that we use the term "formative assessment" throughout the chapter as if it were a singular entity, but there are actually two different faces of FA which may be construed as residing at opposite ends of a continuum. That is, at one end of the continuum lives formal FA, which relates to the more traditional, teacher-centric view of formative assessment; this involves administering tasks and quizzes to students, gathering students' results, and then either providing feedback or altering instructional activities on the basis of the data. The other end of the continuum—informal FA—involves the student-centric, interactive classroom activities and discussions that occur, often spontaneously, in various learning environments. Both formal and informal FA provide evidence to teachers and students about learning progress.

Table 25.1 characterizes four assessment variables (main role in the classroom, frequency of administration, typical format, and feedback) that are characteristic of summative and formative assessment. The examples, per variable, for summative and formative assessment are illustrative and not exhaustive (e.g., formative assessment formats may include other types besides constructed response, such as oral response and even multiple-choice questions). Also note that neither type of assessment is an educational panacea—both have strengths and limitations. Table 25.1 is intended to convey general aspects of each approach in terms of the variables and should not be viewed as definitive categorizations.

Research on Formative Assessment in the Classroom

Research suggests that well-designed and implemented formative assessment is an effective strategy for enhancing student learning. Evidence to date suggests that students in classes where formative assessment was implemented learned in 6 months what would have taken a year in other

Table 25.1 Assessment variables in relation to summative and formative approaches

Variables	Summative assessment	Formative assessment
Role of assessment	Assessment of learning, to quantify fixed and measurable aspects of learners' knowledge, skills, and abilities. Used for accountability purposes, often with norm-referenced tests. Produces a static/snapshot of the learner	Assessment for learning, to characterize important aspects of the learner. The main focus is on aspects of learner growth, employing criterion-referenced tests, used to help learners learn and teachers teach better
Frequency of assessment	Infrequent, summative assessments using standardized tests. The focus is on product or outcome (achievement) assessment. These are typically conducted at the end of a major event (e.g., unit, marking period, school year)	Intermittent, formative assessment. The focus is process oriented (but needn't exclude outcomes). Assessments of this type are administered as often as desired and feasible: monthly, weekly, or even daily. Administration is normally informal
Format of assessment	Objective assessments, often using selected responses. The focus is on whether the test is valid and reliable more than the degree to which it supports learning	Constructed responses and an authentic context, collected from multiple sources (e.g., quizzes, portfolios, self-appraisals, and presentations)
Feedback	Correct or incorrect responses to test items and quizzes, or just overall score. Support of learning is not the intention	Global and specific diagnoses, with suggestions for ways to improve learning and teaching. Feedback is helpful, rather than judgmental

Note: This table is adapted from Shute (2007)

classes (Wiliam, 2006). Studies indicate that the regular use of classroom formative assessment could raise student achievement by 0.4–0.7 of a standard deviation (Black & Wiliam, 1998)—enough to catapult the United States into the top five countries in the international rankings for math achievement (Wiliam & Thompson, 2007). Finally, there is evidence that formative assessment can promote significant gains in student self-efficacy and motivation (Kim, 2007), which are predictors of high school graduation (Black, Harrison, Lee, Marshall, & Wiliam, 2003). Another important finding from studies on formative assessment relates to the benefits for disadvantaged and low-achieving students (e.g., Fuchs et al., 1997).

When teachers know how students are progressing and where they are having problems, they can use that information to make real-time instructional adjustments such as reteaching, trying alternative instructional approaches, altering the difficulty level of tasks or assignments, or offering more opportunities for practice. Again, FA in this sense has been shown to improve student outcomes and achievement (Black & Wiliam, 1998; Shute, Hansen, & Almond, 2008).

Feedback is an important and direct component of good FA, and should generally guide students toward obtaining their goals. Helpful feedback provides specific comments to students about errors and suggestions for improvement. It also encourages students to focus their attention thoughtfully on a specific task rather than on getting the right answer or a passing grade (Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Shute, 2008). This may be considered a direct application of FA.

A more indirect way (compared to feedback) of helping students learn via formative assessment includes instructional adjustments that are based on assessment results (Stiggins, 2002). Different types of assessment data can be used by the teacher to support learning, such as diagnostic information relating to levels of student understanding, and readiness information indicating whether or not a student is ready to begin a new lesson or unit. Examples of instructional support include (a) recommendations about how to use assessment information to alter instruction (e.g., speed up, slow down, give concrete examples), and (b) suggestions for what to do next, links to Web-based resources, and so forth. However, there is much room for improvement in teachers' formative use of assessment results, as one of the most important aspects of formative use (responding to results by modifying instruction and identifying alternative pedagogies) is the least used by classroom teachers and the most neglected with respect to professional development (see Lai, 2009).

Research on Formative Assessment in Computer-Based Learning Environments

A growing number of computer-based educational systems are employing formative assessment as well. A good example of such systems is a Web-based formative assessment platform called ASSISTment (Feng, Heffernan, & Koedinger, 2006; Koedinger, McLaughlin, & Heffernan, 2010). ASSISTment is a Web-based platform that allows teachers to develop formative assessments for fourth- to tenth-grade mathematics classes. In a recent study, Koedinger and his colleagues (2010) reported that the schools using ASSISTment significantly outperformed matched schools on the state mathematics test.

Another example of a computer-based formative assessment system is ACED (Adaptive Content with Evidence-based Diagnosis) (Shute, Graf, & Hansen, 2005). This system uses an evidence-centered design approach (Mislevy, Steinberg, & Almond, 2003) to create an adaptive, diagnostic assessment system to assess and support pre-algebra knowledge and skills. Instructional support is in the form of elaborated feedback. A study was conducted examining its efficacy (Shute et al., 2008). The key issue was whether the inclusion of the feedback into the system (a) impairs the quality of the assessment (relative to validity, reliability, and efficiency), and (b) does, in fact, enhance student learning. Results from a controlled evaluation testing 268 ninth-grade

Table 25.2 Summary of key formative assessment features

Feature	Rationale
Improves student learning	A primary purpose of an FA system is to enhance (or support) student conceptual development as well as skill acquisition. Two kinds of data to support learning include (a) *diagnostic information* relating to levels of understanding and particular misconceptions where the information from diagnostic tasks should be instructionally tractable (i.e., neither too general nor too specific) and (b) *readiness information*, where a general FA task is administered at the outset of a class or a unit and results can show who, in the class, is ready (or not) to begin a new lesson or unit
Promotes student self-efficacy	Feedback in FA should generally guide students through toward obtaining their goal(s) (Ramaprasad, 1983; Sadler, 1989). The most helpful type of formative feedback (on tests, homework, and classroom activities) provides specific comments to students about errors, and specific suggestions for improvement, and encourages students to focus their attention thoughtfully on the task rather than on simply getting the right answer (Bangert-Drowns et al., 1991; Elawar & Corno, 1985; Shute, 2008). This type of feedback may be particularly helpful to lower achieving students because it emphasizes that students can improve as a result of effort rather than be doomed to low achievement due to some presumed lack of innate ability (e.g., Hoska, 1993)
Provides timely feedback	Feedback must be timely to be useful (e.g., Corbett & Anderson, 1989). Whenever possible, the FA system should provide immediate feedback (ideally immediately, but within "same day" time frame). Feedback can be directed to students (e.g., regarding performance on computer-based tasks) or teachers (e.g., summary reports on classroom performance)
Provides information at multiple levels of aggregation	FAs should report out *individual* data and may be *aggregated* to subgroup and full-group levels. Teachers and administrators may be able to specify subgroups based on student demographic variables (e.g., gender, race, attendance, mobility, socioeconomic status, etc.) and also use FA results to create groups with similar performance on specified tasks or sets of tasks
Provides low-to-mid stakes assessment	Given the relatively low-stakes and informal nature of FAs, they should mostly be of two levels: low and intermediate (not high-stakes). Higher degrees of standardization in FAs may occur in certain computer applications. Also note that "low-stakes" does not mean they will be low in reliability or validity (see Shute et al. (2008) for an example of a reliable and valid FA system)
Uses developmental models	Competency models should include developmental aspects that provide pre- and post-requisite relationship information. The function of the developmental part of the models relates to (1) *actual* learning (self- or criterion referenced), and (2) *potential* learning (forecasting near and far term potential—via Zone of Proximal Development and "end of school year" growth modeling research ideas)

students showed that the quality of the assessment was unimpaired by the provision of feedback. Moreover, students using the ACED system showed significantly greater learning of the content compared with a control group. These findings suggest that assessments in other settings (e.g., standardized, state-mandated tests) might be augmented to support student learning with instructional feedback without jeopardizing the primary purpose of the assessment.

Table 25.2 summarizes the key features of formative assessment, along with a brief discussion of each feature.

So far, we have focused on FA. But now consider the following. Rather than stopping an instructional episode at various times to collect information from students and provide support as warranted, what if there was a way to embed FA so deeply in the fabric of the learning environment that the distinction between learning and assessing became completely blurred? This idea, called stealth assessment, is presented next.

Formative and Stealth Assessment

New directions in educational and psychological measurement allow more accurate estimations of students' competencies, and new technologies permit us to administer formative assessments during the learning process; extract ongoing, multifaceted information from a learner; and react in immediate and helpful ways. When formative assessments are seamlessly woven into the learning environment and are thus invisible to learners, we call this *stealth assessment* (Shute, 2011; Shute, Ventura, Bauer, & Zapata-Rivera, 2009).

Stealth assessment can be accomplished via automated scoring and machine-based reasoning techniques to infer things that would be too hard or time consuming for humans (e.g., estimating values of evidence-based competencies across a network of skills). One big question is how to make sense of rich data collected in order to provide meaningful feedback and other support for learning. Another major question concerns the best way to communicate a variety of student-performance information in a way that can be used to inform instruction and enhance learning.

Definition of Stealth Assessment

Stealth assessment is an evidence-based approach to assessment where the tasks that students are engaged with are highly interactive and immersive, such as within video games or other computer-based instructional systems. Like FA, stealth assessment is intended to support learning of important content and key competencies. This represents a quiet-yet-powerful process by which learner performance data is

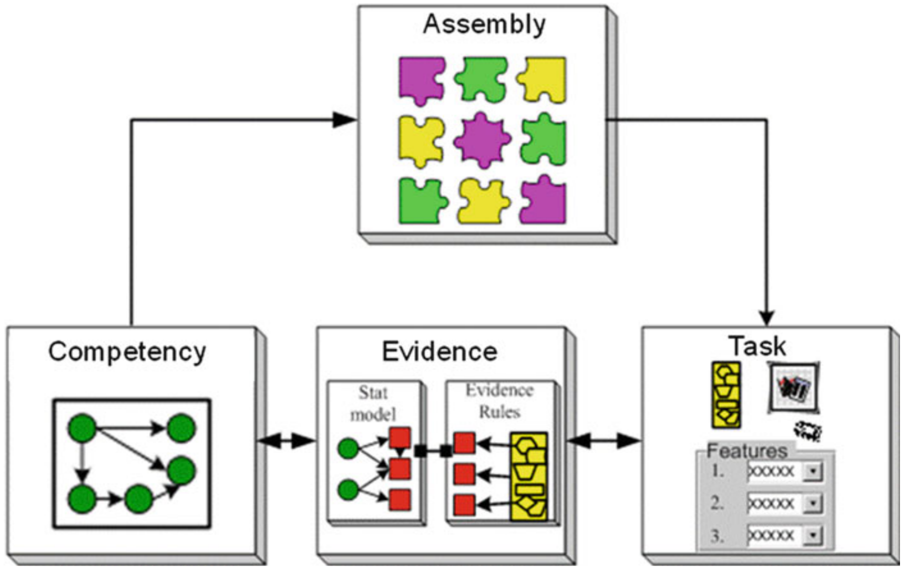

Fig. 25.1 Conceptual assessment framework of ECD (adapted from Mislevy et al., 2003)

continuously gathered during the course of playing/learning and inferences are made about the level of relevant competencies (see Shute et al., 2009). Inferences on competency states are stored in a dynamic model of the learner. Stealth assessment is intended to support learning and maintain flow, defined as a state of optimal experience where a person is so engaged in the activity at hand that self-consciousness disappears, sense of time is lost, and the person engages in complex, goal-directed activity not for external rewards, but simply for the exhilaration of doing (Csikszentmihalyi, 1990). Stealth assessment is also intended to remove (or seriously reduce) test anxiety while not sacrificing validity and reliability (Shute et al., 2008). Again, the goal is to blur the distinction between assessment and learning.

Key elements of the approach include (a) evidence-centered assessment design, which systematically analyzes the assessment argument concerning claims about the learner and the evidence that supports those claims (Mislevy et al., 2003), and (b) formative assessment and feedback to support learning (Black & Wiliam, 1998; Shute, 2008). Additionally, stealth assessment provides the basis for instructional decisions, such as the delivery of tailored content to learners (e.g., Shute & Towle, 2003; Shute & Zapata-Rivera, 2008). Information is maintained within a learner model and may include cognitive as well as noncognitive information comprising an accurate and up-to-date profile of the learner.

Evidence-centered assessment design (ECD), the key element for stealth assessment, is a conceptual design framework to help in the creation of coherent assessments. It supports a broad range of assessment types, from classroom quizzes to simulation-based assessments (Mislevy et al., 2003). The conceptual framework includes several models that work together to answer specific questions, such as "what attributes are to be measured?" and "how do we score them?" (see Fig. 25.1).

The competency model defines variables related to students' knowledge, skills, abilities, and other attributes that we wish to measure. This model accumulates and represents current beliefs about targeted aspects of skill, expressed as probability distributions per variable (Almond & Mislevy, 1999). The evidence model provides detailed instructions about (a) what the student says or does that can count as evidence for those skills (Steinberg & Gitomer, 1996), and (b) how the evidence statistically links to variables in the competency model (Mislevy, 1994). Task/action models express situations that can evoke required evidence. And the assembly model specifies how the competency, evidence, and task/action models work together to form a valid assessment.

Example of a Stealth Assessment

To illustrate the stealth assessment approach, here is an example relating to creative problem solving in a commercial game called Oblivion (*The Elder Scrolls IV: Oblivion,* 2006, by Bethesda Softworks). *Oblivion* is a first-person, 3D role-playing game that is set in an imaginary medieval world. Players enter the game by selecting a character to play (e.g., Argonian, Orc, or Dark Elf). Each character has a particular specialization (e.g., combat, stealth, and magic) and special abilities. The primary goal of the game is to develop the character's skills by completing a series of quests. These quests represent the character's journey to save the empire

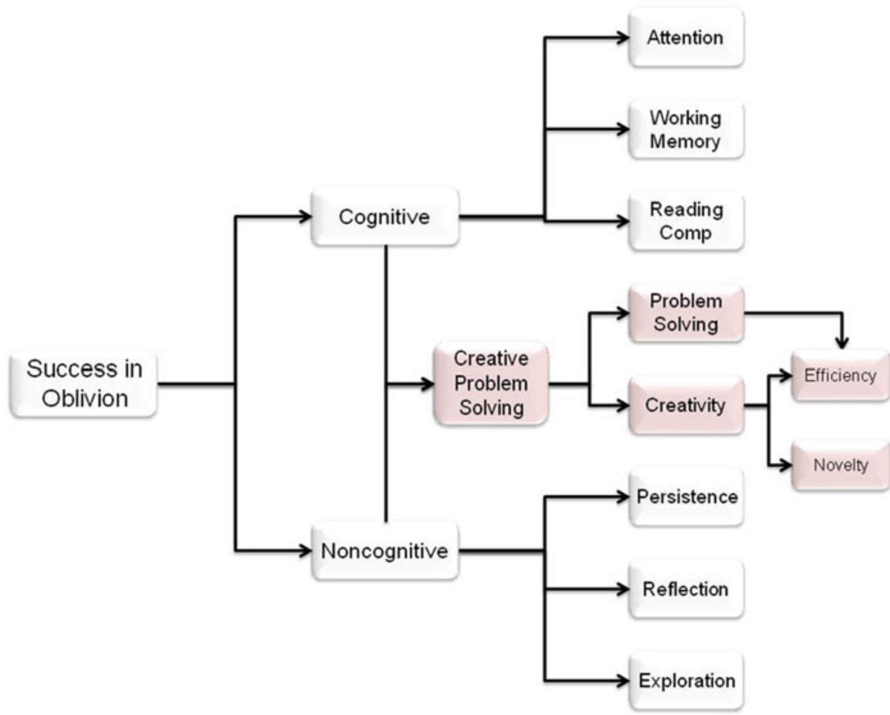

Fig. 25.2 Illustrative competency model for Oblivion (from Shute et al., 2009)

from dark magic, and are typically quite complex problems that players need to solve. During the course of the game, there are about 20 skills that a character needs to develop (e.g., alchemy, illusion, and heavy armor) to level up or to avoid being killed by dark monsters.

Creative problem solving is the main competency in the example, defined as the process of coming up with novel but efficient solutions to a given problem. The shaded competency model variables in Fig. 25.2 represent the nodes of interest in this example.

The evidence model links the specific actions that a player takes in the game with relevant competency variables. This requires the specification of particular observations, and how they differentially inform the level of mastery for different competency variables. The statistical machinery (such as IRT or Bayesian networks) serves to "glue" this information together (i.e., the observable performance data with the unobservable competency variables).

The action model (i.e., task model) in the example relates to the various quests and possible actions that players take in relation to quests. For example, consider a player faced with the problem of having to cross a river full of dangerous fish. Table 25.3 contains a list of actions to solve this problem, as well as the indicators that may be learned from real data, or elicited from experts. For the system to learn indicator values from real data, estimates of *novelty*, for example, may be defined in terms of the frequency of use across all players. For instance, swimming across the river is a high-frequency,

Table 25.3 Example of action model with indicators for novelty and efficiency

Action	Novelty	Efficiency
Swim across the river	$n=0.12$	$e=0.22$
Levitate over the river	$n=0.33$	$e=0.76$
Freeze the river with a spell and slide across	$n=0.76$	$e=0.80$
Find a bridge over the river	$n=0.66$	$e=0.24$
Dig a tunnel under the river	$n=0.78$	$e=0.20$

common solution, thus associated with a low "novelty weight." An estimate of *efficiency* may be defined in terms of the probability of successfully solving a problem given a set of actions—based on time and resources expended.

Swimming across the river would thus have a low efficiency value because of the extra time needed to evade the dangerous fish. On the other hand, digging a tunnel under the river to get to the other side is judged as highly novel, but less efficient than, say, freezing the water and simply sliding across, the latter being highly novel and highly efficient. The indicator values shown in Table 25.3 were elicited from two *Oblivion* experts, and they range from 0 to 1. Higher numbers relate to greater levels of both novelty and efficiency.

Actions can be captured in real time as the player interacts with the game, and associated indicators can be used to provide evidence for the appropriate competencies. This is accomplished via the evidence model using Bayesian network software. Figure 25.3 shows a Bayes net after a player elected to cross the river by levitating over it.

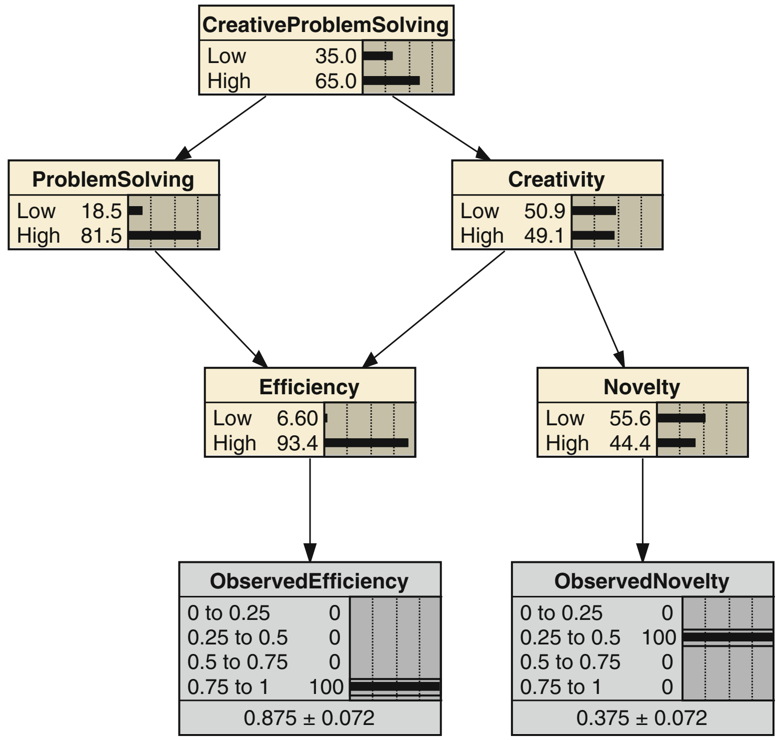

Fig. 25.3 Bayes net estimates from levitating over the river (from Shute et al., 2009)

Even though the player evidenced just average creativity in that solution, the parent node of creative problem solving infers that she is somewhat "high" on this attribute—illustrating that problem solving (based on efficiency) is a more valued competency than creativity, based on the way that the conditional probability distributions were set up in the competency model. Further, the player has more chances to improve this skill during game play. This information can be used in two different ways: (a) as formative feedback, which can be directly communicated to the learner, and (b) adjusting the sequence of quests to focus more emphasis on improving creativity.

Conclusion

In this chapter, we discussed formative assessment in relation to measurement and summative assessment. We also described stealth assessment as a particular instantiation of formative assessment, as employed within a video game or other immersive environment. Despite their intuitive appeal, both formative and stealth assessment have some challenges that need to be addressed for them to be widely adopted in classrooms today.

First, for formative assessment to be embraced more widely there should be more support—such as through professional development—for teachers. This would enable them to be more comfortable and skilled using formative assessment in their classrooms. In particular, teachers should learn to (a) diagnose students' competencies (at various grain sizes) based on different sources of information, (b) figure out what to do next given the obtained data, and (c) build up and employ a pool of rich tasks, probing questions, and other instructionally fruitful activities that can serve to elicit more evidence to inform student models and concurrently support students' learning. In short, teachers should acknowledge that formative assessment is intended to support their decision making for instructional adjustment to help all students grow and learn.

Following are ten recommendations for teachers about how to effectively use formative assessment in the classroom:

1. *Cognitive research*. Employ assessments that have been designed on a cognitive-developmental research foundation.
2. *Complex tasks*. Engage students in cognitively demanding tasks, i.e., ones that actually engage students in thinking about an issue or a problem.
3. *Learning goals*. Inform students clearly of the specific (and more general) learning goals being sought in the lesson or across longer units.
4. *Administration*. Administer assessments (of all types) frequently and usually informally, and require full-class participation in the ongoing, interactive dialog.

5. *Feedback*. Give feedback to students in the form of constructive comments, not grades.
6. *Personal accountability*. Provide students with opportunities to assess themselves and/or their peers to support personal accountability and autonomy.
7. *Evidence-based diagnosis*. Use evidence from formal and informal FAs as the basis for diagnosing students' progress (or lack thereof).
8. *Preplan questions and paths*. Plan questions in advance that probe students' understanding and craft alternative instructional paths based on response patterns.
9. *Leverage prior knowledge*. Build on students' preexisting knowledge and understanding—even if it requires going back through previously instructed material.
10. *Collaboration*. Meet regularly with other teachers to select and share good tasks, discuss student work, plan effective questions, discuss "lessons learned," and so on.

Implementing stealth assessment also poses its own set of challenges. The competency model, for example, must be developed at an appropriate level of granularity to be implemented in the assessment. Too large a grain size means less specific evidence is available to determine student competency, while too fine a grain size means a high level of complexity and increased resources to be devoted to the assessment. In addition, developing the evidence model can be rather difficult in a gaming environment when students collaborate on completing quests. For example, how would you trace the actions of each student and what he/she is thinking when the outcome is a combined effort? Another challenge comes from scoring qualitative products such as essays, student reflections, and online discussions where there remains a high level of subjectivity even when teachers are provided with comprehensive rubrics.

How do teachers fit into this effort? In games designed for educational purposes, the system can allow teachers to view their students' progress relative to the students' competency models. Teachers would then use that information as the basis for altering instruction or providing formative feedback. For example, if the competency models during a quest showed evidence of a widespread misconception, the teacher could turn that into a teachable moment, or may choose to assign struggling students to team up with more advanced students in their quests.

Information about students' competencies may also be used by the game system to select new gaming experiences (e.g., more challenging, ill-structured problems could be presented to students exhibiting high creative problem-solving skills). In addition, up-to-date estimates of students' competencies, based on assessment information handled by the statistical machinery (e.g., Bayes nets), can be integrated into the game and explicitly displayed as progress indicators. Players could then see how their competencies are changing based on their performance in the game. Most games already include status bars, representing the player's current levels of game-related variables. Imagine adding high-level competency bars that represent attributes like creative problem solving, persistence, and leadership skill. More detailed information could be accessed by clicking the bar to see current states of lower level variables. And like health status, if any competency bar gets too low, the student needs to act to somehow increase the value. Once students begin interacting with the bars, metacognitive processes may be enhanced by allowing the player to see game- or learning-related aspects of their state. Viewing their current competency levels and the underlying evidence gives students greater awareness of personal attributes. In the literature, these are called "open student models" and they have been shown to support knowledge awareness, reflection, and learning (Bull & Pain, 1995; Hartley & Mitrovic, 2002; Kay, 1998; Zapata-Rivera & Greer, 2004; Zapata-Rivera, Vanwinkle, Shute, Underwood, & Bauer, 2007).

How is stealth assessment related to the design of instructional systems? Gustafson and Branch (2002) describe five core elements of instructional design: analysis, design, development, implementation, and evaluation. These factors ensure coherence among instructional goals and strategies, as well as the effectiveness of the instruction. Moreover, these five elements should be used iteratively, and evaluation should reside at the center of the iterative revision process. Information obtained from any stealth assessment can also be used by instructional designers to improve learning/instructional systems. For example, information from a stealth assessment may show that many students had difficulty with a particular task. The instructional designer could then examine the task to see if revisions are warranted.

In addition, components of a stealth assessment (e.g., competency, evidence, and task models) are compatible with steps in the instructional design process such as task and content analysis and the development of performance measures. A common goal of both stealth assessment and instructional design is to coherently align learning objectives with how they are measured. Therefore, if instructional designers work closely with assessment developers to design and develop a learning system that has built-in stealth assessment, it can optimize the effectiveness of the instruction.

In conclusion, the ideas in this chapter relate to using formative assessment (in the classroom) and stealth assessment (in immersive learning environments). In both cases, this would help not only to collect valid evidence of students' competency states and support student learning but also to reduce teachers' workload in relation to managing the students' work products. This would allow teachers to focus their energies on the business of fostering student learning. The ideas in this chapter are intended to help teachers facilitate student learning, in a fun and engaging manner, of educationally valuable skills.

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Evaluation of ICT Competencies

26

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Abstract

Information and Communication Technology (ICT) competencies comprise a subset of digital literacy, one of the various areas of technological competencies and skills necessary for real-life functioning in all kind of professional activities and levels of education from preschool to graduate levels. Assessment of ICT competencies involves the definition of specific target activities appropriate to the environment in which they are required. These environments range from the home to the workplace and involve such disparate activities as information-retrieval in healthcare settings or libraries; use of clerical, business, or investment applications; and interactions with government or other public services. The range of ICT competencies also includes the specific abilities needed by professionals responsible for the development of software or communication products and services. This chapter discusses several ICT assessment projects, addresses the primary technical specifications required for evaluation, and explores solutions to problems of test administration. These solutions range from electronic quizzes (similar to paper-and-pencil tests) to more "authentic" forms of assessment using e-portfolios or simulations of real software applications. A detailed analysis of the primary approaches for assessment of social, academic, commercial, or economic environments reveals that these approaches primarily focus on a basic core of skills consisting of Web navigation and the use of e-mail and office tools (text processor, spreadsheet, presentation, and database management). In the future, ICT evaluation will involve automatic scoring of natural language responses in documents, solutions of mathematical problems, and graphical or health applications, among many other real-life endeavors.

Keywords

ICT literacy assessment • Digital literacy • ICT competencies • Assessment standards • Automatic scoring

Introduction

Information and Communication Technology (ICT) curricula are aimed at satisfying the academic and professional motivations of individuals on the development of higher order ICT competencies. In addition, ICT also has the potential to empower minorities and produce benefits resulting from the technology itself, regardless of the user's motivations or application field. This potential is important because

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it may be a tool for reducing the digital divide between people and among countries.

The importance of ICT assessment comes from the academic and professional interest to identify the level of expertise of persons using ICT, because as indicated in studies conducted by the OECD, the digital gap between countries is related to the well-being of people; therefore, those competencies are directly related to the development of a country (Levy, 2010). A convenient approach to assess ICT competencies should be based on a framework and models that target specific skills and use of new technologies, ranging from basic knowledge of ICT foundations to very sophisticated use and management of tools in simulated environments.

ICT literacy is helping people worldwide to increase communications at different levels, among students within schools, between school and home, or within school-social networks. Today, teachers and students can retrieve information and knowledge from online encyclopedias and special-purpose Web pages. This phenomenon is transforming a resource into a magnificent instrument to improve learning ability, readiness for employment, and attainment of higher academic qualifications, all of which may reduce social gaps (ECDL, 2011).

The goals of this chapter are:

1. To provide a panoramic view of the status of ICT assessment according to the main frameworks and syllabuses developed in several countries
2. To present some of the online platforms from questionnaires and quizzes to e-portfolios and other Internet applications
3. To show the basic concepts of the platforms based on computational simulators

Some of the assessment of ICT competency approaches that are presented in this chapter rely on excellent technological solutions, software platforms, or navigator environments, but the authors wish to emphasize the need that assessment projects must be primarily grounded on valid, objective, and reliable measurement tools to provide the best information and feedback to the user, teachers, authorities, and institutions.

Description of ICT Competencies

The first step in an evaluation project should be to describe the set of competencies to be demonstrated by an ICT user. This definition is not simple, because the various applications of ICT in schools, businesses, government, social networks, health services, and transportation are significant for not only children and families using the computer as an everyday tool but also adults who are just beginning to use modern technologies. For the latter, a good understanding of ICT tools will lead to a better appreciation of their implications for society and a redefinition of their role in connecting individuals and communities (Leye, 2007; Umrani & Ghadially, 2003). Technological literacy is producing a significant impact on everyday activities, ranging from educational practices and curriculum planning to professional work and labor tasks, from projects in industry and engineering to health interventions in medicine and nursing, and from long-distance communication using Web-based translators to participation in democratic processes. Recent political events in several countries have revealed how social networks are using the Internet to send information to the world in an unprecedented way.

Defining competencies is an important issue because each author, researcher, association, or group of professionals should specify ICT competencies in their particular contexts. Table 26.1 contains some examples of ICT competencies in specific contexts for the use in this paper.

The first example in Table 26.1, ICT literacy, comprises everyday situations encountered in an information society. In this context, an ICT user integrates a set of competencies to retrieve and effectively use information with digital technology and communication tools, either online through the Internet or through a local network.

Digital literacy is the use of high technology in everyday life. A digitally literate person may use specific hardware such as a computer, a cell phone, or other digital resource in combination with communication software, such as the Internet, to interact with society at large, thus becoming a digital citizen or e-citizen and improving social and economic opportunities. Information literacy is mainly concerned with information-retrieval and should not be confused with digital literacy.

Computer literacy means that an individual can comfortably use commercial or open-source operating systems and programs and may even achieve higher level knowledge about the computer's operation and controls. Computer literacy combines knowledge, attitudes, and cognitive or psychomotor skills to use computers and technology efficiently.

A technologically literate person can solve real-life problems by manipulating computers or other electronic and technological devices and products and is not necessarily related to information-retrieval competencies. Technological literacy includes, but is not limited to, computer technology or the use of information; rather technological literacy deals with other problems and situations in multiple professional or nonprofessional applications. For example, technological literacy in education may involve new e-learning projects using handhelds or other devices to assess and provide feedback to teachers and students. In healthcare settings, it may focus on the use of technological devices for Para clinical diagnosis and management of patient records. In politics, technological literacy might include the use of optical mark readers or other devices to process election ballots and produce instantaneous statistics and voting trends. Technological literacy positively affects the development of other cognitive, affective, or psychomotor competencies. Through its

Table 26.1 Examples of ICT skills or competencies

Concept	Examples of skills or competencies
ICT literacy	Access, manage, integrate, evaluate, create, transmit, or communicate information. Navigate in digital environments. Search, locate, retrieve, and selectively sieve sets of data. Classify, organize, analyze, synthesize, store, and creatively produce new information, according to specified formats Install, use, and apply digital or electronic devices, manage data and information. Use of telecommunications and other information-retrieval devices or programs with a computer. It may involve the ability to select how to use specific tools or devices
Digital literacy	Search, locate, organize, analyze, evaluate, and synthesize information to communicate, manage, produce, and perform other tasks with the information. Competencies are related to the management of the information itself rather than the use of any particular device
Information literacy	Search, locate, organize, evaluate, and use information, mainly as an information-retrieval activity where the Internet, databases, microfiches, and other digital documents are the resources needed for this particular application. Competencies are related to the information itself rather than its management or the use of a particular device
Computer literacy	Install, apply, and modify commercial or open-source operating systems and programs. Competencies are related to the ability to use and control the computer and peripherals
Technology literacy or technological literacy	Understand, select, apply, use, manage, and evaluate all kinds of technology or technological products and devices. Synthesize information, draw conclusions about consequences, and make creative interpretations, analyzing data and projecting forecasts or trends. Competencies are related to the use of particular devices to manage information or control specific tasks and data
ICT advanced and professional	Install, upgrade, and configure hardware and software. Verify and optimize the operation of peripheral and communication devices, perform maintenance activities, and update programs to protect the system against viruses and other undesirable software. Support server and network operations, manage and maintain permissions, passwords, and accounts on the various ICT users' levels

impact on higher order thinking, technological literacy induces individuals to acquire and develop further abilities (Wonacott, 2001). Technological literacy involves computer skills and the ability to use computers and related technologies to improve learning, productivity, and performance. In schools, it focuses on integrating the use of the information superhighway, multimedia resources, online learning, and e-assessment software and tools into the curriculum. Clearly, this definition of technological literacy requires the availability of equipment, trained personnel, and the most advanced hardware and software technologies and resources for connecting to the information superhighway.

Information technology literacy, originally defined as the set of competencies needed to use digital or electronic devices to manage data and information, has evolved into ICT to explicitly include the use of computers and telecommunications to handle information.

ICT competencies are multiple and contextual to the social, educational, professional, or economic environment (OECD, 2006, 2009). For instance, ICT professionals may be interested in the planning of network applications or in new solutions for technical problems in industry, hospitals, business, marketing, government, or education; alternatively, they may focus on the health of ICT users by developing ergonomically sound workplaces and sustainable environments. From a nonprofessional point of view, ICT competencies involve basic and general-purpose applications in the home or the office, such as using the Internet, producing and sending e-mail texts, or making simple calculations on a spreadsheet. These competencies integrate a wide range of tasks from basic manipulation of elementary software to advanced programming for problem solving.

Importance of ICT Assessment

Global statistics and indicators show that ICT development can have a positive effect on a nation's economy, social welfare, politics, and education (UNESCO, 2009). The use of ICT involves the availability of communication facilities within a country, investment in computers and peripherals at home, and technological resources at institutions using public funds.

ICT assessment can identify and measure several characteristics of the knowledge and skills of ICT users, as well as their attitudes and values concerning the use of this tool to solve daily problems. Evaluating ICT users' competency is essential to produce relevant, useful information. For example, governments may use this information to enact political measures to benefit the population, companies may develop training programs to improve productivity, and educational institutions may create courses to better prepare students for their society's current requirements for daily life.

In addition, ICT assessment allows measurement of the digital divide resulting from differing digital literacy levels among individuals and countries. These differing levels of digital literacy produce a gap between those who have high-quality access to information technology and digital resources and those who have low-quality resources or none at all. This digital divide correlates not only to the availability of hardware and software resources but also to the development of skills and knowledge. This knowledge divide results from sociopolitical and socioeconomic factors and reflects existing gaps attributable to gender, race, income, or disability. Among nations, the global digital divide between developed

Table 26.2 Sources of statistics on ICT

Institution	Focal country	Web page
Digital Divide Institute	International	www.digitaldivide.org
Instituto Nacional de Estadística Geografía e Informática (INEGI)	Mexico	www.inegi.gob.mx
International Technology and Engineering Educators Association (ITEEA)	USA	www.iteea.org or www.iteaconnect.org
International Telecommunication Union	International	www.itu.int
National Assessment of Educational Progress (NAEP)	USA	http://nces.ed.gov/nationsreportcard/
National Center for Educational Statistics (NCES) of the US Department of Education	USA	www.nces.ed.gov
Organization for Economic Co-operation and Development (OECD)	International	www.oecd.org
United Nations Statistics Division (UNSD)	International	http://unstats.un.org/unsd/ict/

and underdeveloped countries is increasing at a very high rate, creating bigger gaps between economic groups and social strata within countries (especially gaps based on gender, the solutions of which may involve problems of structural change in some countries). Immediate action on a global scale may avoid major differences in the near future (Axelson, 2005; Katz et al., 2008).

Other statistics report the benefits perceived by ICT users, ranging from entertainment and personal or family gain to the greater convenience of educational and professional activities. Table 26.2 includes sources of statistics for various countries that may be useful to readers interested in the global status of ICT competencies.

Frameworks and Syllabus for ICT Evaluation

ICT assessment is grounded on validity, one aspect of which is content validity. Content validity is conveniently defined by the Test Blueprint or Content Validity Table (CVT), a matrix specifying the syllabus of content or objectives (generally on the rows of the table) that should intersect with taxonomical levels (generally on the columns of the matrix). The columns of the CVT require a taxonomy (or framework) to classify ICT competencies at levels of complexity that will translate to levels of proficiency.

A framework should be based on a multidimensional model that includes knowledge, skills (cognitive or psychomotor), as well as values and attitudes toward technology; taxonomies can be theoretical, empirical, or mixed, but they can also be developed by vendors of tests and educational materials. Within a framework, the definition of a competency consists of a sentence that describes what an individual knows or is able to do in a particular domain or content and in a specific context or situation. The active verb of a competency describes the action defined in the competency at one level of the taxonomy. The active verbs are organized in a hierarchical structure from simple memory tasks to complex decisions. For example, active verbs describing ICT cognitive competencies include search, organize, send, insert, add, retrieve, format, analyze, synthesize, design, evaluate, and construct. Verbs and verb phrases such as be sensitive to, be interested in, protect and respond ethically to, and be aware of are used to define affective domain competencies.

Bloom's (cognitive) and Krathwohl's (affective) general-purpose educational taxonomies remain valid frameworks to construct CVTs, but more ICT-oriented frameworks have also been proposed. These have included nomenclature appropriate to ICT content, although their descriptions of cognitive and attitudinal levels remain very similar to those of general taxonomies (Tannenbaum & Katz, 2008; UNESCO, 2008).

For example, the Scottish Electronic Staff Development Library (Campbell, Littlejohn, & Duncan, 2001) organizes technological literacy in six categories: communication, learning, use of the Internet, standards, and educational hardware and software. Competencies include management and creation of files and documents; communication through e-mail, the Internet, and videoconferencing; planning and design of models, procedures, and algorithms; knowledge of standards and computer safety; and the competent use of the computer and its software and peripheral equipment. Tomei (2005) suggests a six-category framework for the technological domain ranging from basic literacy to evaluation of technology's impact and influence on teaching and learning applications. The Standards for Technological Literacy (ITEA, 2007) outline what a technologically literate person should know and be able to do at each academic grade level from age 6 to 18. These Standards provide 20 specifications in five major categories:

1. Fundamentals of technology and connection with other areas
2. Role of technology in society, culture, and the environment
3. Design of applications and solutions to engineering problems
4. Ability to use technological products and systems in everyday life
5. Applications in seven areas where engineering and health represent a primary focus (e.g., transport, construction, health, agriculture, and ICT)

The test blueprint or CVT is translated into a syllabus describing the complete curriculum (or outline of the content) that will be covered by an individual in an educational course or an assessment program. For ease of presentation, a syllabus may show only the content and omit the competency components, but it should be clear that every area of the syllabus must cover all the taxonomical categories, from simple to complex, by defining expected competency levels from beginner to expert.

An ICT syllabus may target digital competencies for the everyday applications used by a digital citizen, excluding some applications that concern informal activities (entertainment and games) and other competencies that may correspond to advanced applications (for example: desktop publishing and professional photo editing, video and sound production). Particular activities or professional skills may require other competencies such as project management or CAD/CAM/CAE/CNC for drafting and engineering; patient registry, clinical information, and management software in medicine and nursing; and accounting and financial software for administration and investment professionals.

Some commercial syllabi are targeted to specific social groups. Such groups may be older adults (basic tools for the e-citizen or the digital citizen); governmental officials (e-government); technicians in hospitals (e-health, e-clinical); and clerical, secretarial, and commercial employees (e-office, e-business, e-commerce) (Kalu, 2007; Omona & Ikoja-Odongo, 2006). New digital literacy projects could be proposed for other groups, including the consular service of a country, armed forces, call center or telephone company employees, industrial plant or laboratory personnel, technical staff in thermal or nuclear plants, journalists in news agencies, and many others.

Since 1996, more than 60 countries have recognized the certification program known as the International Computer Driving Licence (ICDL or ECDL for its European version, www.ecdl.org). This program defines a core of seven modules that include the basics of ICT, use of the computer and operating system, and a subset of standard office tools (word processor or text editor, slide presentation, spreadsheet, database management, information and communication).

From the frameworks and projects discussed above, it is possible to identify the topics and applications that are considered essential for ICT literacy. It is important to notice that the syllabus may differ from a specific program in a certain academic environment, but it represents the set of areas to be covered by a competent ICT literate person. We have combined the proposals found in these previously mentioned frameworks to propose the following general syllabus for assessment of core ICT competencies:

1. ICT environment: Principal components of a computer, use of hardware and peripherals (desktop and laptop models, monitor, keyboard, mouse, ROM and RAM, ports, use of printers, scanners and other digital devices, CD/DVD burners, data transfer to and from USB devices), operating systems (BIOS, MS Windows®, Mac® or Linux®, freeware and open systems, logical units, registry), networking (intranet, extranet, client-server), and graphical user interface. Career opportunities.
2. Human aspects of ICT: Security and privacy measures for protection of computers and ICT users (passwords and authentication, virus protection, spyware, proxy and firewall); health and ergonomics (design of work areas, guidelines for computer use and posture); environmental protection (resources, electricity, minimizing ecological impact, avoiding paper waste). Attitudes and computer ethics (positive attitude toward ICT and confident use of its resources, use of other abilities and skills to improve ICT management, active participation in ICT forums, blogs, and courses to improve ICT skills).
3. Folders, files, and documents: Organizing folders and files (file managers, hierarchical organization, and size of files). Definition of files and the most common file types (document, image, plain text). Searching for documents and retrieving content. Management of files (copying, moving, locating, and retrieving a file; checking, defragmenting, and cleaning a disk unit; sharing and modifying file properties).
4. Text processing: Templates and document creation (letters, essays, memoranda, notices, technical or commercial letters). Page configuration and styles. Use of headers, footers, and pagination (portrait and landscape page formats). Text and word processing. Paragraph formatting. Copy, cut, paste, and insert functions. Tables. Management of objects (graphics, images, formulas). Spell-check and language tools. Document publishing.
5. Spreadsheet: Organization of spreadsheets and applications (workbooks, calculations, databases). Using and formatting cells. Functions, formulas, and cell references. Spreadsheet formatting. Creation of charts and graphs (e.g., bar, pie, trend).
6. Computer-assisted presentations: Templates and creation of slide presentations (e.g., reports, educational or training sessions, promotional and marketing). Design of slides and display options. Publishing presentations.
7. Database management: Organization of a database and applications (tables of objects, commercial data, and contacts). Using data fields and clusters. Functions and formulas. Searching, sorting, and retrieving data units. Publishing a database.
8. Electronic mail: E-mail management (address books and electronic addresses). Sending and receiving messages (opening and reading messages, responding to messages, composing and sending new messages). Electronic messages (parts of a message, the message body, and attachments). Security and protection (precautions when receiving and sending new messages, spam, scams, and phishing).
9. Image handling: Use of photo editing software (crop, resize, rotate, zoom, copy, color, and black and white functions). Use of painting and drawing software

(color, brush and pencil, erase, adding text to an image, graphic manipulation in vector or raster formats). Import–export in multiple formats (e.g., jpg, tiff).

10. Information technologies: Internet and access to information (connectivity and the information superhighway). Virtual sites (World Wide Web, e-commerce, social networks, and other virtual groups; blogs, forums, RSS, and podcasts). Web and related tools (browsers and search engines; HTML and other file formats, pop-ups and cookies, Web authoring software, and publishing of Web pages). Security and the dangers of virtual communities (alteration or theft of code or personal information, hackers and unexpected intrusion, types of computer viruses, virus detection, and protective software).

Requirements for the Assessment Environments

As with any evaluation project, ICT assessment must incorporate standards that provide evidence for the quality of three primary aspects of evaluation: validity, objectivity, and reliability. In addition, ICT evaluation needs to consider access for disabled users and the use of sophisticated software for special applications (AERA-APA-NCME, 1999).

Teachers may consider that existing technology (such as platforms like Google, Yahoo, and other navigation tools) offers a satisfactory assessment platform of "real" or "authentic" tools and environments in which students can produce e-portfolios to demonstrate their ICT competencies. However, this method has at least two problems:

First, it is time consuming because teachers must supervise the student and spend several hours to analyze and score the products included in the e-portfolio and second, it does not eliminate subjectivity despite the use of a rubric. To solve these two problems evaluators may consider virtual or simulated environments or "real tools" that incorporate measurement models in an objective scheme (Smith, 2007), having the advantage that may be used for academic, professional, and certification purposes.

Virtual learning environments (VLE) or learning management systems (LMS) are software platforms consisting of e-learning tools for authoring, data management, planning and structuring educational curricula, homework tracking, forum/blog/chat communication, Web publication, and course management and assessment. Moodle is one well-known, noncommercial VLE product; commercial examples include WebCT, Blackboard, and Virtual Campus. Assessment is a minimal component of these platforms, for two reasons. First, they do not provide relevant psychometric models to score tests; in fact, classical test theory, logistic models, and IRT or Rasch models are rarely included—and in some cases actively avoided—in the development of VLE software. Second, these platforms do not focus on evaluating specific ICT competencies; they provide only a few tools (such as closed-response items) that can be used to assess ICT competencies covering the core syllabus described in the previous section.

Two major issues with computer-based tests must be solved: First, video monitor size and resolution must facilitate test administration for persons with low vision and second, visualization of test items. Computer-based tests should not be merely computerized versions of paper-and-pencil tests. A good visual interface must allow back-and-forth browsing of items and provide information on test status (such as missing items and elapsed and remaining time).

Output feedback is important to provide recommendations for individual test takers; however, it seems preferable not to report details about correct and incorrect answers, especially if the student may submit a test several times, as this may artificially maximize the score without representing a real improvement in competency.

ICT assessment software must work in multiple environments with a variety of hardware (desktop and laptop, handhelds, touchscreens, in-classroom assessments) and software (open-source, Microsoft® or Mac® operating systems). The selection of the most suitable device and platform depends on the application, facilities available (Web, broadband, and Wi-Fi capabilities in a country or a region), and the economic resources of the project. Paper-and-pencil tests will still be used in certain environments where one computer per student is an impossible goal. In these settings, new logistics rules should be implemented to change the practice of assessing all students at one time, along with incorporating improvements in student ethics to prevent cheating. Table 26.3 demonstrates that it is possible to use 20 computers to administer 1-h tests every month to a group of 20 students taking five courses. However, it becomes impossible to use this kind of assessment in a school with 500 students if only 20 desktop computers are available at the school for all educational purposes (teaching, learning, Internet and Web navigation and research, and grading and giving feedback on assignments). Test designers should consider the fact that this unfavorable scenario is very common in underdeveloped countries where ICT is not widely used, where computers and software are out-of-date or where schools have no Internet access or even no electricity at all.

Software for item banking organizes the database, provides multimedia capability for editing items, and generates tests that can be used in either paper-and-pencil or online versions. The most common environments for online testing are local area networks, which are usually supervised by a proctor to authenticate student identity and to ensure the security of the testing system against cheating. Testing at home or in uncontrolled settings is used only for homework, assignments, surveys, and other low-stakes tests because it is impossible to practically standardize and control the conditions of the testing environment or to prevent the availability of external tutors and resource materials.

Table 26.3 Infrastructure requirements for assessment in two educational scenarios

Element	Scenarios	
School	A	B
Number of students	20	500
Computers available	20 (1 laptop per student)	20 (general-use desktops)
Availability of computer time/day	$6 \times 20 = 120$	$6 \times 20 = 120$
Courses to be evaluated every month	5	5
Total hours/month × students	$1 \times 5 \times 20 = 100$	$1 \times 5 \times 500 = 2{,}500$
Days needed for assessment/month	$100/120 = 0.8$	$2{,}500/120 = 20.8$

Online Testing

First-generation online testing platforms merely adapt paper-and-pencil tests, quizzes, and questionnaires to a computer environment (Higgins, Patterson, Bozman, & Katz, 2010). This kind of testing software has two operating modules: management module and testing module.

The management module is controlled by a proctor who monitors the testing area, sends messages to students, solves operating problems, and checks progress during the test (Fig. 26.1).

The testing module is an environment that provides the student with a very simple and user-friendly interface to answer test questions and receive feedback, if appropriate to the test (Fig. 26.2). This module controls the flow of items and, depending on permissions built into the test, can allow the student to go back and modify answers, to ask for hints or access to information capsules giving some help to answer the items, to view a video, or to hear a sound or a piece of music.

An environment for online testing as described here can have several applications for ICT assessment and can address all the topics on the core syllabus described in the previous section. How a question must be answered and how the answer must be submitted can involve one or several competencies within the ICT framework: searching, organizing, analyzing, sending, retrieving, and so forth. The creativity and imagination of the test designer play an important role in achieving the goals of assessment in this environment.

Other capabilities offered by these environments include multimedia resources, simulations, and instructions for specific actions to be performed in a certain sequence. Computerized adaptive tests (CAT) represent another online option. Adaptive tests are based on the psychometric properties of the items and the student's response patterns. CAT requires logistic models to score responses and to determine when to stop administering items, at the point where the student's measurement is convergent to a stable value. With this option, it is possible to assess other kinds of competencies in addition to the core syllabus, for example, those required for professional and health specialties (Ylizaliturri, 2007).

Several studies show no significant differences in scores on a single test administered under different management schemes, from paper-and-pencil to online testing (Cole, MacIsaac, & Cole, 2001). However, security represents a major problem, particularly the need to authenticate student identity; a huge investment in hardware and software is necessary to restrict the use of e-mail and Web pages, opportunities to work with tutors, and other unexpected instances of cheating. Despite the investment, computer-aided testing produces some benefits, for instance: management simplification; reduction of time and effort for teachers and students, elimination of expensive optical forms and optical mark readers; low frequency of errors during input; feasability to use free-response essays.

Other environments provide tools for opinion polls and attitude surveys in a spreadsheet-like environment. In other situations, an assessment may require submitting an essay or other document produced on a text processor or a Web page. New testing techniques may involve the use of a text processor to produce an e-portfolio; however, this capability is not sufficient because more advanced scoring techniques are required to reduce or eliminate the need for teachers to score responses.

Analyzing a sequence of actions performed by a student on a text processor and measuring the quality of the response and the ICT competencies involved may be based on data mining and automated essay-scoring engines that use lexical techniques and knowledge bases, artificial intelligence, and other heuristic methods. The sequence of steps used by the student in a response is stored in a log file during the session that can be reviewed to determine the number of failures and correct actions; it is also possible to obtain a measure from the combination of commands, mouse movements, or keyboard actions that a student performs. These actions are compared to one or several sets of commands that an expert could perform to solve the task or the problem presented in the test. With these techniques, it is possible to automatically score the use of specific tools, such as the production of a document in a text editor or in a presentation environment, the calculations on a spreadsheet, the integration of an e-portfolio, or any other ICT application. Many specific examples of how automated scoring works and how it's being used as well as its growing importance in education have been reported in research and case studies in several coun-

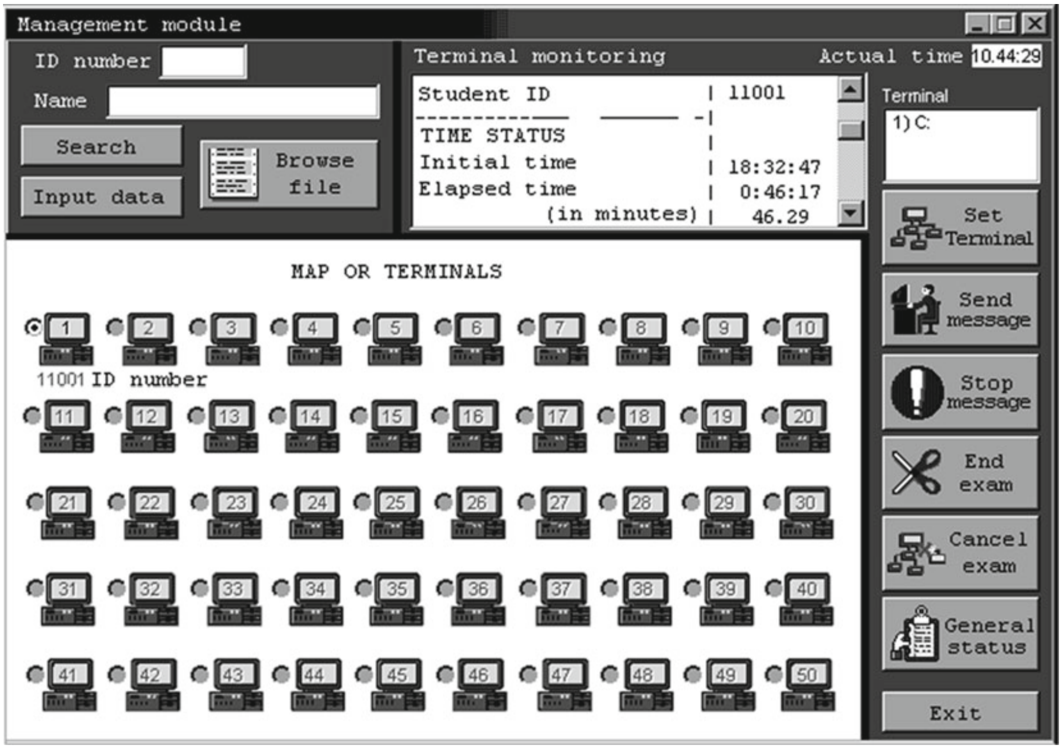

Fig. 26.1 Management module for online testing. Reproduced with authorization by IEIA

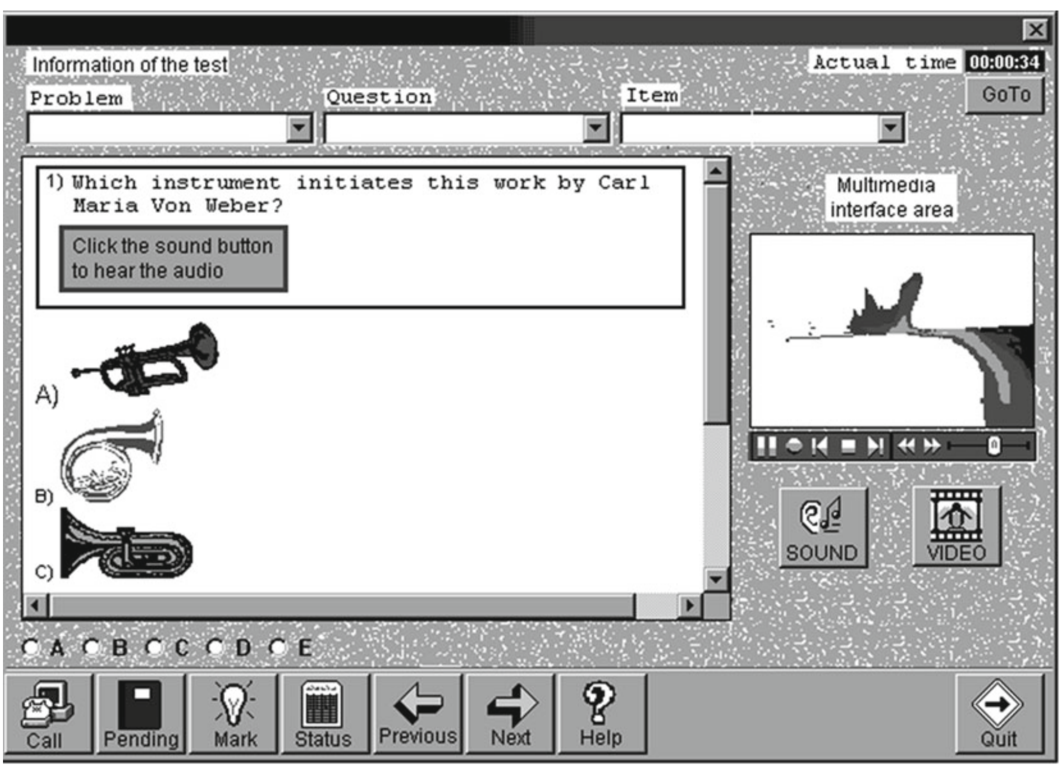

Fig. 26.2 Testing module for online testing. Reproduced with authorization by IEIA

tries (Dikli, 2006) and educational conditions: for the GRE, TOEFL, and other Educational Testing Service (ETS) tests (Attali, Bridgeman, & Trapani, 2010); e-portfolios and Web 2.0 (Kelly, 2007; Mason, Pegler, & Weller, 2004); geometry tests (Masters, 2010); essays in Spanish (Tristán, 2007); and complex tasks (Williamson, Mislevy, & Bejar, 2007).

Several vendors in more than six countries involved in ECDL programs produce courseware and assessment software that include advanced visualization capabilities using Flash® and similar tools to record students' activities. These software products include some tools provided for the management and marketing of the product; however, these vendors are not interested in psychometric models for measuring student competency.

The ETS provides an online scoring service for essays (Criterion®, www.ets.org/criterion) based on an automated scoring engine (e-rater®) proposed by Monaghan and Bridgeman (2005). Other companies also offer solutions in this area: IntelliMetric (www.vantagelearning.com) has an artificial intelligence engine for scoring essays using natural language models of English; IEIA (www.ieia.com.mx) offers an online testing system including multimedia simulation of clinical cases and automatic scoring of essays in Spanish with adaptive options.

ICT-Simulation Assessment Software

Existing assessment techniques for academic or certification purposes have adopted the intensive use of software to assess computer skills in an environment that simulates "real" platforms and real-world situations, according to the specifications of the syllabus presented previously. Simulation software requires design tools both for items and tests; options for customizing the appeareance of the environment to be used by the student or candidate to solve the items and perform the requested activities; network management tools to control a local network or an Internet platform; scoring modules with statistical and measurement models to produce feedback reports.

This kind of assessment platform provides an environment that simulates a suite of windows-based ICT software tools to be used by a student (called candidate) to perform actions defined as a sequence of tasks created by the test designer. All activities and actions are stored by the system in the form of log files that are subsequently processed by a data-mining model and a lexical analyzer to assess the quality of candidate's products, as described previously.

ICT-Simulation Assessment Software (ICT-SAS) is not a local solution in a single country; instead it has been developed for ICT certification or national assessments by institutions such as the Australian Council for Educational Research (ACER, www.acer.edu.au) as mentioned by Ainley and Fraillon (2007), the ETS (www.ets.org) in the United States, Algebra in Croatia (www.algebra.hr), Instituto de Evaluación e Ingeniería Avanzada in Mexico (www.ieia.com.mx), WebScience in Italy (www.webscience.it), Activsolutions in the UK (www.activsolutions.co.uk), and higher education in the United States (Katz & Macklin, 2007), and Mexico and Latin America (Tristán & Ylizaliturri, 2008).

There are several benefits of this technology:

1. Flexibility to use one or several tools according to the set of tasks defined by the designer.
2. Possibility to define a fixed sequence of tasks or to leave the candidates to solve according to their needs.
3. Possibility to get measures of actions or products; then the designer may focus on the procedures or on the results according to particular needs.
4. Independency of specific brands or platforms through a neutral environment.
5. Capability to grow in parallel to future developments for academic, professional, or any other social environment or orientation.
6. Ability to produce psychometric indicators of the quality of the tasks, the activities, and other elements concerning the scale, reliability, and standard error using classical test theory or logistic models. These capabilities may be partially developed using other environments such as Google® or Microsoft Office® but the experience has shown that some of those environments have disappeared or are no longer representative (Eudora, geocities, Lotus, or dBase) while the competencies to be evaluated are practically the same.

Software for ICT-SAS is organized in three modules:

1. Test design, where an expert test designer can describe the tasks to be performed by the candidate, the scoring model, the type of reports, and other test characteristics.
2. Test administration, where the manager of the test can control all testing activities from a server.
3. Test workstations, or terminals, within a local network environment where the candidate will interact with the ICT tools.

A beginner designer can receive training to produce valid and objective assessment tasks in accordance with the purpose of the test; reliability is controlled by the software and the statistical models.

In ICT-SAS candidates do not answer questions. Instead, candidates perform a series of tasks simulating a real-life situation. Each task can comprise two or more activities, which can be categorized as actions or exhibits (Fig. 26.3). The designer should consider the most appropriate items to divide an activity and the possible options to solve them. The software must be able to document procedures that lead to the expected solution in ways not anticipated by the designer. These nonstandard options should be included in the platform's knowledge base and used during the scoring procedure for other candidates. The module for test design provides the tools to specify a test and all its combinations of actions and exhibits obtained during online testing.

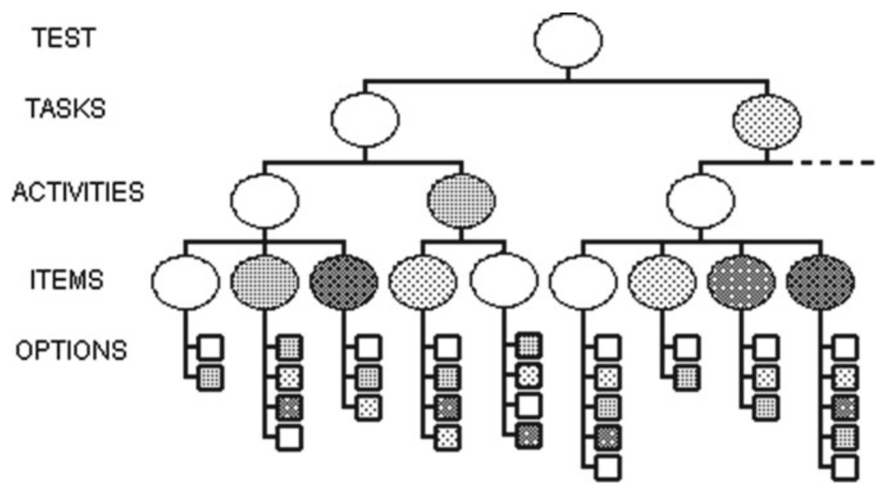

Fig. 26.3 Hierarchical scheme for ICT-simulation assessment software

Fig. 26.4 Desktop environment for ICT-simulation assessment software. Reproduced with authorization by IEIA

Experience with this kind of testing environment can be used in an educational environment, but it is not limited to this focal group. On the contrary, it can involve a wide range of ICT users from children to older adults and from beginners to experts, and has demonstrated its suitability for assessment of ICT competencies in more than 60 countries (ECDL, 2010). Despite the artificial appearance of the platform, the advantages of this environment include time efficiency, little or no anxiety experienced by candidates, and the ability to customize applications in different languages and contexts, not associated with a specific commercial brand. An ICT competent person may work in this platform with a minimal training of less than a minute previous to the administration of the test. The ICT-SAS platforms include a short tutorial that can be studied in 5 or 10 min.

The ICT-SAS platforms provide what is defined as a neutral windows environment, independent of commercial products, based on tools and an online screen display similar to the samples presented in the following figures. ICT-SAS follows the basic syllabus core, including the following:

Desktop: Windows-style main screen where the system controls procedures and runs different applications (Fig. 26.4). At the left of the screen there is a zone to display the tasks or the activities to be performed by the candidate. Other area shows the tools and there is a special area to display messages from the software.

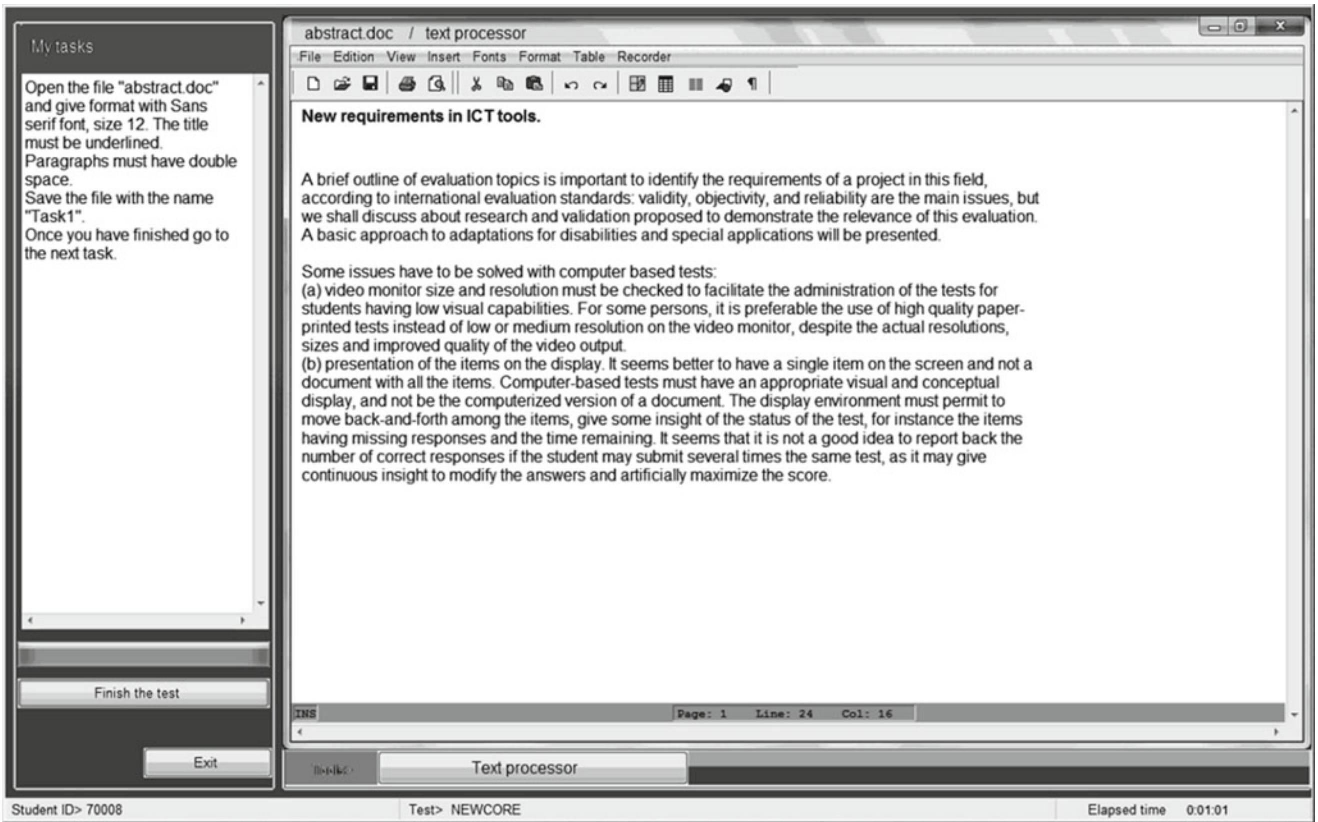

Fig. 26.5 Text processor for ICT-simulation assessment software. Reproduced with authorization by IEIA

Operating system: A file browser is used to browse the directory tree to create, rename, copy, and delete folders or open, save, copy, and delete files.

Notepad: Contains a simplified text editor. Functions include open, save, write, copy, and paste text.

Text processor: Simulates the essential functions of a text editor (Fig. 26.5): open, save, and close files; fonts (type, size, color, bold, italic, underline); and paragraph formatting (such as justification, centering). Vignette management (numbers or symbols), design of tables (defining horizontal and vertical cells, background color, and borders), insert, delete, copy, and paste.

Worksheet: Simulates a grid or a matrix to manage data and functions with spreadsheet features (Fig. 26.6) like open, save, and close files; cell selection and format (numeric, text); menus to perform calculations using basic expressions (sum, average). This module allows the candidate to format data as well as create graphs and sorting options.

Slide presentation: Permits the person to produce, capture, and display a set of "slides" including competencies such as open, save, and close files and the presentation itself; insert, copy, paste, delete, and edit slides; slide design in three basic models (filled area; filling two horizontal zones; title and contents filling two vertical zones); typefaces (fonts, sizes, colors, bold, italic, underline); paragraph formatting (such as justification, centering). Vignette management (numbers or symbols), design of tables (defining horizontal and vertical cells, background color, borders), insert background and display presentation (no special effects).

E-mail: This module simulates an e-mail client. With its main features, the candidate can send and receive fictitious messages, attach documents, and manage the inbox, outbox, address book, and more.

Internet: Lists pages in html for the candidate. This application simulates the Internet search engines and browsers, using fictitious Web pages whose content is limited only by the designer's imagination.

Database: This tool allows the design of data tables and edit, search, and browse functions, using table views and forms.

To use this kind of platform, the test designer has to build a script using pseudo code or, depending on the producer of the platform, a command recorder that simplifies the construction of the sequence of commands. A command is the combination of the ID number of the application tool plus the code of the function to be performed. Every step

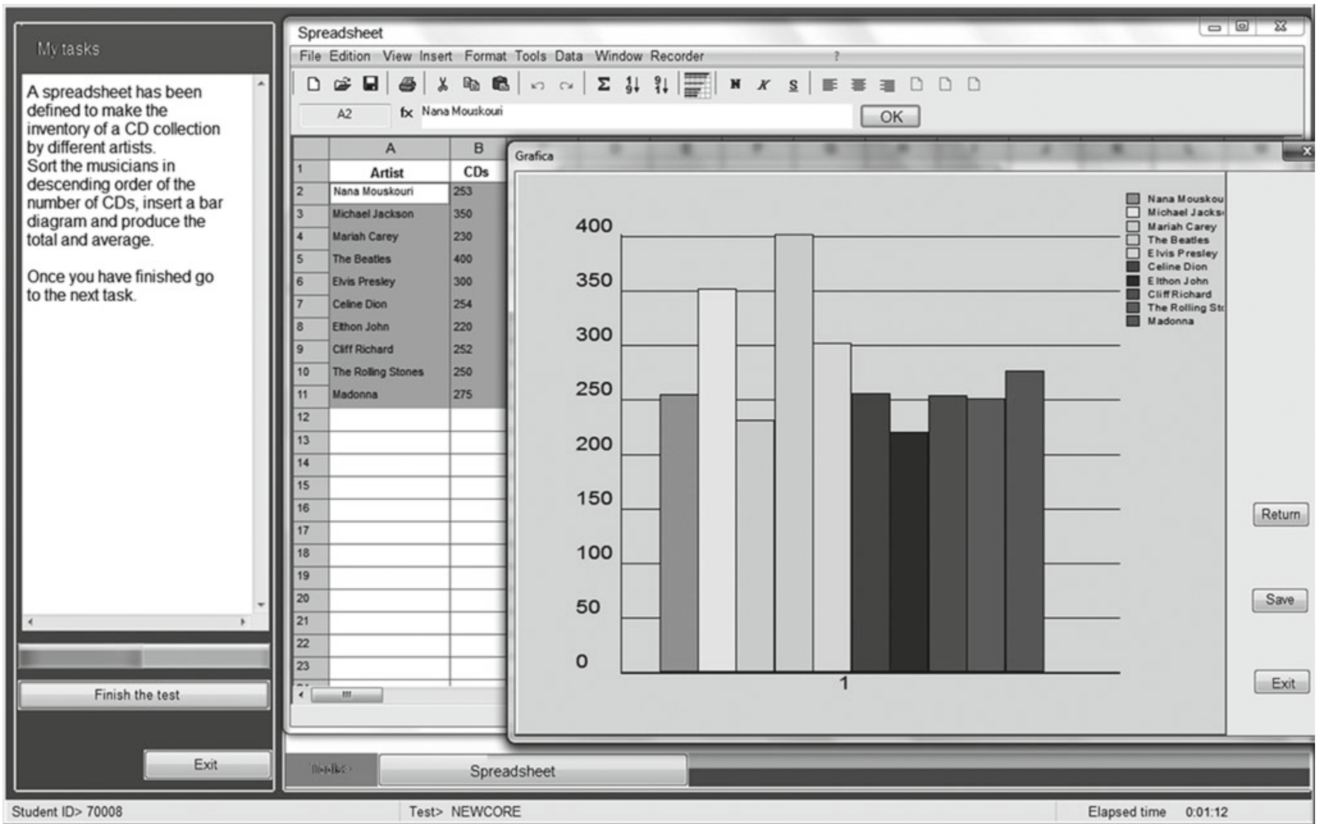

Fig. 26.6 Spreadsheet for ICT-simulation assessment software. Reproduced with authorization by IEIA

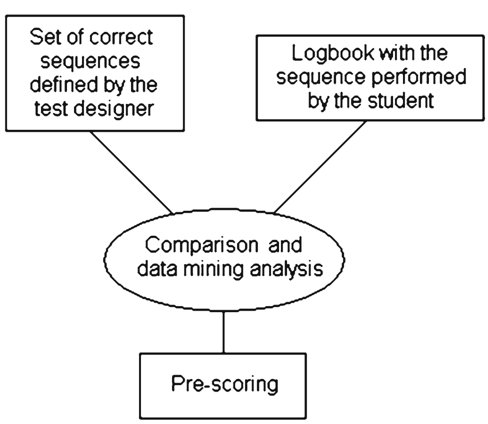

Fig. 26.7 Scoring scheme for ICT-simulation assessment software. Reproduced with authorization by IEIA

produced by the candidate is encoded and can be compared with the sequence of commands that should be produced by the candidate. The recorder can be used to store all the steps performed with the tools; a backup is stored in a log file for later use. All commands stored in the recorder may also be reproduced and can be used as a tutorial or to verify the sequence produced by the candidate.

The scoring process and the production of feedback reports are organized in three subprograms: prescoring, scoring, and reports (Fig. 26.7).

Prescoring compares the script with the sequence of actions performed by the candidate as stored in the log file. The prescoring review uses data mining technologies and may follow multiple criteria to score the whole set of commands or a minimal subset of critical commands.

During scoring, the software uses the prescore registry and counts correct and wrong sequence of commands for each task or activity where the pseudo code is an important tool for scoring (Fig. 26.8). Raw scores can be assigned according to various criteria following classical test theory (including or excluding omissions). Measures using Rasch or IRT models, may be calculated with maximum likelihood or other schemes based on the item's psychometric parameters.

Report capabilities provide two types of reports suitable for this kind of assessment. A test report may be produced on a template including the candidate's name, the school or the location, date, answer sequence, number of correct steps, and actions or sequences that are translated into a raw score. A feedback report contains a set of recommendations for each candidate based on the level of achievement and the competencies demonstrated on the test.

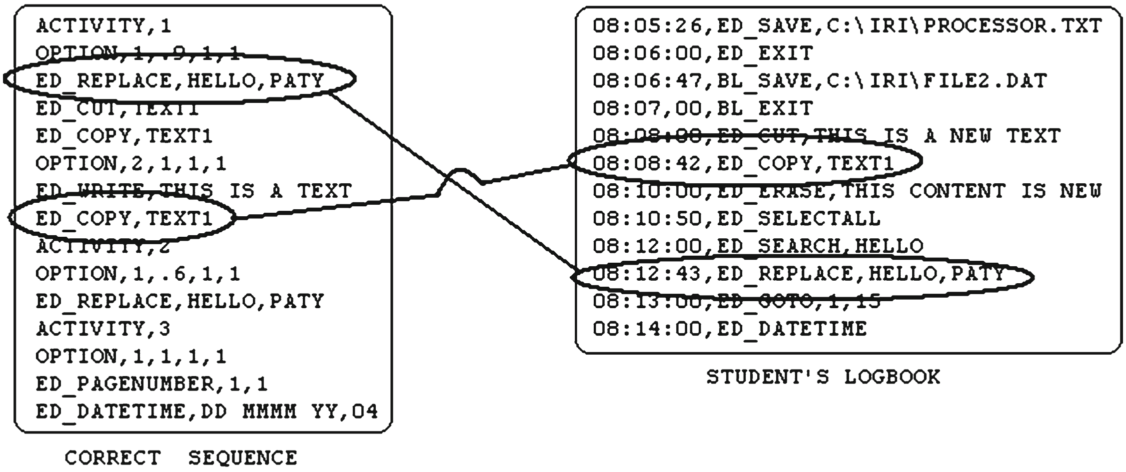

Fig. 26.8 Scoring pseudo code comparison for ICT-simulation assessment software

Conclusions

ICT literacy is a means to empower people in situations where minorities suffer from unfavorable conditions, for example, in countries where women's rights are constrained by law or tradition. ICT assessment can be used for academic and professional certification purposes, or even as a way to increase self-esteem at home, regardless of people's age or social condition at any level of education. As a result, some minority groups which hadn't had the chance to attend a school for example can still become ICT literate (to a certain extent). In these situations, people may consider ICT a tool that represents new labor options or a way to have better opportunities for education, learning, and professional and personal growth. For this reason, ICT assessment is of paramount importance in the modern world.

Online testing is a feasible method to assess ICT competencies. Some approaches were presented from the use of environments able to submit questionnaires and quizzes that are mostly a computer version of paper-and-pencil tests, the use of e-portfolios and other Internet tools, and up to simulated environments where the student must produce documents, search information, send messages, and perform other ICT actions.

ICT assessment instruments and software should incorporate psychometric models to obtain valid, objective, and reliable measures of the competency level of students or professionals in specific contexts. That is the reason why simulators are a suitable option for online scoring of the actions performed by the student, for automatic scoring of a text, and to produce feedback reports that improve the way to identify the ICT competency level of the person.

Existing developments focus primarily on simulated environment software, because it allows actions performed in the simulation to closely mirror those performed with real tools. This type of assessment software provides a "neutral" impressive visual platform similar to real digital applications (but not linked to a single product or brand) and may integrate measuring models in a powerful way, including statistical and psychometric models for item and test calibration.

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27 Data-Driven Decision Making in the K-12 Classroom

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Abstract

During the past decade, data-driven decision making (DDDM) has been at the forefront of many discussions on how to improve public education in the USA. Professions such as medicine, business, politics, engineering, etc. have embraced a data culture and built tools to systematically collect and facilitate analysis of performance data, resulting in dramatic performance improvements. Every day the public depends on companies like Google that collect and aggregate data in ways that help us make decisions about everything from online purchases, to stock investments, to candidate selection. This chapter introduces current research undertaken to bring comparable advantages to education, with the goal of helping classroom- and school-level stakeholders incorporate DDDM as integral to their work. The chapter outlines several different theoretical perspectives currently applied to the DDDM challenge, including the lenses of cultural change, assessment, implementation/adoption, and technology. The bulk of the chapter focuses on research related to models of successful local DDDM implementation, including the design of technological tools and processes to facilitate collection and analysis of actionable data in ways previously not possible. The chapter concludes with implications for research and development that are relevant to those in the fields of instructional technology and learning sciences.

Keywords

Data-based decision making • Data-driven decision making • Evidence-based practice

Introduction

Everyday examples of data-driven decision making (DDDM) include the nearly ubiquitous systems that continually provide unsolicited suggestions. If you buy a book on Amazon, Amazon will use a sophisticated collection of data and algorithms to recommend other books. If you rent or stream movies from Netflix, Netflix will track your data and recommend more movies. The Genius feature in iTunes recommends additional music based on the genius of data. Even your neighborhood grocer probably prints personalized coupons based on data concerning your purchasing behavior.

While a broad array of businesses and organizations now rely heavily on empirical data to drive continuous quality improvement, education seems to lag behind. As Wayman

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(2005) wrote, "Turning data into information has long been a staple in fields such as business and medicine, but the use of student data for educational improvement has not been widespread" (p. 235). Use of empirical data to inform decision making appears under a wide array of names in a broad range of practices: e.g., *business intelligence*, *data-mining*, and *analytics*. The authors who have applied the topic to education use terms including *data-based decision making*, *evidence-based decision making*, and *data-driven decision making*.

With data driving recommendations and affecting decisions in so many fields, educators naturally ask what educational benefits might come from applying these techniques to teaching and learning. Through an examination of current and emerging research and practice, this chapter explores the implications of DDDM for the classroom setting and larger K-12 educational context.

Theoretical Framing of DDDM

No single existing framework is sufficient as a foundation for understanding a complex organizational process such as DDDM. This section integrates concepts from a few existing frameworks setting a basic definition of DDDM, introducing the role of teams and collaboration in DDDM, and the potential for technology to enhance DDDM in education.

DDDM is the use of data analysis to inform choices involving policies and procedures. Data analysis informs but does not replace the expertise, intuition, and judgment of competent educators. Inherent in this definition is the development of reliable information resources to collect and analyze the data on which decision making depends (Picciano, 2006).

Decision making may be defined as choosing among alternatives. In a school organization, decision making is integral to complex management processes like academic planning and policy making. Fundamental to the definition of DDDM is assumption of a rational process directed by values and based on data.

Rationale decision making requires participation by relevant stakeholders and information that will help all who are involved. Much literature is available on the importance of collaboration in decision making, especially as applied to education. Authors such as Senge (1990; learning organizations) and Wenger (1999; communities of practice) see collaboration as crucial for organizations to thrive. In a sense, organizations are considered as organic entities that learn and advance, advance and learn. Sergiovanni and Starratt (1998) reenvisioned educational administration as reliant on "organic management" that makes the promotion of the community the "centerpiece" of supervision.

These patterns of collaborative behavior are not typical in K-12 schools especially in data-based conversations and decision making, prompting Elmore (2004) to express concern that teachers have not been encouraged to engage in organizational decision making dialogue, nor are they given sufficient time to do so. The above authors have promoted concepts to change school management from the bureaucratic top-down style to an increasingly collaborative activity, lined with information sharing, especially regarding the use of data as the fulcrum upon which communities develop. Later sections of this chapter illustrate these suggested changes in practice.

Technology has long promised to improve educators' ability to collaborate in the face of limited time and structure to do so. The evolution of the Internet, for example has allowed timely data to be distributed throughout organizations. Watts (2003) and Birabasi (2002) have studied the effects of networks on various people-intensive processes and found that technological networks can enable individual behavior to aggregate into collective behavior, as individual entities interact to form larger collaborative groups Whether through technology or not, harnessing the collective capacity of a school to improve the teaching/learning experience is an important element of DDDM.

Implementation Contexts for DDDM

DDDM takes place in a wide variety of contexts, from the federal and state levels down to the classroom and individual student levels, each with its unique "reporting and analytical needs" (Thorn, 2001). Currently DDDM is most prevalent at the top levels at which accountability measures such as *No Child Left Behind* (NCLB) have required systematic collection and analysis of high-stakes test data. At the same time there is general consensus that DDDM can have the greatest impact at the local classroom level (Means, Gallagher, & Padilla, 2007; Means, Padilla, & Gallaghar, 2010). This section of the chapter briefly outlines the various contexts in which DDDM takes place, as well as the nature of the data that are useful at the various levels.

State/Federal Level

Federal and state legislation related to school accountability has been a primary driver of the increased emphasis on DDDM in the USA. DDDM at this level is characterized by high-stakes statewide testing that is usually administered once per school year by each state. Many of these high stakes tests have an origin in the 1990s with the standards movement, which culminated in the reauthorization of the Elementary and Secondary Education Act (titled "No Child Left Behind") in 2001.

Data collected as part of No Child Left Behind, while intended to support teaching, is more appropriate as data for state and federal level decision makers. Chen, Heritage, and

Lee (2005) indicate that these "annual tests tell teachers how well students did on the test, but they give limited information about what students did well on, and even less information about why they did well" (p. 310). The indication of which students did well on which topics is a significant improvement upon having no such information. However, teachers need information on why students did well or poorly in order to change instruction to change the outcomes. The summative nature and timing of the assessments used at this level provide very little information that is useful to educators within a school year (Crawford, Schlager, Penuel, & Toyama, 2008).

Instead, end of year state tests that are mandated by the federal government are best used to identify changes in performance across school years. The time required to score and report on these tests is typically 2–5 months, which again makes them more useful to state and federal policymakers who make programmatic and policy decisions than those looking to make immediate decisions (such as classroom teachers).

School/District Level

A significant focus in DDDM has occurred at the district and school levels. Schools and districts are trying to implement both human and technological processes that encourage DDDM. Districts continue to fulfill compliance requirements from state and federal bodies, but those requirements are no longer new. Therefore, more attention has turned to creating processes that inform decision making that is intended to impact student outcomes.

Wayman and Cho (2007) highlight common approaches that districts and schools are adopting to create human processes for DDDM, including common planning time, dedicated collaboration time, and subject- or grade-level teaming. An example of school level teaming for DDDM can be found in the New York City Schools' use of "inquiry teams" tasked with investigating and generating solutions for specific challenges associated with patterns of low student performance (Tucker, 2010). In New York City, like many other school districts, these data-focused teams dig into multiple data sources to identify areas of student weakness. Data is again invoked when plans are made to address these areas of weakness, in order to measure progress as new initiatives are implemented.

While the focus on human processes is increasing, the technological systems that are required for effective district and school DDDM lag in many areas. The simultaneous attempt at fulfilling both policy requirements and decision-making needs of practitioners has left much to be desired in the design and implementation of district data systems (technological tools for DDDM). Systems are often underutilized by end-users (such as teachers or other school-level practitioners) because they find it difficult to access reports that are straightforward to interpret and facilitate quick decisions.

One area of more prominent use of DDDM at the district and school level is in making programmatic decisions. More than ever, education leaders can evaluate the effectiveness of programs and student placement based on longitudinal data systems that are becoming more commonplace in the USA. Examples of programmatic decision making can include decisions about student placement into specific programs or grades, the effectiveness of existing initiatives, and the creation of new ones.

Classroom Level

Classroom level DDDM involves using formative, interim, and summative data to make instructional decisions that impact student performance. Effective classroom level DDDM requires multiple data sources, each of high quality, in order to ensure that well-informed decisions are being made.

While effective teachers always use information about their students to inform their instruction, the quality and timeliness of assessment data available to them for making decisions are rudimentary compared to data given professionals making complex decisions in other high-performance professional fields (Crawford et al., 2008; Tucker, 2010). A 2010 US national survey found that the "greatest perceived area of need among districts is for models of how to connect student data to instructional practice" (Means et al., 2010, p. 47). Research data indicated that a heavy focus of DDDM is on making goals for school improvement and making curriculum decisions rather than on changing classroom teaching strategies (Means et al., 2010).

Classroom level DDM holds much promise for improving teaching and learning in US schools. While randomized controlled experiments, attempting to measure the impact of DDDM on classroom practice, have been rare and inconclusive, much hope remains for DDDM at the classroom level. It is extremely intuitive and logical to even the most experienced classroom teachers that robust information about students can only enhance a teacher's ability to serve her students. Additionally, teachers often find formative assessments, those assessments that provide immediate results, more useful in informing their instruction than larger-scale, more formal interim or summative assessments.

Models of DDDM

The growth of DDDM in districts and schools has highlighted the particular needs specific to the school environment. The previous decade has experienced a marked increase in the development of data systems and decision making tools, but not a corresponding increase in the use of these resources to actually inform classroom-level decision

Table 27.1 Distinguishing features of common DDDM models (Kaufman, Grimm, & Miller, 2012)

DDDM model	Commonalities	Distinguishing features	Number of steps
Data wise improvement process (Harvard Graduate School of Education)	• Have iterative cycles that use data to identify school-based problems • Use instruction as the primary lever to address student learning needs • Emphasize planning for and ongoing progress monitoring of the effects of implemented changes • Use school-level data teams to implement the process, including data examination and the identification of relevant instructional changes • Encourage collaboration, particularly among teachers	• *Includes a "prepare" phase* that emphasizes effective teaming and assessment literacy • *Observes instruction* as part of data collection to understand a root cause of student learning needs • *Develops single, whole-school focus* on an instructional strategy to address a priority need	8
Decision Making for Results (D. Reeves)		• *Focuses on both high- and low-achievers* with a focus on setting SMART goals • *Identifies multiple strategies* to address prioritized needs	6
Plan-Do-Check-Act (P. Davenport)		• *Employs tutorials* to target students at various levels of proficiency (geared around reteaching concepts) • *Facilitates enrichment* pull out to support students who have mastered content • *Encourages instructional grouping* of students based on their performance on standardized assessments	4

making (Mandinach, Honey, & Light, 2012; Means et al., 2010). An increased emphasis on data collection that reveals specific and timely information on individual and collective student learning is necessary for using data to directly inform instruction.

As a result of this need, emerging models of DDDM define *data* broadly, emphasizing the value of classroom data—including student work and instructional practice—to inform decision making. These sources are necessary in developing a deep and collective understanding of student learning, teaching practice, and in their interaction with one another and with content. Likely current efforts at DDDM have been ineffective in part because they depend on large-scale and complex electronic databases, which have proven to be inaccessible and irrelevant to classroom-level instructional decisions (Means et al., 2010).

Despite heightened interest in accountability in public education over the past decade, opportunities for genuine DDDM have been limited. This is in part due to the limited frequency and awkward timing of mandated assessments that form the basis for such decision making. Reeves (2010) likens the current timing of state tests to addressing teen obesity by "weighing students on May 1 each year, lecturing them in September, and giving them meaningful feedback 6 months after we last observed them inhaling a bacon cheeseburger" (p. 15). Current and effective models recognize this shortcoming and emphasize a need for ongoing progress monitoring through DDDM. With an expanded definition of data, teachers and school leaders are better equipped to collect and analyze data—whether in the form of student interviews, student assignments, or more traditional benchmark tests—throughout the school year and make relevant instructional adjustments.

Current models for DDDM address the specific needs and deficiencies that have surfaced over the past decades, many of which we have described in this chapter. In addition to broadening definitions of data, these practices acknowledge the necessary element of collaboration at the center of data analysis and data-informed decision making. Widespread models, including Data Wise (Boudett, City, & Murnane, 2005; Boudett & Steele, 2007), Doug Reeves' Data Teams (Reeves, 2004), and Bernhardt's Portfolio Model (Bernhardt, 2009), emphasize creating and developing collaborative teams that drive data collection, analysis, and decision making within a school. Furthermore, these models all utilize classroom instruction as the primary lever to address student learning needs.

Rather than being linear processes, with a clear beginning and end, current DDDM models are iterative, engaging schools in data analysis, need identification, implementation of identified strategies, and progress monitoring of strategies grounded in data analysis. This cyclical process guides schools in the use of data to regularly to inform decisions, actions, and later adjustments. This deviates from common school improvement efforts that involve creating an action plan that remains unexamined or amended over the course of the school year. Furthermore, an iterative and defined process provides the necessary structure for schools to continue moving forward in the work and ultimately to make data-driven decisions that lead to improvements in teaching and learning. See Table 27.1 for distinguishing features of several common DDDM models.

Establishing Goals and Inquiry Questions

Contrary to the quick identification of problems and solutions characteristic of many school environments, current models of DDDM emphasize a thorough data examination to deeply understand problems, including their root causes. Many contemporary DDDM models utilize quantitative data (student performance data, attendance reports, statistics on discipline referrals, etc.) as a starting point to identify deeper questions and to frame subsequent steps in the inquiry process. For example, a team of teachers may identify a need for students to develop their reading comprehension skills based on standardized test data. After identifying specific areas of need, teachers and school leaders are able to identify additional data that will increase understanding of the problems they hope to address.

Student Work and Teaching as Data

For some time now, DDDM models have encouraged practitioners to use multiple sources of data to provide a comprehensive understanding of specific school needs. Extending beyond student performance data, current models emphasize collection and analysis of student work and teaching practice as data. Through the examination of student work and teaching practice, teachers identify deeper student learning issues, and they are able to also identify a root cause embedded in teaching. This type of analysis enables schools to focus on improving what they can control: instruction.

Rather than looking at student work or examining teaching practice as evaluative processes, in a DDDM model these sources are often considered data. These data sources inform understanding of student thinking and its relationship with instructional practices; this increases the capacity of teachers and school leaders to use data to inform decision making. As data sources, student work and teaching practice more easily translate into informed pedagogical decisions than the numbers of standardized student performance data because student work and teaching happen regularly and are therefore more timely and accessible by nature.

Analyzing and Interpreting Data

Collaboration, which is central to many DDDM models, is a noted absence in current school improvement efforts (Wei, Darling-Hammond, & Adamson, 2010). Research finds that data become more meaningful and more likely to lead to systemic and lasting reforms when examined collaboratively (Means et al., 2010). To support such practice, effective DDDM models utilize both diverse data teams and whole-school involvement and decision making to drive data analysis.

Effective DDDM models provide educators with a structure to analyze and interpret data to identify root causes and to create and implement solutions that effectively address student learning problems. Without a deep understanding of a problem, the solutions created are likely to be ineffective. As noted in the Reeves' (2010) model, the process of analyzing and interpreting data also involves prioritizing needs within the school improvement process: e.g., identifying areas where the needs are most urgent, where the potential for growth is greatest, or where a school community can most readily address a root cause with the resources available.

Similarly, the Data Wise model, used in many school districts in the USA, emphasizes identification of find-grained and specific problems of practice (Boudett et al., 2005). The narrow entry point enables those involved in school improvement efforts to focus their energy and intervention in a specific area, increasing the likelihood that they can develop shared understanding, drive collective action, and directly address the root cause.

Acting Based on Data

Analyzing and interpreting data is meaningful only if those activities result in changes in the practices within schools. While identifying and analyzing data lays the groundwork for impactful improvements to student learning, the resulting actions and progress monitoring will ultimately determine the efficacy of DDDM efforts.

Identifying a root cause and selecting strategies to address it require parallel assessment of available resources—including (but not limited to) teachers' knowledge and existing skills, time, and available funding. This action-oriented focus of DDDM models requires clarity in and support for collective changes in practice.

While models vary in the scope of their focus, several emphasize change at the classroom level. Rather than addressing the larger structures of schools (scheduling, attendance policies, etc.), the three models discussed in this section emphasize implementing change at the classroom level and recognizing instruction as the point of leverage for increasing student learning. This classroom focus places teachers at the center of DDDM.

Along with identifying instructional strategies, DDDM models promote the identification of results indicators. This step requires schools to examine the ways in which progress can be assessed throughout an improvement process and identify specific sources of data that will be collected to support progress monitoring.

Thus the process of creating and implementing an action plan involves implementing specific strategies or changes in practice accompanied by simultaneous ongoing data collection and analysis. This progress monitoring requires increased investments in time and other resources if teachers are to collaboratively examine and analyze data. But the investment provides an ongoing and consistent picture of the effects of changes, both to assess their effectiveness and to inform mid-course adjustments.

The Role of Technology and Data Systems in DDDM

Technological data systems are a critical part of DDDM in the twenty-first century because aggregating, analyzing, and maintaining large complex sets of data would be virtually impossible without them. Brunner et al. (2005) have noted that "the relative ease of use and sophistication of data-gathering, storage, and delivery systems has made data accessible in a meaningful format to whole sets of constituents whose access to data in the past was either nonexistent or presented in dense and unintelligible reports" (p. 47).

Some of the key capabilities that technology enables in a data system include

- Timely access to data (Means et al. 2007)
- Improved mechanisms for data collection (including mobile technologies) (Mandinach et al., 2012)
- Ability to aggregate data across organizational/institutional boundaries in a timely manner (Breiter & Light, 2006; Thorn, 2001)
- Data mining capabilities (Baker & Yacef, 2009)
- Improved data usability and visualization of data (Breiter & Light, 2006)
- Real-time feedback and analysis capabilities (Crawford et al., 2008)

For two decades researchers have been studying how tools such as knowledge management systems and electronic performance support systems (EPSS) can be used to improve human and organizational performance in complex organizational contexts (Alavi & Leidner, 2001; Haney, 2006; Hudzina, Rowley, & Wager, 1991). Both systems incorporate the human/organizational dimension as a critical component of developing a data system. These principles of knowledge management are increasingly applied in data-driven educational decision making (Cho & Wayman, 2009; Thorn, 2001).

Knowledge management systems are intended for capturing and managing organizational knowledge (Alavi & Leidner, 2001). Thorn (2001) articulates four primary goals of educational knowledge management systems: (1) to create knowledge repositories, (2) to improve access to knowledge, (3) to enhance the educational environment through knowledge sharing, and (4) to manage knowledge as an asset to make sure that it contributes to bottom line success (pp. 5–6). Primary concerns of knowledge management include the relationship between tacit and explicit knowledge and ways organizations manage the creation and access to that knowledge (Cho & Wayman, 2009; Nonaka, 1994). Making tacit knowledge about student performance explicit and developing strategies for addressing performance gaps are critical to DDDM in schools.

Electronic performance support is another lens through which one can look at the design and development of data systems for educational decision making (Hudzina et al., 1991; Kirkley & Duffy, 1997). A major focus of the literature on performance support is how to improve performance by providing appropriate integrated support in real time, as opposed to support that is disconnected from the performance task (Cavanagh, 2004). In the educational setting teachers might have access to day-to-day student performance data that will directly affect classroom instructional decisions. Use of the system might go beyond student performance data to include professional development training focused on effective methods and strategies, made available to the instructor when immediately relevant (Hudzina et al., 1991). Or instead of providing real-time access to professional development content, an EPSS could provide "instantaneous and impromptu" access to networks of professionals or communities of practice that could provide support for instructional problem solving (McManus & Rossett, 2006). In addition to providing performance support for instructors and educational administrators, EPSS can also be designed to provide real-time support to the learners themselves and to communicate performance data with parents (Chen et al., 2005; Means et al., 2010; Tucker, 2010).

As noted in practice, the technological systems are only as effective as the capacity of teachers and school leaders to access, understand, and collaboratively analyze the information (Tucker, 2010). As Tucker notes, "Unless systems are designed to be obvious value to these educators—to give them insights into students—then their use will be limited" (2010, p. 14). Despite this progress noted in this section, researchers still acknowledge that "teachers do not have the data-rich, performance-support, and information-feedback work environment that virtually all other high-performance professionals and many service professionals have at their disposal" (Crawford et al., 2008, p. 112). To reach its potential, DDDM within education requires increased development of technological data systems alongside the skills of educators to effectively leverage these resources to inform day-to-day practice.

Implications of DDDM for Educational Research

While technology has contributed to the growth of data available to K-12 practitioners and iterative models of DDDM are increasingly gaining traction within schools, work remains in fully realizing the potential of DDDM to affect classroom instruction and student learning. This section of the chapter focuses on three potentially productive areas of research for those interested in studying DDDM: (1) implementation and adoption, (2) data system development, and (3) evaluation and measurement.

Implementation and Adoption Issues

The most difficult issues related to DDDM are not technological, but rather human issues concerned with changing professional practices and altering the culture of educational organizations. Research has shown that increased attention and access to student achievement data over the past decade has done little to drive wide-scale improvements in student learning. A study commissioned by the US Department of Education, which surveyed hundreds of districts across the USA in 2007 and followed up with site visits to selected districts during the 2006–2007 and 2007–2008 academic years, explored challenges impeding current DDDM efforts (Means et al., 2010). This research found significant adoption challenges, particularly at the level that would impact classroom instruction. "Even in districts that are actively promoting the use of data, however, school staff provided relatively few examples of teachers using data to diagnose areas in which they could improve the way they teach" (Means et al., 2010, p. xiv). Future research could focus on how to improve and even speed up adoption of effective data use practices in school settings.

To address shortcomings in current DDDM efforts, teachers need additional support in using the student data they receive to improve their teaching and in structuring opportunities for collaboration in this endeavor. This capacity-building effort should begin during teacher preparation and continue through on-the-job professional development. Means et al. (2007) documented that "only six percent of teachers surveyed reported having had formal course work on data-driven decision-making" (p. 16)—a finding which may indicate that teacher preparation programs are behind the curve in preparing teacher candidates for DDDM. In contrast, the report showed that 60 % of teachers surveyed had participated in some form of professional development on DDDM within their school or district. Districts identified connecting data to instructional practice as their greatest area of need, including "examining student data to identify which practices work best for which students," "adapting instructional activities to meet students' individual needs," and "collaborating and sharing ideas with colleagues regarding data inquiry and analysis issues" as particularly weak areas (Means et al., 2010). Each of these needs aligns directly with research on effective school improvement efforts, which identify a focus on high-quality instruction, peer collaboration, and regular data collection and analysis as features essential to effective schools (Bryk, Sebring, Allensworth, Luppescu, & Easton, 2009; Chenoweth, 2007, 2009; Ratner & Neill, 2010). Research should also look at how teacher preparation programs and professional development opportunities are preparing candidates with the most critical knowledge and skills identified and how well skills from those programs are transferring to the actual working environment.

Finally, schools that effectively implement a process for DDDM engage in shifts in ideology as well as in practice. Using data to deeply inform an understanding of student learning and thus to make impactful decisions requires a shift in focus from what teachers have taught to what students have learned (Bambrick-Santoyo, 2010). Many schools that have demonstrated measured increases in student learning have worked to create a culture of inquiry and support (in resources including time and training) around the use of data (Bernhardt, 2009; Gallimore, Ermeling, Saunders, & Goldenberg, 2009; Reeves, 2010). As noted by the US Department of Education, "Human and organizational supports for data use are just as important as the technical quality of the data system" (US Department of Education, 2010). In addition to the teaching and adoption of high impact data skills, researchers should consider the perspective of changing school data cultures. Knowing how to use data does not ensure a school environment that supports the application of those skills.

Data System Development Issues

The quality of data systems strongly impacts data use in schools. Marsh, Pane, and Hamilton (2006) outline some of the factors that affect how data are used in schools: (1) accessibility of data, (2) quality and acceptability of data, (3) user motivation to use data, (4) timeliness of receiving data, (5) staff capacity, (6) curriculum pacing pressures, (7) lack of time, (8) history of state accountability, and (9) organizational culture and leadership. Three of these factors have to do with the development of the data system itself, and others have to do with the social and cultural environment in which the data system is used. Research on data system development can focus on the accessibility, quality, and timeliness of data used for decision making.

For DDDM to take place in districts and schools, the faculty, staff, and administrators must first have access to the data and information affecting their decisions. "Although schools have been 'data rich' for years, they are also 'information poor' because the vast amounts of available data they have are often stored in ways that are inaccessible to most practitioners" (Wayman, 2005, p. 296). The problem is one of easy and practical access to data that can be used in real time. Teachers and administrators have had access to large amounts of hard-copy data for decades; however most data have been poorly organized and difficult to work with, often accessible only for short periods of the year. Much of the data that teachers and administrators have had access to have been district, state, and national norm- and criterion-referenced testing data, not formative student performance data. In addition to these district, state, and national datasets, teachers and administrators need a system that is flexible enough to allow them to input and use their own idiosyncratic data and student information in conjunction with the standardized data forms. To design and deploy these data systems, in addition to understanding the types of data, researchers need to understand how, when, why, and under what conditions, teachers and administrators access data for DDDM.

In addition, current research has found issues concerning educators' confidence in data validity.

> Many educators questioned the validity of some data, such as whether test scores accurately reflect students' knowledge, whether students take tests seriously, whether tests are aligned with curriculum, or whether satisfaction data derived from surveys with low response rates accurately measure opinions. These doubts greatly affected some educators' buy-in, or acceptance of and support for the data, which research has identified as an important factor affecting meaningful data use. (Marsh et al., 2006, p. 8).

Evidently, much of the data that teachers and administrators presently have available do not provide the types of insight they need to make critical instructional decisions. Research is needed to understand what types and quality of data teachers and administrators value and how that data can be collected and made available in practical useful ways.

Finally, classrooms and schools continually change and often operate at a rapid pace, and many instructional decisions must be made hourly. If teachers and administrators cannot quickly access decision-relevant data, they will have to rely primarily on their instincts and past experiences. Data systems must make data available to teachers and administrators when they need it. Research concerning knowledge management and electronic performance support has emphasized providing just-in-time data to enhance decision making and performance. How just-in-time access to student performance data will be received by a typical classroom teacher and how the teacher will use the data to change instructional pathways for students are also important areas of investigation.

Evaluation and Measurement Issues

Of the many important evaluation and measurement issues related to DDDM, this chapter focuses on two that are critical: value-added measures and common assessments. The purpose of these sections is not to provide comprehensive coverage of these important issues, but to highlight the issues as important and relevant to current DDDM discussions.

Value-Added Measures

The ultimate goal of value-added measures is to be able to accurately estimate the individual teacher's contribution to student learning (Harris, 2011) and make educational decision making more effective by controlling for factors like prior achievement, access to resources beyond school, and family factors outside the control of the educator (Harris, 2011; Marsh et al., 2006). Once measurement challenges are satisfactorily resolved, value-added considerations can provide accountability focused on educator-influenced growth outputs rather than on inputs or "snapshot" outputs (Harris, 2011).

Value-added measures are concerned with making accountability systems more reflective of what teachers and administrators can and do control in schools and districts, with significant involvement of DDDM and its supporting data systems. Examining how value-added measures work and contribute to the overall data picture in schools and districts will clarify how DDDM is impacted and how it may bring greater equity to these accountability systems.

While value-added measures can contribute to the identification of successful teachers, these measures are limited in their capacity to inform our understanding of the effectiveness of specific practices. Additionally, questions remain regarding the ability of value-added measures to effectively isolate the effects of the current teacher (Amrein-Beardsley, 2008).

Common Assessments

In February of 2009, President Obama signed into law the *American Recovery and Reinvestment Act of 2009,* which included funding for the *Race to the Top Fund* (RTTT), to be administered by the US Department of Education, encouraging "building data systems that measure student growth and success, and inform teachers and principals about how they can improve instruction" (US Department of Education, 2009, p. 2). Additionally, a state-led initiative coordinated by the Council of Chief State School Officers and the National Governors Association came together and drafted *the Common Core State Standards* that have been adopted by 45 of the states (Common Core Standards Initiative, 2011a, 2011b).

In providing a "a clear and consistent framework" and "appropriate benchmarks for all students," the Common Core State Standards (CCSS) have cleared a path for the development and use of common assessments for all students that can cross state lines in ways that have never before been possible. Common assessments, which are the norm for national- and state-benchmark testing, are intended to allow teachers to see how their students' achievement compares with other students across the nation; however before the Common Core it has been a stretch to compare student achievement across states since each state developed its own standards. With these developments educators nationwide will have an unprecedented opportunity to access and analyze data on their students in relation to those across the country.

In addition to the common summative assessments that may be used across states, the CCSS may allow for common interim assessments to be used across states. This addition will enhance educators' abilities to deeply assess specific standards in a formative manner. Furthermore, these interim assessments will give teachers and administrators multiple data points across the school year to monitor student achievement prior to year-end testing. As cross state assessment systems are built on the foundation of the Common Core, research on DDDM will need to go in directions not yet considered.

Conclusions

DDDM is an important area of inquiry for educational researchers in the twenty-first century. In an era of access to powerful technologies for collecting and analyzing data, as well as an increasing demand for accountability in our school systems, the presence of DDDM in K-12 education will continue to increase. Simultaneously, researchers and practitioners are developing and refining DDDM models and tools that meet the unique needs of teachers, school and district leaders, and policymakers. As noted in this chapter, work remains in developing our understandings of the implementation and adoption of DDDM, the development of data systems, and the ways in which DDDM can support effective evaluation and measurement.

Additionally, the development of DDDM models and an increase in access to data from technological advancements must be accompanied by a focus on developing educators' capacities for transforming data into instructional decisions that affect student learning at the classroom level. Without such a development, DDDM will remain a largely unleveraged resource within K-12 education.

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Section IV
General Instructional Strategies

Jan Elen and M.J. Bishop

Any handbook related to educational technology and/or instructional design has some key chapters that discuss the heart of the enterprise. This section on "general instructional strategies" presents those core chapters and shows the dynamics of the field by discussing recent research in each area. While some of these chapters reveal perspectives from which (research on) instructional strategies can be discussed, others point to strategies aimed at attaining important instructional goals, and still others focus on particular instructional strategies, approaches, or methods. This section is complementary to earlier sections in previous editions of the *Handbook* (Jonassen, 2004; Jonassen, Harris, & Driscoll, 2001; Spector, Merrill, van Merriënboer, & Driscoll, 2008) as it builds upon and elaborates on those earlier chapters by presenting new perspectives and new research insights. This section is also complementary to the next section of this *Handbook* edition in that it addresses general instructional strategies rather than domain-specific ones. In that sense, the chapters in this section are more abstract and theoretical whereas their applicability range is larger.

One of the major, more recent theoretical insights pertains to the role of context. The field has become well aware that learning and instruction are situated processes. It is no surprise, therefore, that research on the role of culture in learning is growing. The first chapter in this section by Young addresses this issue. This chapter reviews current research across disciplines (i.e., mathematics, science, and e-learning) to provide a critical analysis of applications and conceptualizations of culture in learning. Given this research, implications for culture-based instructional strategies are offered.

The cognitive revolution in research on teaching and learning has brought about a concern for developing learning ability. This has not stopped and research now focuses on the development of self-directed and self-regulated learning skills. The chapter by Brand-Gruwel, Kester, Kicken, and Kirschner argues that the development of these skills requires a flexible learning environment with personalized learning trajectories. The chapter discusses recent research on the design of such learning environments. A rich pallet from well-structured learning materials over portfolios and advisory models is presented.

Instructional strategies and information need to be delivered. With evolutions in technology offering a more diverse set of technological possibilities, research is now delving into these new possibilities and investigating how they can stimulate learning. The chapter by Bishop reveals the need to pay far more attention to instructional messages by considering the highly interactive nature of these messages. The author argues that research on instructional messages has not yet endorsed more constructivist perspectives and reestablishing instructional message design as a valid area of inquiry in instructional design will require that recent reorientations in communication theory be considered. This will help to bring about a research domain that is oriented towards message design for learning. In the chapter on multimedia learning, Mayer provides a concise overview of multimedia research. In multimedia instruction text and images are combined with the intent of enhancing learning. The author argues that this instruction becomes more effective when cognitive architecture is considered in the design of that instruction. The design of effect multimedia instruction implies that research principles with respect to reducing extraneous processing, managing essential processing, and fostering generative processing be considered.

Research in the field of instructional design and educational technology gradually reveals the importance of a number of fundamental aspects of learning environments. Three of them are the need for authentic learning environments, for feedback, and for adaptivity. In the chapter on authentic learning environments by Herrington, Reeves, and Oliver the theoretical background of authentic learning environments is extensively discussed. Furthermore, the authors highlight the

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great potential of new technologies and review the recent research on authentic learning environments. The chapter by Molloy and Boud addresses feedback. In addition to a critical analysis of definitions and theories, the authors offer an overview of recent empirical work. The chapter concludes with the insight that feedback is an integral part of any productive learning environment, suggesting a greater focus on formative rather than on summative evaluation as well. Adaptivity and even personalization remain a goal of many learning environments, which aim to optimize learning by considering individual characteristics and providing targeted support. Vandewaetere and Clarebout discuss research on advanced technologies and personalized learning environments. The authors claim that the integration of artificial intelligence and educational data mining provides a firm basis for personalized systems. The chapter concludes with the authors' plea to use the potential of these new developments to foster learning.

Specific instructional strategies are presented in the four (or five) chapters. In each of these chapters an up-to-date overview is presented of the theoretical background and the empirical evidence with respect to one particular strategy. Goodyear, Jones, and Thompson do so for computer-supported collaborative learning; Lazonder for inquiry learning; Seel for model-based learning; and Tobias, Fletcher, and Wind for game-based learning (perhaps still reference to case-based learning chapter). Strikingly, what becomes clear in each of these chapters is that good instructional design decision making first requires that an in-depth analysis is made of the cognitive processes in which learners must engage. An instructional strategy cannot be expected to be effective unless it elicits appropriate cognitive processes.

The provision of instructional support often in the form of scaffolds is addressed in the last two chapters. Belland provides an in-depth overview of research on scaffolds. Given the broad meaning attributed to the term and hence the overwhelming amount of research on scaffolds, some restrictions had to be considered. Great insights emerge from this overview: In order to make learners stronger, fading support is a key characteristic of powerful learning environments and general support are far less effective than scaffolds with a clear domain-specific orientation. This calls for more domain-specific instructional design research as illustrated in another section of this *Handbook*. But even well-designed scaffolds or well-designed instructional support may not be as effective as hoped; the main reason is that learners are self-regulated agents and their interpretation of the support and of the entire learning environment and their motivation will determine whether the support is actually used and/or used as intended by the designer. The issue of support use is the focus of the last chapter by Clarebout and her colleagues.

While this section is long and gives a good overview of recent thinking and current investigations on instructional strategies, it is far from exhaustive. This edition of the *Handbook* is clearly missing chapters on distributed learning. Internet and e-learning have become mainstream and this implies that instruction can now be provided anytime anywhere. The implications of these new possibilities for learning and research on appropriate instructional strategies in distributed learning settings are issues to be discussed in the fifth edition of the *Handbook*.

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The Presence of Culture in Learning

28

Patricia A. Young

Abstract

The selection of instructional strategies for learners requires consideration of the role of culture in learning. This chapter reviews current research across disciplines (i.e., mathematics, science, and e-learning) to provide a critical analysis of applications and conceptualizations of culture in learning. Given this research, implications for culture-based instructional strategies are offered.

Keywords

Culture • Learning • Instructional strategies • Culture-specific • Science • Mathematics • e-learning

Introduction

Worldwide there is growing concern about how to educate all people and understand the intricacies of human learning. Given this fact, culture has become a preeminent factor in understanding learners and learning.

The role of culture in learning moves beyond challenging dominate ideologies or world views; it is about defining and identifying instances, methods and processes of learning that are specific to individuals and groups. Thereafter, the selection of instructional strategies begins. That is, instructional strategies cannot be applied to learners; in this sense, instructional strategies must be developed from an ethnographic evaluation of the learner. Instructional strategies are derived from versus applied to the learner.

This chapter reviews international research in the areas of culture, learning, and a specific discipline (i.e., mathematics, science, and e-learning) to determine relevant instructional strategies in this context. Each section begins with a review the qualitative and quantitative studies. This is followed by a review of conceptual and theoretical articles that approach the same topic area. Mathematics, science, and e-learning are each approached differently depending on the literature reviews. In the mathematics and science literature, specific themes arose so those themes were reviewed in context to best compare and contrast the literature.

Other disciplines have been excluded because of the volume of research that is developing in these areas and publishing constraints. In particular, there is a growing body of research related to culture, learning, and disciplines such as computer technology, human computer interaction, instructional design, and game design.

Culture Defined

Culture remains a term institutionally defined and applied. Theoretical and conceptual definitions of culture derive out of the need to make culture discipline specific or to understand processes or practices. Some of these disciplines include: psychology, social psychology, education, anthropology, sociobiology, sociology, and cognitive science to name a few. Matsumoto (2009) situates culture in the field of psychology and associates culture with human behavior and mental processes. For Matsumoto, culture is a "meaning and information system, shared by a group and transmitted

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across generations" that allows for human survival, the coordination and transmission of social behaviors, and the pursuit of happiness, health and a meaningful life (p. 5). For another psychologist like Gurung (2009), culture is static as it captures a groups shared attitudes, beliefs, and goals, but culture is also dynamic; it is always changing because of the beliefs held by human beings in the group. Hollins (2008), an educator in sociocultural theory, positions culture as "who we are and how we exist in the world" (p. 18). Hofstede, a social psychologist and anthropologist, states that culture is "the collective programming of the mind that distinguishes the members of one group or category of people from others" (Hofstede, Hofstede, & Minko, 2010, p. 6). Anthropologists propose that culture is a "system of learned behaviors, and explore the ways that humans use it to organize and give meaning to the world around them" (Wanda & Warms, 2011, p. 74). Anthropologists agree that cultures are shared by people and groups who have learned behaviors. Cultures are adaptive to surviving in the world. Cultures change and are never static. Cultures are patterned and relational to one another. Cultures contain symbols (Pieterse, 2009). Sociobiological representations situate culture as an attribute to natural selection. That is, there is a natural selection for behaviors and these behaviors can be transferred from generation to generation. By example, current research in sociobological sciences contends that human behavior is influenced by cultural factors and specific genes (Chiao & Blizinsky, 2010; Fincher, Thornhill, Murray, & Schaller, 2008). Then there are sociologists who delve in cultural studies and argue that culture is about meaning making—that is the exchange and production of meaning, between members in a group or society (Hall, 1997). Rogoff (2003), who studies human development and cognition, proposes that culture is what all humans do; further these cultural practices and cultural processes are enacted by humans in different ways, for different reasons but that they are part of the culture of human development.

This review of disciplines confirms the institutionalization of culture as a theoretical and conceptual term that is transmuted based on human need and desire. This mutation suggests the need to clarify the definition of culture as it pertains to human learning. Therefore, within this chapter, culture is all that we know and have come to know, do, and produce as human beings. Culture is everything! It is everything around us and everything ever created. Culture is all that is man-made, and even those things made by nature.

Notions of Culture in Learning

An interdisciplinary examination of research particular to notions of culture in learning reveals similar conclusions—that learning is actively mediated through learners participation in their culture (Choo, Austin, & Renshaw, 2007; Fischer, 2009; Gutierrez & Rogoff, 2003; Ito et al., 2010; Lee, 2009; Nasir, Rosebery, Warren, & Lee, 2006; Thomas & Brown, 2011). This means that situating learners within culture-based contexts enables learning to happen naturally. Culture-based encompasses culture-neutral (generic) and culture-specific (specialized) contexts (Young, 2008, 2009).

Studies in Culture

Studies that have examined culture and learning reveal culture as the primary focus of the research, and that culture is central to determining the learning preferences, styles, approaches and experiences of learners. Culture is determined to be central to learning. These studies are supported through an interdisciplinary selection of theory that relates to sociocultural, Afrocultural, cooperative learning, cognition, culture, learning styles, and language learning. This suggests the need for an interdisciplinary interpretation of culture and its relationship to learning. The methods of analyses considered both qualitative and quantitative research. All of the studies administered culture or learning related questionnaires or surveys to determine learners' learning styles, strategies, preferences, orientations, or cultural knowledge. The findings indicate that there is a positive correlation between culture and learning preferences; this means that culture influences learners preferred learning pathways (Boykin et al., 2005; Charlesworth, 2008; Ellison, Boykin, Tyler, & Dillihunt, 2005; Sulkowski & Deakin, 2009; Tsou, 2005). These learning pathways can be culture-specific or particular to an ethnic or racial group; however, learning pathways are not always dictated by membership in a racial group as it can be by exposure and lived experiences that an individual acquires these preferences (Boykin et al., 2005).

Theoretical and Conceptual Research in Culture

Theoretical and conceptual notions of culture in learning are articulated as "cultural practices" (Gonzalez, Moll, & Amanti, 2005; Lee, 2009; Nasir et al., 2006), "cultures of participation" (Fischer, 2009), a new "culture of learning" (Thomas & Brown, 2011) and "genres of participation" (Ito et al., 2010).

Researchers propose that cultural practices can be observed through an examination of learners everyday interactions with their environment. For example, Taylor (2009) documented the mathematical competencies of African American youth through their purchasing practices of buying candy and other items at a neighborhood store. These cultural practices were exemplified through school aged children engaged in reading priced items, figuring the costs of purchases, deciding the correct currency for purchase and determining the remaining monies from a transaction as these practices unfolded within a sociocultural context. Observing and analyzing cultural practices supports the modeling of instructional pathways (Lee, 2009); aids in the design of learning environments (Nasir et al., 2006); brings meaning to discipline specific learning; assists in bridging cross-cultural understandings and situates learning in a cultural context (Barta & Brenner, 2009). In this sense, instructional strategies and methodologies are modeled and designed from empirical evidence of learners' interactions with cultural practices; thereby, instruction is derived from versus applied to learners.

Similar research in this area proposes that learning has been altered by twenty-first century networked technologies. In particular, the World Wide Web has shifted the way we learn, why we learn, how we learn, who we learn with, and where we learn. Fischer (2009) argues that there are "cultures of participation" where all individuals can meaningfully interact through networked technologies. Thomas and Brown (2011) conceptualize this digital phenomenon as a new "culture of learning" where individuals learn from and with each other thereby creating collectives. Ito et al. (2010) describes these ongoing learning and technological engagements as "genres of participation," conducted through "networked publics" that engage learners in social and cultural contexts (p. 14). Networked technologies allow individuals to learn by interacting (Fischer, 2009), doing, experiencing and watching (Thomas & Brown, 2011). Learning is mediated by the learner's age, desires, expertise, identity, income, interests, gender, talents, values, etc.—culture.

Ethnography for Culture-Based Analyses

Capturing the culture of learning requires an ethnographic analysis of individuals or groups as they engage in their culture or society. Ethnographic work, in general, aids in describing and understanding "a given process, experience or group" (Orellana & Bowman, 2003, p. 30). An ethnography allows for the construction of in-depth social categorizations that explore the intricacies of culture (Orellana & Bowman, 2003). Kumpulainen and Renshaw (2007) describe it as follows: "To investigate learning as an ethnographer, therefore, is to focus on the practices and understandings of the members of a community, and the interactive processes that establish and maintain such practices and understandings" (p. 110).

It takes an ethnographic analysis of cultures and societies to determine and understand how individuals and groups learn. This point is demonstrated by Ito et al.'s (2010) study where they conducted an ethnographic analysis of youth engagement with new media to better understand literacy and learning.

The use of ethnography for culture-based analyses is becoming common place in cultural studies (Subramony, 2009). Ethnographic work supports the study of learning (Barta & Brenner, 2009), focuses on the localization of knowledge (Crabtree, 2010), assists in the improvement of learning (Lipka et al., 2005), allows for the interpretation of the *purposes* of practices (Carlone, Haun-Frank, & Webb, 2011), enables microanalyses of cultural meanings in learner interactions (Brown, 2004), and encourages the building of learning technologies (Hall & Sanderville, 2009).

This research suggests that notions of culture in learning are real and relevant. If learning happens through learners interactions with their culture; then culture cannot be separated from the learning or learner. Whether it is determined through cultural practices, cultures of participation, cultures of learning or genres of participation, the learner is engaged in a semiotic relationship with their culture and this in turn influences human learning and the acquisition of knowledge. Ethnography can be the method of measurement to better understand the learner and how knowledge is acquired.

Interdisciplinary Applications of Culture and Learning

A growing body of literature in culture and learning proposes that human learning and development are keenly influenced by culture (Lee, 2009; Lee, Spencer, & Harpalani, 2003; Orellana & Bowman, 2003). That is, culture influences and is influenced by human learning and development. Given this, scholars continue to advocate for cultural considerations in the design, teaching, learning, and assessment of content area knowledge (Hood, Hopson, & Frierson, 2005; Swartz, 2009; Warikoo, 2009). This advocacy for the integration of culture seems to have made advances in school aged STEM (science, technology, engineering, and mathematics) related literature and in higher education literature on e-learning.

This section begins first with an overview of theoretical perspectives and paradigms. This is followed by studies and literature reviews in mathematics education, science education and e-learning education. Suggestions about the meanings of the literature are provided throughout.

Perspectives and Paradigms

Theoretical perspectives and learning paradigms that grounded the research in mathematics, science, and e-learning education were diverse. The mathematics education studies situated their research on learners knowledge constructions through social interaction and artifacts (Leont'ev, 1978; Vygotsky, 1978), communities of practice (Lave & Wenger, 1991; Wenger, 1998), cooperative learning and the Confucian

Heritage Culture as advocated in Chinese philosophy (Chang, Hsiao, & Barufaldi, 2006). The science education studies situated their research in sociocultural theory positioning science as a cultural and social process (Aikenhead, 2006) that needs further understanding through human learning, action and development (Cole, 1996; Vygotsky, 1978; Wertsch, 2002). Other science education perspectives and paradigms included the following: cultural historical activity theory that places learners in historical and cultural contexts (Rogoff, 2003), critical and emancipatory theory for the liberation of learners (Freire, 1993), identity as a lens to understand ethnicity, gender and culture (Gee, 2001), cognitive paradigms that allow science learners to explain and predict (Ioannides & Vosniadou, 2002; Wellman & Gelman, 1992), and constructivist paradigms where the learner builds upon prior knowledge (Vygotsky, 1978). The e-learning education studies situated their research in Hofstede et al.'s (2010) five dimensions of culture (i.e., power distance; individualism vs. collectivism; masculinity vs. femininity; uncertainty avoidance; long vs. short term orientation) or general e-learning research. This diversity of theoretical perspectives and paradigms suggests that research about culture and learning can be situated in a multiplicity of ideologies.

Mathematics Education

An analysis of recent studies in the areas of culture, learning, and mathematics reveals a focus on what learners already know as a basis to build mathematical competency. What learners know is articulated as prior understandings (Taylor, 2009); prior knowledge (Hurley, Allen & Boykin, 2009; Leonard, Davis, & Sidler, 2005); or foundational knowledge (Ni, Li, Li, & Zhang, 2011). Collectively, these studies also sought to fill a gap in the mathematics education research.

Several studies administered multiple evaluations to determine learning outcomes. The first evaluation obtained data specific to the learner's cognitive abilities as they engaged in mathematical concepts. Mathematical concepts included calculations and explanation skills (Ni et al., 2011; Wong, 2002); estimation (Hurley et al., 2009); whole numbers (Taylor, 2009) problem solving, word problems and basic geometry (Leonard et al., 2005). The second evaluation obtained learning outcomes data as measured through factors such as behavior, affect, and conceptions. Behavior was measured through learners involvement, communication, participation and affect (Hurley et al., 2009). Leonard et al. (2005) examined behaviors related to tasks, social interactions, dispositions and problem solving. Learning outcomes were also measured through affective factors such as learners' dispositions and interests towards learning mathematics (Ni et al., 2011). Wong (2002) examined learners conceptions to hypothetical mathematical situations to illicit learner feedback on whether performing mathematics was required of the mathematical equation. This suggests that it is important to evaluate mathematical learning outcomes based on cognitive (i.e., knowledge), anthropological (i.e., behavior) and psychological (i.e., affect) states of the learner. Thereby a more holistic portrait of the learner can be fully assessed and accessed.

China and Mathematics Education

Studies from China focused explicitly on the preservation of the Chinese culture. By example, Ni et al. (2011) reported that the goal of the study was to determine whether a new curriculum weakened the foundation of Chinese mathematics particular to mathematical concepts and mathematical skills. In this study and Wong's (2002) the performance of students in mathematical assessments, the culture of schools, and curriculum materials were all intricately tied to the maintenance of the Chinese culture and China's global leadership in mathematics. This suggests that the academic achievement of learners and the maintenance of the nation are intricately tied to the culture of China.

Reviews in Mathematics Education

The role of culture in the learning of mathematics is significant (Eglash, Bennett, O'Donnell, Jennings, & Cintorino, 2006; Ernest, 2009; Leonard, 2008; Martin, 2009; Mukhopadhyay, Powell, & Frankenstein, 2009; Swetz, 2009) enough that it should change the course of teaching, instruction, curriculum and learning theory. Understanding learners can pave the way for understanding human learning across contexts.

Reviews of literature in the learning of mathematics for ethnically diverse populations conclude that culture is integral to the learning of mathematics and learners understanding of mathematics (Kaahwa, 2011; Melis, Goguadze, Libbrecht, & Ullrich, 2011; Ng & Rao, 2010). It is suggested that mathematical language, notations and notions (i.e., story contexts) should be specific to the culture of the learner (Kaahwa, 2011; Melis et al., 2011; Ng & Rao, 2010). In particular, the use of the native language of learners, for the teaching of mathematics content, assists in improving mathematics knowledge. Ng and Rao's (2010) review of literature revealed that the Chinese oral and written language for numbers provided a simpler system to learn counting especially with numbers above ten. These findings disclosed the mathematical advantages and higher achievement of Chinese learners in early grades and beyond based on the Chinese language and other cultural nuances (e.g., days of the week and months are referred to as numbers—Weekday No. 1 or tenth month).

Learners bring their ways of interacting, observing, problem solving, and thinking. These ways of being, seeing, thinking and doing in the world are culture-based and can be utilized to develop instructional methods, avenues for learning, and bridging home and school contexts (Kaahwa, 2011; Leonard, 2008; Moschkovich & Nelson-Barber, 2009). Learners bring their cultural stories and these stories can provide contexts for learning (Gonzalez et al., 2005; Kaahwa, 2011). Kaahwa (2011) used cultural artifacts in teaching mathematics. These cultural artifacts would be evident in the learner's communities (e.g., bean pods in Uganda), thereby bridging home and school learning. The Algebra Project, an urban middle/high school alternative curriculum, drew on the sociocultural and linguistic world of learners to bridge understanding and computing mathematical concepts (Moses, West, & Davis, 2009). According to Moses et al. (2009) the path to learning is enabled through learner's native language articulations and personal experiences that translate into written form and then further articulated into written and verbal mathematical concepts.

Culture-specific learning or framing mathematics learning in a local context signals a valuing of the learners culture, provides a conceptual foundation to build content knowledge (Moses et al., 2009), and validates the local community and its knowledge (Barta & Brenner, 2009). Ethnomathematics exemplifies the use of indigenous or nondominant knowledge to explain and teach mathematics (Eglash et al., 2006). Contrary to this research, Meaney (2002) found that the inclusion of mathematical practices from indigenous cultures presents some areas of concern such as: loss of cultural intent and a focus on more Western dominance.

Nasir, Hand, and Taylor's (2008) comprehensive review of mathematics literature that related to the role of culture in teaching and learning argues that mathematical concepts must be presented to learners in a context that reflects their lived experiences and that these contexts for learning be generated through "conversations and shared experiences (p. 226)." Intersubjectivity or a third space (Gutierrez, Rymes, & Larson, 1995) is offered as a way to bring together cultural knowledge (knowledge acquired outside of school settings) and domain knowledge (knowledge prescribed by math educators) into a hybrid space for discourse about mathematics. Nasir et al. (2008) further argue that these experiential practices should socially and conceptually support deep learning of mathematics and build positive identities for math learners. Math knowing is a "cultural activity, math learning" is a "cultural enterprise, and math education" is a "cultural and political activity (p. 227)."

Similarly, Lipka, Yanez, Andrew-Ihrke, and Adam (2009) argue for a "third way" that is a combination of knowledge and pedagogy – both local and Western. The idea behind the third way is to increase motivation and provide access to the instructional material. Through these curriculum and pedagogical changes both methods as reported by the researchers show improved academic performance as represented by empirical studies (Lipka et al., 2005).

All knowledge (Nasir et al., 2008), curricula, and pedagogy (Lipka et al., 2005) is culture-based. However, whose culture is this knowledge, curricula, and pedagogy based on? Culture-based mathematics education, in the USA in particular, seeks to provide a voice for the marginalized that is as privileged as the dominant cultures (Lipka et al., 2005).

The mathematics education reviews call for a more inclusive examination of how culture influences and is influenced by the learner. It is a rallying call to serve the needs of the few and the many. The lived experiences of learners seem to be the core of this cultural thrust and to use learners lived experiences as a conduit to more culture-specific learning applications.

Science Education

An analysis of studies in the areas of culture, learning, and science reveals a focus on equity, identity, and agency to build scientific competency in marginalized populations living in the USA (Barton, Tan, & Rivet, 2008; Basu, 2008; Brown, 2004; Carlone et al., 2011; Elmesky, 2011; Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008; Lynch, Kuipers, Pyke, & Szesze, 2005; Polman & Miller, 2010; Rivet & Krajcik, 2004; Schademan, 2011; Seiler, 2001; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). The focus on equity, identity, and agency is learner centered with the intention to improve academic achievement.

Equity: Equity is not about offering the same educational experiences, content, instruction, etc. to youth based on their age, gender, race, ethnicity, or socioeconomic status. Equity is about providing the knowledge base, specialized skills, and diverse worldviews needed to succeed in a global economy (Jordan, 2010). In the science classroom, equity allows all students to contribute, participate and perform equally. A hierarchy of race, class, gender, privilege, language, dialect, or difference does not exist (Brown, 2004; Carlone et al., 2011; Jayaratne, Thomas, & Trautmann, 2003; Lynch et al., 2005; Schademan, 2011). This includes the acceptance of diverse learners' ways of knowing, articulating, thinking and what they bring to science (Elmesky, 2011; Schademan, 2011; Warren et al., 2001).

Equity can be achieved through the identification, examination, and elimination of inequitable practices enacted, in educational environments, against minority learners in science classrooms (Carlone et al., 2011; Polman & Miller, 2010). Minority learners' "scientific literacy" has been a source of cultural conflict (Brown, 2004) as their science discourse may offer alternative perspectives than "mainstream" expectations.

Other equity issues relate to the curriculum and educational access. Conflicts exist in the one size fits all curriculums that do not meet the needs of diverse student populations (Lynch et al., 2005). Access to scientific knowledge has been denied to ethnic youth in US public schools. This denial is exhibited through the lack of access to high level science courses (Gollub & Spital, 2002), scientific literacy, and qualified science teachers (Barton et al., 2008).

Identity: Identity is tied to how learners perceive themselves amongst others. In the science classroom, these culturally produced meanings of self can be positive or negative and can influence scientific learning and interactions (Barton et al., 2008; Brown, 2004; Carlone et al., 2011; Polman & Miller, 2010; Schademan, 2011). That is, cultural conflict as manifested through science discourse can challenge or create conflicts that prohibit learning (Brown, 2004). Learners, in the science classroom, need to be able to see themselves as successful and as someone who can be identified as a "scientist" (Carlone et al., 2011; Elmesky, 2011; Warren et al., 2001). Learners cultural commodities are their forms of capital that needs to be respected and valued (Seiler, 2001). By example, Basu (2008) found that when given the freedom to create their own conceptions of physics, high school students situated their understandings of science in their identities; specifically, they enacted lessons through how they understood science and how science aided them in achieving their goals.

Agency: Agency in the science classroom is enacted through learners participation in the act of scientific thinking, being able to engage in science practices that promote learning, feeling comfortable enough to verbalize scientific understanding, and bringing the culture of themselves into the mix. Research studies report that agency is performed when learners feel empowered by their cultural knowledge (Schademan, 2011); express their identity through scientific enactments and articulations (Basu, 2008), and build cultural capital and affiliations with others based on engaging in the act of cultural practices (e.g., African American students used hip-hop culture and developed a rap about the speed of sound as a path to understanding science and expressing identity) (Elmesky, 2011).

These studies found equity, identity, and agency to be important issues in better meeting the academic needs of marginalized groups. This suggests that there are social, political, and economic issues that must be addressed concurrently with the academic issues in order to provide a learning environment where equity is provided, identity supported, and agency given.

Interventions in Science Education

Several studies conducted science interventions with ethnically diverse populations of learners to examine learning gains and considerations of culture in the design of a curriculum unit and professional development materials. Rivet and Krajcik (2004) developed the Big Things program that focused on a sixth grade project based science curriculum with learning technologies and real-world applications that would be of interest to urban youth. Students showed improvement; however, learning gains were not as high as expected.

Lynch et al. (2005) used a "highly rated" preexisting middle school science curriculum called Chemistry That Applies (CTA) with the goal of better understanding student learning and the implementation of CTA in an ethnically diverse setting. In the overall study, academic gains were realized in the content area assessed; however, the impact of the curriculum on a small group of ethnically diverse students was inconclusive.

Lee et al. (2008) developed a science and professional development intervention for elementary school teachers that sought to promote science achievement in English Language Learners. For example, the curriculum integrated science terms in English, Spanish, and Haitian Creole, included teacher guides about misconceptions and disconnects that students encountered with the curriculum, provided literacy development for English Language Learners in their native language, and used multiple modes of communication to educate the learner (e.g., visual, kinesthetic, textual). Overall, students demonstrated a significant improvement in science achievement and performed better on high stakes testing.

These science education interventions demonstrate the need to find new ways to educate all. In particular, the inclusion of more culture-specific content into academic disciplines like science have the potential to improve learning gains for ethnically diverse learners and provide an avenue to truly educate the underserved.

International Studies in Science Education

International studies in science education focused on how learners learned through scientific reasoning (Ozdemir & Clark, 2009; Robottom & Norhaidah, 2008), learning preferences (Chang, Hsiao, & Chang, 2011), and different learning environments (Chang, Hsiao, & Barufaldi, 2006; Chang & Tsai, 2005). Other studies examined affective factors related to beliefs, feelings (Robottom & Norhaidah, 2008), and attitudes (Caleon & Subramaniam, 2008; Chang, Hsiao, & Barufaldi, 2006) of learners engaged in science education.

Consistent across these studies is the use of large sample sizes of students from upper elementary to high school age levels (Caleon & Subramaniam, 2008; Chang, 2005; Chang, Hsiao, & Barufaldi, 2006; Chang, Hsiao, & Chang, 2011; Chang & Tsai, 2005; Robottom & Norhaidah, 2008). Further, the methodology sections of these papers reveal the development of an instrument to measure epistemological beliefs about science (Robottom & Norhaidah, 2008), actual and preferred learning environments and teaching methodologies (Chang, Hsiao, & Barufaldi, 2006; Chang, Hsiao & Chang, 2011; Chang & Tsai, 2005), general attitudes towards science (Caleon & Subramaniam, 2008), and understandings and appreciations of humans to nature (Chang, 2005).

International studies in science education advocate for a science curriculum that is indicative of learners lived experiences (Chang, 2005; Lewthwaite et al., 2010). By example, the Taiwanese Science and Life Technology Curriculum Standards and Earth Systems Education are curriculums that focus on helping learners apply science in their daily lives (Chang, 2005). Chang, Hsiao, & Barufaldi's (2006) findings argue that student's cultural histories and identity should be considered when designing learning environments. Chang and Tsai (2005) begin to exemplify the inclusion of the Chinese culture by redesigning an American instrument into the Chinese Constructivist Learning Environment Survey. Ozdemir & Clark (2009) found that Turkish elementary, middle, and high school aged students varied greatly in their understandings of the concept of force due to their diversity. That is, student's cultural diversities (i.e., language, understandings, education) attributed to their varied interpretations and meanings of science education content. Robottom and Norhaidah's (2008) research of Islamic learners further supports the notion that learners meanings of science are shaped and constrained by their culture.

The international studies in science education demonstrate a focus on how learners learn but in particular how learners feel about the learning experience. Further there is a focus on learners lived experiences. This suggests that there are psychological (i.e., beliefs, feelings, attitudes, reasoning) and anthropological (i.e., lived experiences) factors to better understanding learning. Studies about learning require more of a holistic orientation to get at the intricacies of human learning that manifest through learner's engagement with their culture.

Worldviews on Science Education

Worldviews on science education argue that there is a space and place for indigenous knowledge and global perspectives that get at other ways of knowing, being and seeing the world within science education. The point is to bring equity into science education through the inclusion of indigenous and marginalized groups' worldviews and perspectives of science and provide these groups with successful science learning opportunities (Aikenhead & Ogawa, 2007).

Studies in science education research argue that Western science education fails to serve the needs of indigenous and marginalized groups due to its (1) epistemological conflicts, (2) irrelevance to lived experiences, (3) domination of Western science and scientific thought (Brayboy & Castagno, 2008), and (4) inability to meet their social needs (Mutegi, 2011). A harmonizing science education that honors two ways of learning from the Western worldview and the indigenous worldview is believed to best serve the needs of the Inuit communities in the Northern Qikiqtani region of Nunavut (Lewthwaite & McMillan, 2007), Māori communities of Aotearoa New Zealand (Wood & Lewthwaite, 2008), and Zulu communities of Chibini, South Africa (Keane, 2008).

Emdin (2010) promotes the inclusion of students lived experience through hip-hop culture as a tool to connect learners to science education; his work continues to explore other urban science education conceptualizations such as neo-indigenous, communal practices and rituals (Emdin, 2007a, 2007b; 2009). Mutegi (2011) advocates for a socially transformative curriculum approach that is particular to the African Diaspora experience and at the core it asks African American students to understand their colonial status, colonialism, and their colonizers.

Lewthwaite et al. (2010) argue that expressions of local and indigenous content in science education can only come through policy and leadership that supports "culture-based education programs" (p. 1). Culture-based education, as endorsed by the Government of Nunavut, Canada, provides children with educational content and experiences that affirms and reflects the Nunavummiut culture; in particular this culture-based education should be integrated throughout the school management, operations, curriculum, pedagogy, and programs.

It is evident that indigenous and marginalized groups around the world are seeking to preserve and document their knowledge, ways of being, identity, etc.—that is their culture. Further, they seek to capture their culture and use it as an instructional tool to advance the academic achievement of children and youth. Some of these cultures chose to exclude all Westernized and Eurocentric interference others seek to find a middle ground where both indigenous and European worldviews can be learned in harmony.

International Perspectives in E-Learning

An analysis of empirical research in the areas of culture, learning, and e-learning reveals predominately a focus on international learners in higher education settings. These studies seek to quantify and qualify learners based on their perceptions about e-learning (Jung, 2011; Ku & Lohr, 2003; Liu & Magjuka, 2011; Wang, 2007), attitudes towards e-learning (Ku & Lohr, 2003; Thompson & Ku, 2005), behaviors (participation and usage) while engaged in e-learning (Yang, Olesova, & Richardson, 2010; Zhao & Tan, 2010), communication styles during e-learning (Yang et al., 2010), and critical thinking in an e-learning environment (Al-Fadhli & Khalfan, 2009).

The studies covered in this review all examined some aspect of culture; however, some research made explicit cultural concerns such as: cultural differences (Chase, Macfadyen, Reeder, & Roche, 2004; Yang et al., 2010), cultural influences (Hannon & D'Netto, 2007; Ku & Lohr, 2003; Zhao & McDougall, 2008), cultural barriers (Hannon & D'Netto, 2007), and cultural orientations (Wang, 2007). Ultimately, it seems that there is concern about how culture influences the learner and learning in an e-learning environment.

The methodological approaches of the e-learning research demonstrate the dynamics of evaluating culture within an e-learning environment. Across the studies, the participants varied greatly in terms of race and ethnicity (e.g., Chinese, Australian, Eastern Slavic, American, etc.); however, all of the studies focused on international higher education aged learners. Sample sizes varied from 6 to 299 participants. The analyses considered qualitative, quantitative, and mixed methods (Al-Fadhli & Khalfan, 2009; Chase et al., 2004; Hannon & D'Netto, 2007; Jung, 2011; Ku & Lohr, 2003; Liu & Magjuka, 2011; Thompson & Ku, 2005; Wang, 2007; Yang et al., 2010; Zhao & McDougall, 2008; Zhao & Tan, 2010). Most of the studies administered research specific surveys, except Liu and Magjuka (2011), Thompson and Ku (2005), and Zhao and McDougall (2008) who conducted interviews. Chase et al. (2004) analyzed content from the courses' online discussion board and Al-Fadhli and Khalfan (2009) administered a critical thinking test. This suggests that multiple methodologies of analyses have been effective in evaluating culture and learning within an e-learning environment.

The findings of culture, learning, and e-learning research indicate that learners are influenced by what they learn, how they learn, how much they learn, when they learn, where they learn, and their culture. The e-learning environment in-turn influences how learners reacted and responded through their perceptions, attitudes, and behaviors—ultimately their culture.

The most emphasized findings across the studies focused on technology, synchronous and asynchronous learning, communications, and the instructor. Overall, the technologies used in e-learning environments failed to support e-learners, serve the cultural and international needs of groups and only highlighted Westernized styles (Chase et al., 2004; Wang, 2007). Cultural issues such as technology experience and differences in cultural backgrounds were not addressed by the technology or through technological supports (Hannon & D'Netto, 2007). A more personalized technological environment is suggested to better improve e-learning environments (Jung, 2011).

Synchronous and asynchronous e-learning environments should better support users. E-learning environments should consider the cultural variability of learners and learning to better address the needs of learners (Jung, 2011; Liu & Magjuka, 2011; Wang, 2007; Yang et al., 2010; Zhao & McDougall, 2008). Asian students in particular found that asynchronous environments allow them time to reflect, think, and learn more (Wang, 2007; Zhao & McDougall, 2008).

Communicating in e-learning environments is a great concern of researchers because learning is supported through communication. Culture affected the way learners approached and responded in the e-learning environment, to classmates and with the instructor (Jung, 2011; Wang, 2007; Yang et al., 2010). Cultural issues were apparent in ways of communicating (Chase et al., 2004; Hannon & D'Netto, 2007; Liu & Magjuka, 2011; Wang, 2007; Zhao & McDougall, 2008), values, language, and learning preferences (Ku & Lohr, 2003); and participation behaviors (Yang et al., 2010).

The power dynamics between teacher and learner is culturally shaped and it influences learner's interactions with the e-learning environment (Chase et al., 2004). Several studies found that Chinese learners operated on the cultural belief of instructor as knowledge source and that these expectations carried into the e-learning environment. When instructors did not respond with these cultural expectations, the learner and learning experience were disengaged (Ku & Lohr, 2003; Wang, 2007; Zhao & McDougall, 2008).

Culture influenced how learners performed and persisted in an e-learning environment (Wang, 2007). Of note, the studies that focused on perceptions and attitudes included participants who were Asian (i.e., Chinese, Korean) (Jung, 2011; Ku & Lohr, 2003; Liu & Magjuka, 2011; Thompson & Ku, 2005; Wang, 2007; Yang et al., 2010; Zhao & McDougall, 2008). This may be significant in that this research finds the analysis of the psychology (e.g., perceptions, attitudes, beliefs) of the learner as important as the anthropology (e.g., behavior, etc.). That is, learning in an e-learning context may require both an analysis of psychological and anthropological factors to best access the intricacies of human learning.

Reviews in E-learning

Reviews of literature in e-learning focus on nation building, formulating frameworks that support sociocultural learning and considering diverse learning needs. Nation building through e-learning involves competing with global economies; educating, preparing, and supporting the countries human capital (Perkins, Gwayi, Zozie, & Lockee, 2005); building and supporting information technology infrastructures; and creating an environment that fosters knowledge construction (Kim & Santiago, 2005). Further, the act of nation building is very particular to the maintenance of culture. Frameworks, models, and guidelines that support e-learning center on knowledge development, building community, supporting learners, considering culture (Gunawardena et al., 2004; Gunawardena et al., 2006; Taylor, 2005), identifying manifestations of culture in e-learning (Gunawardena & LaPointe, 2008), and evaluating e-learning courses (Edmundson, 2007). Considering the needs of learners means making allowances for their diverse learning approaches (Alias, 2011); attributes and contexts and conditions for learning (Mitchell & O'Rourke, 2008).

It seems that this e-learning research is very much focused on the needs of the learner and how the learner can support country and ultimately their culture. This research suggests that there is much improvement needed to address the international higher education learner in an e-learning environment.

Implications

There are growing concerns across disciplines that learners, from children to adults, need a more specialized education to meet their academic needs. In the twenty-first century, this should not be an issue with the wealth of information, multiple means of literacy outlets and the technological resources available. The present methods and strategies that are being used fail to appropriately address the needs of all learners. Therefore, there is a need to rethink and rebuild curriculum, instruction, theories, methodologies, etc.

This research sought to examine international research in the areas of culture, learning, and mathematics, science and e-learning education to determine relevant instructional strategies in this context. The implications of this literature review indicate the following:

- Explicit instructional strategies that enable learning do not exist for ethnically diverse populations in the USA. Innovative instructional strategies must be derived from versus applied to learners.
- Research about learners should be more broadly structured to include anthropological and psychological factors to acquire a more holistic picture of the learner and their learning. This holistic picture aids in building learning applications that are culture-specific and more appropriately aligned to learner needs.
- Methodologies of analysis vary; however, ethnographies seem to capture a more holistic picture of the learner and more specifically their culture. By example, 10 of the 12 science education studies employed ethnographic methods to acquire information about the learner (Barton et al., 2008; Basu, 2008; Brown, 2004; Carlone et al., 2011; Elmesky, 2011; Lynch et al., 2005; Polman & Miller, 2010; Schademan, 2011; Seiler, 2001; Warren et al., 2001). The collection of ethnographic data can include videotapes, observations, assessments, interviews (Carlone et al., 2011), group interviews, content-based think-alouds, reflection notes, student work, informal conversations in and out of school; social gatherings (Barton et al., 2008); and archival documents (Basu, 2008).
- Multiple assessment methods may be needed to get at academic and affective learning. There is a need to determine if learning is happening and if so in what ways and why. Determining how learners feel about the academic experience may be as important as their academic progress.
- Instructional strategies that are derived from human interactions will prove the most valid in designing curriculum, improving e-learning environments, making learning happen, knowledge construction, and improving academic gains.
- Building on the life experiences of the learner seems to be the nexus of moving towards more culture-specific applications. This need to situate learning in the life experiences of the learner is supported by mathematics education research, science education research, and e-learning education research.

Conclusion

Culture matters in the selection of instructional strategies. However, it is better to assess the learner to let the educational strategies be derived from the learner versus applied arbitrarily to the learner.

A variety of research has been excluded because of space constraints or content. Studies that focused on teachers versus learners were excluded or minimally highlighted to maintain the focus of the chapter on learners. Some of this research examined what instructors should do in relation to culture, learning, and science education (Emdin, 2007a, 2007b; Lewthwaite et al., 2010; Milner, 2011; O'Neill, 2010), math education (Civil, 2002; Correa, Perry, Sims, Miller, & Fang, 2008; Gutstein, 2003; Lipka et al., 2005; Leonard, Brooks, Barnes-Johnson & Berry, 2010; Seah, 2002), and e-learning education (Burniske, 2003; Goold, Craig & Coldwell, 2007; Sánchez-Franco, Martínez-López, & Martín-Velicia, 2009).

Culture, learning and computer technology education offers another area for in-depth study. This research examines a variety of issues such as the following: global knowledge in local contexts, instructor focused concerns, perceptions of using technology, the role of technology in cultural change, ethnically diverse learners, technology enhanced learning, and technology integration (Aydin & McIsaac, 2004; Chitiyo & Harmon, 2009; Ezer, 2006; Gudmundsdottir, 2010; Heemskerk, Brink, Volman, & Dam, 2005; Hornik & Tupchiy, 2006; Lee, 2003; Lieberman, 2008; Lim, 2007; Luck & Peng, 2010; Olaniran, 2009; Robbins, 2007; Swigger, Alpaslan, Brazile, & Monticino, 2004; Zhang, 2007, 2010; Zhao, Zhang, & Tan, 2010).

The areas of culture, learning and instructional design provide guidance in educating diverse populations. This research examines a variety of issues such as: ethnically diverse learners, culture-specific curriculum content, multiculturalism, cultural diversity, culture-specific pedagogy, indigenous languages and knowledge, and designing in cross-cultural contexts (Amiel, Squires, & Orey, 2009; Campbell, Schwier, & Kanuka, 2011; Frederick, Donnor, & Hatley, 2009; Igoche & Branch, 2009; Joseph, 2009; Kinuthia, 2007; Leonard, 2008; Russell, 2011; Scott, Aist, & Hood, 2009; Thomas & Columbus, 2009; Young, 2009).

Future research in culture, learning, and a discipline might examine the literature coming from Human Computer Interaction and game design. These disciplines are growing in these areas and finding innovative ways to educate learners through information and communication technologies.

Of course, it is possible to miss some important studies or reviews of literature. This chapter has tried to locate a representative sampling of what has been published in the last decade.

If culture matters in educating learners in mathematics and science education, why has there been little movement in North America to design learning technologies to meet the needs of marginalized groups? If e-learning systems do not meet the needs of international populations why have not e-learning companies accommodated to the needs of these groups? Why has culture been ignored?

It seems that considering culture in the development of instructional strategies is only part of a complicated equation to educate learners. There are many factors that must be seriously considered. Situating the learner at the center of this nexus is a place to begin.

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Learning Ability Development in Flexible Learning Environments

29

Saskia Brand-Gruwel, Liesbeth Kester, Wendy Kicken, and Paul A. Kirschner

Abstract

Education has come to recognise the importance of the development of learning ability, that is, the acquisition of self-directed learning (SDL) skills and self-regulated learning (SRL) skills, because these skills equip students for functioning in our constantly changing society as life long learners. To give students the opportunity to develop these skills a flexible learning environment is needed. Such an environment enables learners to determine more or less personalised learning trajectories for themselves. Moreover, a flexible learning environment should be designed in such a way that the acquisition of SRL and SDL skills is supported. In this chapter after addressing the concept of learning ability or more specifically the concepts of SRL and SDL and the way the two are intertwined, the basic elements needed in the design of a flexible learning environment are discussed. The need for well-structured learning materials, assessment criteria, portfolios, advisory models and instructional support for acquiring SRL and SDL skills is discussed.

Keywords

Learning ability • Self-direct learning • Self-regulated learning • Flexible learning environments

Learning Ability Development in Flexible Learning Environments

This chapter discusses flexible learning environments (FLEs) that foster the development of learning ability, that is, the acquisition of self-directed learning (SDL) skills and self-regulated learning (SRL) skills. A flexible learning environment refers to an environment in which learners are able to follow their own learning trajectory given the formal learning goals. Concisely stated (as this is discussed extensively in the rest of this chapter), SDL encompasses the ability to formulate learning need, determine learning goals and select learning resources. Moreover, SRL is the ability to monitor and steer own learning processes. Education has come to recognise the importance of SDL and SRL. It is important because these skills equip students for functioning in our constantly changing society as life long learners. To give students the opportunity to develop these skills in education a flexible learning environments is needed in which a student can follow their own learning trajectory and get the support needed to create the most optimal learning path. Such an environment enables learners to have choices in term of what, where, when, why and how they learn (Hill, 2006). Based on formulated learning needs and learning goals learners should be able to identify human and material resources for learning in a flexible learning environment. In this way, such an environment enables learners to determine personalised learning trajectories given the formal learning goals. But just given the learners the opportunity to choose is not

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recommended, because research shows that learners are not always capable of making substantiated, appropriate, and effective choices (e.g. Williams, 1996), resulting in ineffective learning and low transfer of learning. So, we argue that a flexible learning environment can be a good starting point to encourage learners to become self-directed and self-regulated learners. But the support and guidance given in the environment to the learners in acquiring these skills and make appropriate choices seems essential.

A flexible learning environment differs from what is called an adaptive learning environment. In an adaptive environment the learning trajectory and learning materials are personalised, but the system does this for the learner. Adaptivity can be defined as the capability of *a system* to alter its behaviour according to the learners and other characteristics (Vandewaetere, Desmet, & Clarebout, 2011). The "system" could be a teacher, a trainer, an intelligent agent or tutor, etc. In any event, the system adapting the materials and trajectory to the learner is not the learner herself/himself and thus the learner cannot develop the needed SRL and SDL skills in such an environment, unless the "system" decides the environment should allow flexibility.

This chapter outlines the basic elements needed in the design of an FLE. The need for well-structured learning materials, assessment criteria, portfolios, advisory models and instructional support for acquiring regulation skills is discussed. But before we go into that, we address the concept of learning ability or more specifically the concepts of SRL and SDL and the way the two are intertwined. The chapter concludes with a discussion section in which theoretical and practical implications are addressed and directions for future research are given.

Learning Ability

Learning ability is related to SDL and SRL. The SRL and SDL skill can be referred to as higher-order skills, skills overlooking and governing the cognitive system, while simultaneously being part of it (Veenman, Van Hout-Wolter, & Afflerbach, 2006). In the literature, SDL and SRL are often difficult to distinguish from each other with confusion being the result. The constructs are regularly used interchangeably (Boekaerts & Corno, 2005; Bolhuis, 2003; Dinsmore, Alexander, & Loughlin, 2008), often no precise definitions are given and a variety of related terms (e.g. autodidaxy, SDL, independent study, SRL, self-planned learning, self-guided learning and learner control) is used to indicate both constructs (Brockett & Hiemstra, 1991). Moreover, SDL and SRL are complex constructs that focus on different aspects of the learner and her/his learning processes (e.g. motivational or cognitive processes, organisation of learning). Although the constructs are closely related, they differ in theoretical background as well as empirical methods to study them and, therefore, should not be used interchangeably.

Self-Directed Learning

SDL is described by Knowles (1975) as "a process in which individuals take initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes" (p. 18). Although the concept of SDL was introduced in adult education, Knowles pointed out that SDL does not exclusively apply to adults. Brockett and Hiemstra (1991) developed a conceptual framework for understanding SDL called the "Personality Responsibility Orientation" with personal responsibility as the starting point for SDL. In their view, individuals need to be owners of their thoughts and actions and should have—or be willing to take—control over how to respond to a situation and make choices concerning their learning process without ignoring the social context. The freedom to make choices implies that learners need to be able to make good choices during their learning process (Brockett, 2006), and must be responsible for the consequences of their thoughts and actions. Self-directed learners, thus, are able, ready and willing to independently prepare, execute and complete learning (Van Hout-Wolters, Simons, & Volet, 2000).

Different authors have described characteristics of a skilful self-directed learner. These include initiative, intentions, choices, freedom, energy and responsibility (Tough, 1979, in Levett-Jones, 2005), the ability to learn on one's own, personal responsibility for the internal cognitive and motivational aspects of learning (Garrison, 1997), independence, autonomy and the ability to control one's own affairs (Candy, 1991). These characteristics stress a key aspect of SDL, namely, that the learner determines the planning and execution of her/his learning trajectory in the long term. Therefore, as stated by Jossberger, Brand-Gruwel, Van de Wiel, and Boshuizen (2010) SDL can be situated at the macro level and concerns the person's learning trajectory as a whole. Self-directed learners are able to decide what needs to be learned next and how their learning can best be accomplished. Skilful self-directed learners can—based on an evaluation of previous learning—diagnose their own learning needs, formulate learning goals, and identify and choose human and material resources for learning, and determine appropriate learning strategies (cf. Kicken, Brand-Gruwel, Van Merriënboer, & Slot, 2009; Knowles, 1975).

Self-Regulated Learning

SRL, in contrast, functions on a micro-level and concerns processes within the execution of a specific learning task. It is argued (Jossberger et al., 2010; Loyens, Magda, & Rikers, 2008) that while SDL includes SRL, the opposite is not the case. In other words, self-directed learners are supposed to be able to also self-regulate their learning, but a self-regulated learner is not necessarily able to self-direct her/his learning.

SRL deals with subsequent steps in a learning process (Loyens et al., 2008). However, in the SRL literature there is a variety of perspectives on how cognitive, meta-cognitive, motivational and contextual factors influence the learning process (e.g. Boekaerts, 1997; Pintrich, 2003; Zimmerman, 2002). A well known and often used perspective is that of Zimmerman (1989, p. 329) who states that "students can be described as self-regulated to the degree that they are meta-cognitively, motivationally, and behaviourally active participants in their own learning process". Important in this citation is the word degree. The more the learner is intrinsically motivated, is learning in an active way and is metacognitively involved in the process the more self-regulated the learner is.

Zimmerman (2000, 2006) describes three phases and underlying sub-processes that involve behavioural, environmental, and covert self-regulation. The *forethought phase* is a preparatory phase where learners orient themselves to the learning task and plan the steps that need to be taken to carry out the learning task. Self-regulated learners analyse the learning task, set a clear goal, make a plan and select strategies for achieving the goal. Task demands and personal resources must be considered before beginning a task so that potential obstacles can be identified (Ertmer & Newby, 1996; Zimmerman, 2000, 2006). In the *performance phase*, monitoring and adjusting are central skills during the learning process. Monitoring is essential, as learners should be constantly aware of what they are doing by looking back at the plan and looking forward at the steps that still need to be performed to achieve the goal in mind. When learners realise that things do not work out as planned, they need to adjust their approach. In the final *reflection phase*, assessing and evaluating are key skills. After having carried out the task, learners evaluate the effectiveness and efficiency of the plan and of their strategy use (Ertmer & Newby, 1996; Zimmerman, 2000, 2006). Evaluating the process and reflecting on experience can increase learning from actual experience and can possibly be used in the future (Ertmer & Newby, 1996; Fowler, 2008). Reflection is, therefore, critical for the link between previous learning experiences and future learning experiences because a learner can, by reflecting, draw upon previous knowledge to gain new knowledge (Ertmer & Newby, 1996).

To conclude, learning ability is related to both SDL and SRL which are two distinctive types of learning that describe learning processes on a macro level (SDL) and on a micro level (SRL). Learning ability includes both SDL skills (learning trajectory level) and SRL skills (learning task level). In Fig. 29.1, the way the two skills are interrelated is visualised. As can be seen, the two skills act on different levels but

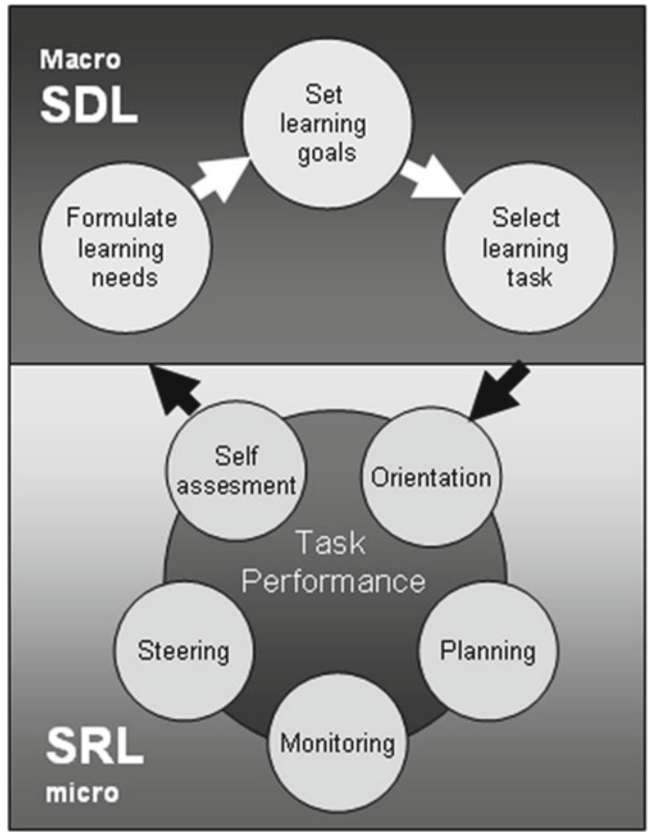

Fig. 29.1 Relation between self-regulated learning (SRL) and self-directed learning (SDL)

proper execution of both skills is needed to optimise the learning process. The outcome of the task performance and the assessment of the task helps learners to formulate learning needs and goals and to direct learning, and select tasks for future learning.

It is important to realise that guidance and support in these skills must be embedded in the domain specific content of the curriculum. As mentioned these skills are higher-order skills and Van Merriënboer (1997) assumes higher-order skills can only be trained in a particular domain. Furthermore he claims that "…if we want the strategic component of higher-order skills to transfer between domains, they should be trained in as many domains (or, courses) as possible and it should be made explicit to students that a higher-order skill that works in one domain may also work, or may not work, in another domain" (pp. 15–16). This promotion of mindful abstraction and decontextualisation of general principles of higher-order skills, is referred to as "the high road of transfer" (Perkins & Salomon, 1987). This assumption has its consequences for the way the instruction to acquire these skills should be designed. The next section discusses the design of an FLE and the instructional support that can be embedded in it to acquire these skills.

Flexible Learning Environments: Enabling Self-Directed Learning

As stated, a flexible learning environment is an environment that enables learners to make choices, select learning materials (e.g. subsequent learning tasks) and personalise their learning trajectory based on the formulated learning needs and learning goals. These needs and goals are based on the assessment of the previous performed learning tasks. Furthermore, we argue that a FLE should be designed in such a way that the acquisition of these skills is supported. The responsibility of the choices made in the learning environment can be gradually shift from the teacher (or intelligent agent) to a learner. When the learner acquired a set of well-developed SDL skills, the learner can be given full control and complete freedom to decide on the learning trajectory. But when the learner is not yet able to accomplish a self-assessment, formulate learning needs and goals, and select appropriate tasks, the teacher and learner should share the control. A flexible learning environment based on shared control is an environment where learners can learn to become self-directed in a guided way.

When designing a flexible learning environment the design elements necessary to foster SDL must be thoroughly considered. Based on the work of Knowles (1975) on SDL, of Zeichner and Wray (2001) on portfolio use, of Bell & Kozlowski, 2002 on enhancing self regulation, and of Tennyson (1980) on instructional strategies Kicken, Brand-Gruwel, and Van Merriënboer (2008) developed what they called the *informed self-directed learning* (ISDL) model in which three components or information resources are distinguished to support SDL skills development in an FLE. The elements are (1) learning tasks with metadata, (2) a development portfolio and (3) an advisory model. Figure 29.2 shows how these components are related in a learning environment with shared control. The components at the top of the figure (development portfolio, advisory model, task metadata) negate the major problem in many so-called flexible learning environments, namely, the learners' lack of information essential for successful SDL. The inclusion of the advisory model here is based on the empirical findings that learners often have not yet sufficiently developed their own SDL skills and, thus, need to be explicitly supported in developing them. The information provided by the development portfolio and task metadata is directly related to the activities of performance (self-) assessment, learning goal formulation, and resource selection (e.g. learning tasks) (Knowles, 1975). The rule bars indicate the amount of support given to the learner in order to perform the SDL-skills to a sufficient level and make adequate decisions on the learning trajectory. The model by Kicken et al. provides the basis for the development of a FLE.

The ISDL model implemented in an FLE supports a cyclical learning process. The learner selects one or more learning tasks from the task database, carries it/them out, gathers assessments of the task/tasks in the portfolio based on assessment criteria, selects one or more new learning tasks from the database taking the information in the portfolio into account, and so on. In each cycle, the updated information in the portfolio is used to formulate/reformulate individual learning

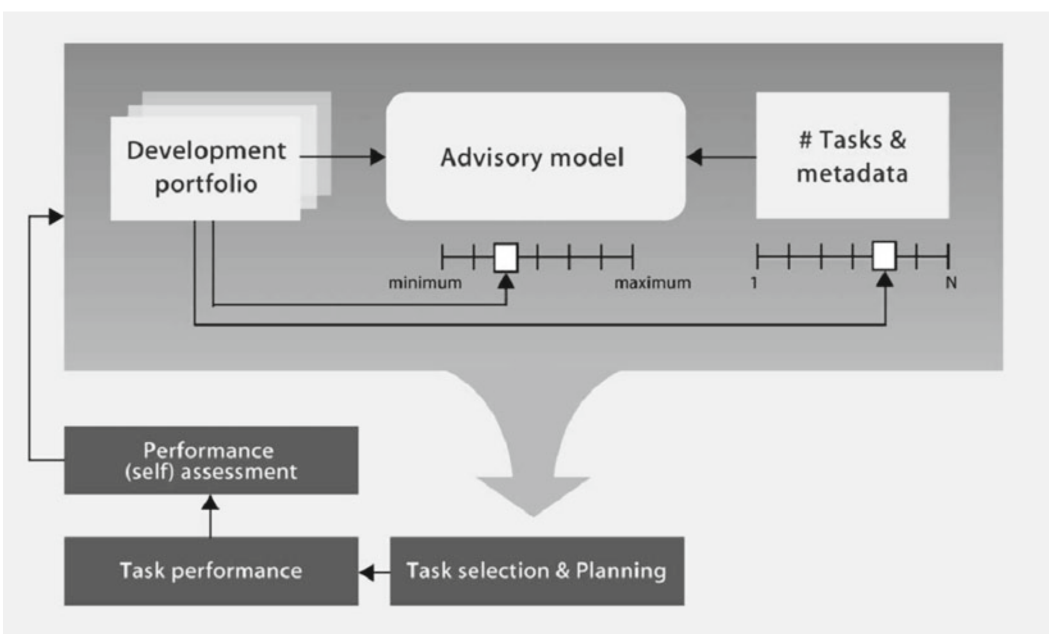

Fig. 29.2 The Informed Self-Directed Learning (ISDL) model (Kicken et al., 2008)

needs and set new learning goals to select suitable subsequent tasks. The teacher or computer system uses the coaching protocol based on the advisory model to support and guide the process of formulating learning needs, setting learning goals, and selecting new tasks and so optimises the development of both domain-specific skills and SDL skills. The model gives insight in the process of SDL but also provides information about the important design elements of the FLE. We briefly discuss the design elements and address research that has been conducted to concerning the models' elements.

Learning Tasks with Metadata

Learners should be supported in selecting new learning tasks according to their level of performance, because such a selection is a difficult aspect of SDL. When the learning environment is too open, providing learners with to many choices and too little guidance or advice to help them make appropriate decisions, it can lead to even negative effects on cognitive, metacognitive, and affective learning variables (Katz & Assor, 2007; Williams, 1996). Selecting new tasks or resources for learning must be learned by practising and receiving feedback on the quality of the selection process and the appropriateness of it. To help students to select appropriate tasks that fit their learning needs it is necessary that a large set of learning tasks is available. To select tasks from this set, learners should have the tasks' relevant metadata available (Bell & Kozlowski, 2002). These metadata can include the tasks' objectives, the skills that can be acquired, the task's level of difficulty and support provided, the applicable performance standards for determining whether the task has been carried out to a predetermined level, and the prerequisite skills, knowledge and attitudes necessary to perform it (Kicken et al., 2008). The goals and skills that can be acquired is of major importance, because taken the personal learning goals and learning needs one has to choose if the new tasks is in essence suitable.

Development Portfolio

A development portfolio, which can be electronic or paper-and-pencil, gives an overview of assessments of task performances and keeps track of the learning process by providing an overview (Kicken et al., 2008, 2009). Several studies reported that development portfolios are effective tools to help students reflect on their learning and to think about the development of their skills (Chen, Liu, Ou, & Lin, 2000; Driessen, van Tartwijk, Overeem, Vermunt, & van der Vleuten, 2005; Mansvelder-Longayroux, Beijaard, & Verloop, 2007; Zeichner & Wray, 2001). An important aspect in the assessments is the use of assessment criteria. These criteria should be specific and related to the learning goals of the task. The assessor(s) (e.g. teacher, coach, peer or intelligent agent) can put the assessment into the portfolio. In that case the learner and the teacher have an overview of the learners' progress. A development portfolio also allows the learner the opportunity—or can even require—that the learner bring his or her self-assessments into it. Finally, the portfolio can allow the comparison of these assessments. This kind of information make that learners acquire more experience in self-assessments, and can gain more insight in their progress or lack of progress (Birenbaum & Dochy, 1996; Falchikov & Boud, 1989). The assessments gathered in the portfolio and the information they provide on competency development offer a sufficient basis for identifying individual learning needs. The learning needs, formulated either by the learner or by the learner and the agent (e.g. teacher, tutor, peer, computer) in a shared control condition should also added into the portfolio. These learning needs can be related to the assessment criteria. Students are not used to think about or formulate their learning needs (Holme & Chalauisaeng, 2006), and therefore, it is important that learner perceive that assessments for a basis for formulating learning needs. Also the learning goals for future learning can be part of the portfolio; in this way the goals can be related to the learning needs and the tasks that can be selected to fulfil these learning needs.

Advisory Models

FLEs should make learners increasingly responsible for their own SDL process and advisory models can help teachers to integrate support on these skills in their education. Providing students with advice has shown to be an effective method to help students make better choices and develop their task selection skills (Bell & Kozlowski, 2002; Tennyson & Buttery, 1980). For giving advice the teacher can use different advisory models (Taminiau, Kester, Corbalan, Van Merriënboer, & Kirschner, 2010). A procedural advisory model provides the students with feedback on their self-assessment skills and formulated learning goals, by informing them whether the self-assessments are in line with expert assessments and the SMART rules. Feedforward is provided merely by informing learners which task(s) they could select in order to improve their performance. A strategic advisory model provides the learners with feedback on their self-assessments and self-formulated learning goals in terms of their accuracy and effectiveness, and provides directions for improvement of self-assessment skills and formulating learning goals. With respect to feedforward information, the directions for task selection are heuristic in nature and extend the basic information on suitable tasks with in-depth explanations and arguments for their suitability. A strategic model makes explicit how assessments of prior performance are interpreted and converted into directions for the selection of new learning tasks (Kicken et al., 2008).

Flexible Learning Environments in Practice

Kicken et al. (2009) investigated the effects of giving students specific portfolio-based advice on the development of their SDL skills in a flexible environment. In a flexible hairdressing programme in vocational secondary education, one group of students received feedback on their achievements while a second group received specific portfolio-based advice (i.e. feedback and feedforward) in regular supervision meetings. In the environment, learning tasks were of different complexity levels, were all authentic tasks and the tasks differed concerning the amount of support. To help students take responsibility for their own learning process and make effective choices, a web-based development portfolio called Structured Task Evaluation and Planning Portfolio (STEPP) was designed and implemented. STEPP has three functionalities, namely, helping students to (a) assess their own task performance using assessment standards and criteria, (b) formulate learning needs based on assessed shortcomings in task performance and (c) select future learning tasks with characteristics that help to fulfil the formulated learning needs. Figure 29.3 is a screen dump of this electronic portfolio.

On the left side of the screen, a hierarchical menu with all possible hairdressing skills and subskills are presented and on the right side students can add their self-assessment and their points of improvement. On another screen students were able to select future learning tasks, skills and subskills that need further practice to meet the formulated learning needs. Finally, STEPP provides three structured overviews with all portfolio data necessary for discussing a student's progress during supervision meetings. The first screen presents all learning tasks performed by the student, together with the corresponding self-assessments and, if applicable, teacher assessments. The second screen gives an overview of all formulated learning needs. The third screen presents the working plan for the forthcoming week.

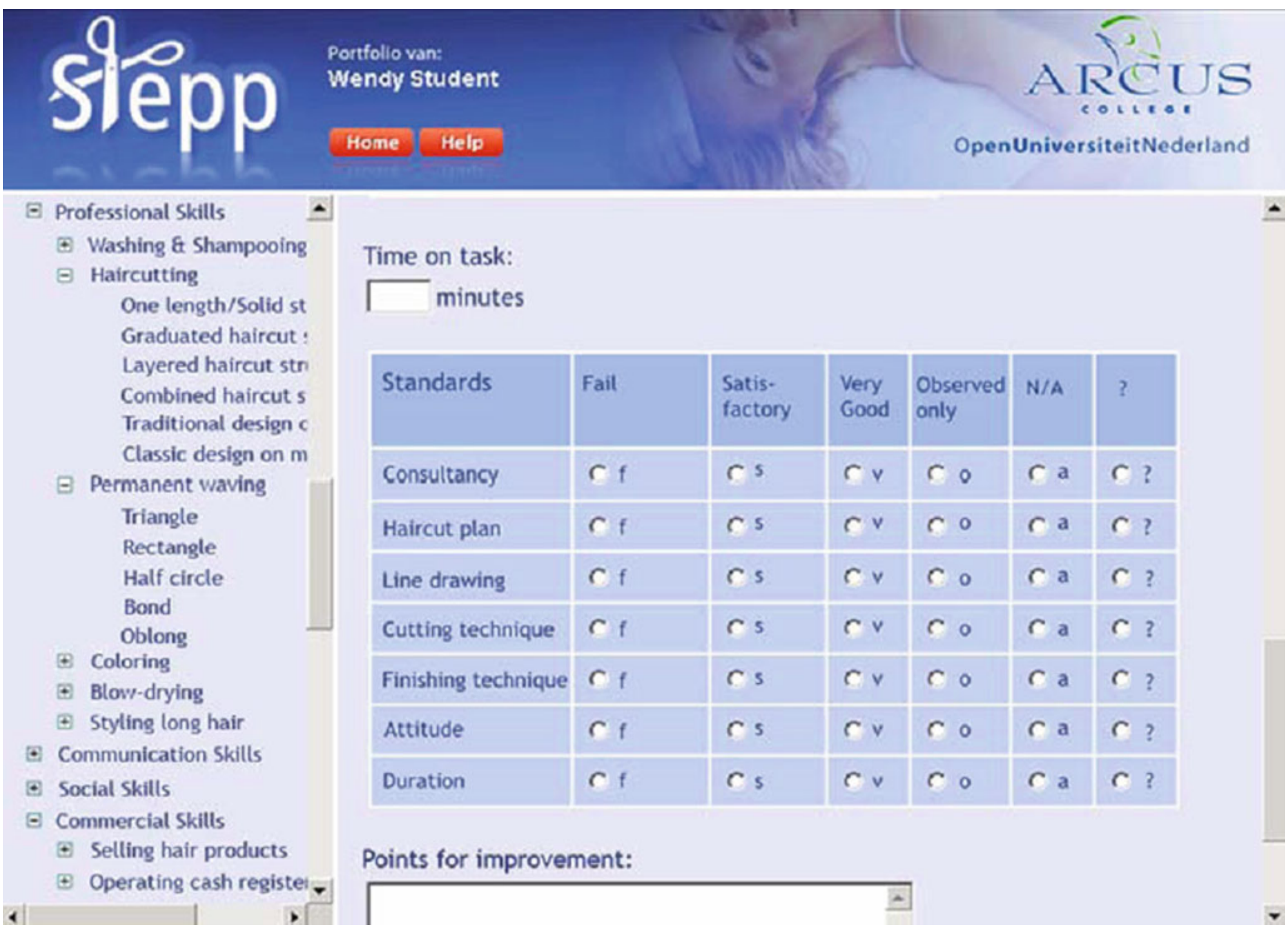

Fig. 29.3 Self-assessment and formulation of learning needs functionality in STEPP: Overview of skills (*left column*), standards for performance assessment (*table*) and possibility to formulate learning needs (*textbox*)

In both the advice and the feedback-only group, the supervisor provided feedback on the student's progress report and planning of learning over the previous 2 weeks, while discussing the three above mentioned STEPP overview screens in a fixed order. In the advice condition, the supervisor provided not only feedback but, in addition, advice on how to improve SDL skills.

Effects were studied on the development of SDL skills (i.e. self-assessment of performance, formulating learning needs and selecting new learning tasks), learning results, and student perceptions of the effectiveness of the supervision meetings. The effect of giving advice was evident in students' ability to formulate learning needs. Students who received advice were better able to diagnose possible cause(s) of their weaknesses and formulated relatively more diagnostic learning needs than students who only received feedback. With respect to task selection skills, providing feedback on task selection was to some extent effective, provided that students selected tasks from a limited number of available tasks. With respect to self-assessment skills, students did not reach a stage where they were able to assess their own performance at a sufficient level. So it can be concluded that the SDL skills of the students were to some extent improved, However, transfer to other learning situations and over time were not measured in this study. Further research should be conducted to gain insight in how transfer processes occur. Furthermore, students in the advice condition showed better learning results.

Flexible Learning Environments: Embedded Support on Self-Regulated Learning

When functioning in an FLE it is also important that learners receive support on the acquisition of SRL skills, because for functioning well in an FLE also requires regulation of learning processes when accomplishing learning tasks. In the following, four well-known instructional interventions that facilitate the acquisition of SRL skills and which can be embedded in the tasks used in the FLE are discussed. These are process worksheets (e.g. Nadolski, Kirschner, & Van Merriënboer, 2006), prompting (e.g. Stadtler & Bromme, 2008), modelling (e.g. Collins, Brown, & Holum, 1991) and feedback (e.g. Butler & Winne, 1995; Hattie & Timperley, 2007).

Process Worksheets

To help learners to attend to their micro level learning process providing general strategies and heuristics can enable them to carry out the task and meet the assessment criteria for the task (Van Merriënboer, 1997). According to Nadolski et al. (2006) a process worksheet provides a systematic approach to accomplish a learning task, presenting descriptions of the steps that need to be taken to carry out the task, and hints or rules of thumb that may help the learner to successfully complete the task. They support both the acquisition of domain-specific skills and SRL skills such as monitoring task performance and adjusting one's behaviour when task performance is not successful. Powerful scaffolds that can be added to a process worksheet are the presentation of keywords or leading questions reflecting a strategic approach to carrying out the task (Land & Greene, 2000). Wopereis, Brand-Gruwel, and Vermetten (2008) taught students to solve information-based problems while searching for information on the Internet, making use of process worksheets to structure and regulate the solution process. They found that, after the intervention, students who had received the process worksheets regulated their task performance, more often than the students who had not. In other words, using process worksheets enabled students to acquire SRL skills when accomplishing a similar task as during the intervention.

Prompts

A prompt is a cue given to someone to help or remember him or her to act on time or immediately. Prompts embedded in the learning context trigger the learner to execute specific SRL skills on a regular basis (Bannert, 2004) directing the learner's attention towards her/his own cognition during the learning process (Brown, 1997). Empirical evidence for the effect of using prompts on SRL skill acquisition has been found in a number of experimental studies. These studies have been carried out in different content domains such as mathematics (Gerjets, Scheiter, & Schuh, 2005; Kramarski & Gutman, 2006), psychology (Bannert, 2003), software programming (Schmidt & Ford, 2003), physics (Veenman, Elshout, & Busato, 1994), educational measurement (Kaufman & Lichtenberger, 2006) and biology (Lin & Lehman, 1999). Stadtler and Bromme (2008), for example, prompted students to monitor their comprehension process while studying multiple hypertext documents and found that repeated prompting assisted domain novices in detecting comprehension failures and inconsistencies in their text representation thereby enabling them to regulate their information processing accordingly (e.g. by re-reading difficult parts of the text or slowing down their reading speed). Further evidence showing that prompts indeed have a positive impact on SRL skill acquisition has been found in studies using think-aloud methodology (Bannert, 2004; Veenman et al., 1994).

Modelling

Modelling is an instructional strategy that can be seen as a first step in cognitive apprenticeship, "a model of instruction that works to make thinking visible" (Collins et al., 1991, p. 1). Modelling refers to the teacher or instructor (or actually any expert in a domain) demonstrating the carrying out of a task and also thinking aloud about what she/he is doing while performing that task. By verbalising her/his thoughts, the teacher makes it possible for learners to conceptually understand the task as well as observe the regulation aspects involved in carrying out the task. A teacher is likely to offer explicit description of each part of the process while performing the task, thus providing the learner with both a conceptual overall understanding and an analysis of the regulation processes involved. Effects of using modelling as an instructional measure to foster regulation have been studied for example by Brand-Gruwel, Aarnoutse, and van den Bos (1998). Primary school children learned to regulate their reading comprehension process during a 1-month intervention where the process of reading comprehension was modelled by both the teacher and peers. Compared to students in the control condition, students receiving the modelling intervention exhibited more regulation behaviour. Furthermore, when measuring transfer over time, the effects were not found anymore. It seems important to keep supporting the children in using these skills.

Feedback

According to Hattie and Timperley (2007), feedback is a powerful tool or teaching strategy in supporting learners in enhancing their learning performance. Feedback can be defined as "information provided by an agent (e.g. teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding" (Hattie & Timperley, 2007, p. 81) and it is "information with which a learner can confirm, add to, overwrite, tune, or restructure information in memory, whether that information is domain knowledge, metacognitive knowledge, beliefs about self and tasks, or cognitive tactics and strategies" (Winne & Butler, 1994, p. 5740). Feedback aims to bridge the gap between the current level of performance/understanding and the learning goals. According to Hattie and Timperley, the effectiveness of feedback depends on its focus. Task mastery is especially promoted by feedback on process level and self-regulation level because this feedback is related to learning (Hattie & Timperley, 2007). Focusing feedback on the learning process can guide learners how to learn, set learning goals, choose and execute learning activities, diagnose and monitor the learning process, and evaluate learning results (Bolhuis & Voeten, 2001).

Discussion

To foster the acquisition of SRL and SDL skills, learning environments in which learners can develop these skills must be designed and developed. The environment should be flexible and learners should be able to direct their learning by formulating their own learning needs, setting their learning goals, and identifying resources for learning on the trajectory level supported by instructional measures embedded in the curriculum that stimulate acquiring necessary SRL skills.

Integrating support and guidance in acquiring SDL and SRL skills into a flexible learning environment is essential because these skills do not develop spontaneously (Zimmerman, 2002). Instructional strategies to foster SRL skills are the use of process worksheets, modelling and prompting (e.g. Bannert, 2004; Collins et al., 1991; Nadolski et al., 2006). As learners' SDL skills develop, the control over needs identification, goal setting, and task selection must gradually shift from the teacher to the learner. The learner, thus, takes increasing responsibility over her/his own learning process. Eventually, the learner must be able to identify her/his own concrete individual learning needs on the basis of self-assessments and—possibly deviant—assessments made by others who use given criteria and standards, set realistic and feasible learning goals to fulfil identified learning needs, and select appropriate new learning tasks that help reach the learning goals. Taking these aspects together and integrating them from an educational design perspective will provide insight into how learning environments should be designed to foster learning.

The practical implications of all of this are very demanding when designing a FLE. Although the environment seems loosely organised from the learner's perspective, the system itself should be very well organised. The learning tasks that the learners can or must accomplish should be well ordered (i.e. in complexity levels/task classes) and should be companied by necessary metadata such as goals, skills involved, kinds of support, and so forth. Furthermore, the assessment criteria must be clearly and transparently formulated for the learner. And finally, when guiding learners to become self directed learners, teacher/agent feedback and guidance in a shared controlled situation is indispensable.

Concerning directions for future research, more research is needed to determine and study the important elements in the design of a FLE and how these design elements function and what effects are on learners' performances and especially on their SDL and SRL skills. Research questions for the future concern how a database of tasks should be arranged to support learners in selecting tasks for future learning. How many tasks should be offered and of what complexity and support level to have an impact on the effectiveness on learners learning? Or research on how to gradually reduce the amount of support in a shared control environment and give more responsibility to the learner. Based on which criteria should a teacher decide that a learner is capable to self direct own learning? These kind of questions can give more insight in how to effective design flexible learning environment; environments that prepare learners to become self-directed and self-regulated learners and for the future also lifelong learners.

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Instructional Message Design: Past, Present, and Future Relevance

30

M.J. Bishop

Abstract

Instructional message design explores how various media and delivery systems might be used more effectively to help optimize instructional communications within context-specific instructional situations and learner needs. But use of the term appears to have fallen out of favor over the years since the mid-1990s. A review of the historical and theoretical foundations of instructional message design reveals that, while instructional design generally has shifted from objectivist to more constructivist perspectives on learning theory, the instructional message design field remains firmly rooted in early "transmission oriented" communications models. It appears that instructional message design has also suffered from definitional problems as well, with more recent narrow views of the field focused on media attributes supplanting earlier broad views of the field as an applied "linking science" between theory and practice. And, finally, while findings from studies on media attributes provide designers with some guidance for generally what will *not work* in terms of cognitive processing, the guidelines seldom shed light on what one should actually *do* within a particular learning context. It appears that reestablishing instructional message design as a valid area of inquiry within the field of instructional design will require catching up with recent philosophical shifts in communication theory while adjusting our definitions and research foci accordingly. The chapter concludes with recommendations for a revised guiding theoretical framework based on conversation theory, a broader definitional focus that looks at more than just optimizing cognitive processing, and a new systems view of our approach to research in this area.

Keywords

Instructional message design • Instructional communications system • Message • Systems philosophy

Introduction

The research in educational media indicates that any medium used for teaching and learning is only as effective as the design of the message it is intending to communicate. Poorly designed instruction is poorly designed instruction, regardless of delivery mode (Cuban, 1986, 2001). In order to devise technologies that truly make a difference within an instructional communication system, instructional designers must

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be supplied with development guidelines that are based on the unique ways specific groups of learners interact with various communication technologies and media presentations to construct knowledge. Instructional message design, therefore, explores how various media and delivery systems might be used more effectively to help optimize instructional communications within context-specific instructional situations and learner needs. As such, it applies learning theory, communication theory, and systems theory to the design and evaluation of instructional media.

Instructional message design has been described as the "next step" in the instructional design analytical process—moving beyond deciding what methods are best for bringing about desired changes in student knowledge (Reigeluth, 1983) toward specifying the exact form an instructional communication system should take for optimal learning (Grabowski, 1991). But since the mid-1990s, use of the term "instructional message design" appears to have fallen largely out of favor. Database searches for new literature on instructional message design come up more-or-less empty, referring repeatedly back to Fleming and Levie's earlier texts (1978, 1993). Even Wikipedia has no entry for it as of this writing.

So, what has happened to instructional message design? In 1995, Berry noted that some had begun arguing traditional instructional message design orientations were antithetical to the learner-centered approaches that were just emerging at the time. Could it be that instructional message design has become irrelevant as the field's philosophical focus shifted from *instruction* to *learning* instead? Or perhaps instructional message design has been supplanted by other areas of inquiry? While studies identified specifically as instructional message design research have been fairly sparse since the early 1990s (Molenda & Boling, 2007), vast empirical work in related areas termed "multimedia learning" and "cognitive load theory" has continued, for example. Or maybe there really is no problem at all but rather the guidelines derived from the instructional message design research done before 1995 are all we need?

This chapter examines these questions by reviewing the theoretical and historical foundations, discussing current issues, and exploring the potential future relevance of instructional message design research as a subdiscipline of our field.

Theoretical and Historical Context

Traditionally, instructional message design has explored the application of communication and learning theories to the design and development of media used for teaching and learning (Bishop, 2000; Bishop & Cates, 2001). This section briefly summarizes these theoretical foundations to provide a context for the discussion of current issues and future directions for instructional message design. For a more complete review of the evolution of learning and communications theories and their impact on the field, readers are encouraged to consult Driscoll (2005), Reiser (2001a, 2001b, 2012), Richey, Klein, and Tracey (2011), and Saettler (1990).

Communications Theory

Educational technologists have typically viewed teaching–learning problems as communication problems. The traditional instructional message design literature has, therefore, approached the instructional process as an instructional communication system with a set of interrelated parts working together to produce learning (Berlo, 1960).

Communication as Transmission

Early communications models focused on the way information is passed from one location to another and have been characterized as *transmission* models (Richey et al., 2011). Shannon and Weaver's *The Mathematical Theory of Communication* (1949) was particularly influential in shaping early thinking in the field about human communication.

The Shannon–Weaver model proposed that all communication processes begin when a source, desiring to produce some outcome, chooses a *message* to be communicated. A transmitter then encodes the message using a set of perceptual elements or cues that are assembled in a deliberate way to produce a signal appropriate for transmission over the channel that will be used. After the message has been transmitted, a receiver then decodes the message from the signal transmitted and passes it on to the destination.

According to the model, communication is "perfect" when the information contained in a message affects the receiver in exactly the way intended by the source. Communication is rarely perfect however; spurious information, or noise, can introduce errors at any point in the transmission that make the signal harder for the receiver to reconstruct accurately. Offsetting noise in communication involves adding redundancy to messages. Redundancy is the information that message cues share: the parts that "overlap" (Attneave, 1959). While the word "redundancy" has lately been defined as something that is superfluous or unnecessary (for example, see Chap. 31), in the Shannon and Weaver sense the surplus may not necessarily be uncalled-for. They posited that redundancy in communication systems that helps a receiver separate transmitted information from system noise increases understanding and is, therefore, desirable.

However, Shannon and Weaver (1949) also acknowledged that all channels have limited capacity. That means redundancy not needed by the receiver or that fails to increase understanding may actually impede the flow of new information and, consequently, decrease communication effectiveness. When redundancy exists at the expense of new information, it can introduce its own sort of noise into the system. Thus, while highly redundant messages can overcome noise in communications effectively, they are not very efficient. When a source anticipates problems in communication, the trick may be in knowing how much and which sort of between-cue message redundancy to include in order to counteract noise. According to the Shannon–Weaver model, striking the right balance in messages between redundancy and new information appears to be the key to successful communication (Reza, 1961/1994).

Communication as Interaction

In 1954 Schramm was among the first to alter the Shannon–Weaver model by conceiving of decoding and encoding as activities happening simultaneously by sender and receiver while messages are exchanged interactively and reciprocally. Schramm further suggested that the sender's and receiver's fields of experience play a large role in successful communication. The sender encodes messages based on what is known about the receiver's experience and the receiver's experience impacts message decoding. If there is no commonality in the sender's and receiver's fields of experience, communication does not occur.

In 1960, Berlo's Sender–Message–Channel–Receiver (S–M–C–R) model further expanded thinking about human interactions by focusing on "the ingredients of communication" within each of the four communications elements. Like Schramm, Berlo's model acknowledged the importance of shared experience between the sender and receiver (communications skills, attitudes, knowledge, social systems, and culture) and also emphasized the role of feedback from the receiver requesting clarification for how the message was decoded. But Berlo's model viewed the communications channel as the five human senses rather than a mechanical conduit for messages. Additionally, Berlo's model placed the message squarely at the center of the process and examined the extent to which content elements, treatment elements, and code structure affected communication outcomes.

Learning Theory

Berlo (1960) also suggested that the study of communication processes and the study of learning processes differ only in their point of view. While communication models most often begin with and focus on how messages are constructed and sent, learning models generally pick up with and focus on how messages are received and processed by learners. Designing optimally effective instructional messages must also, therefore, involve understanding learning theory. Thus, in addition to communication theory, traditional instructional message design thinking has also been firmly rooted in the behavioral and cognitive sciences as well.

From Behaviorism to Cognitivism

The behaviorist orientation prominent in psychology during the first half of the twentieth century viewed learning as the ability to perform new behaviors. Organisms respond to stimuli and, if repeated over time, eventually form stimulus–response bonds or chains. These responses can be strengthened or weakened as a result of whether they are positively or negatively reinforced. Behaviorists suggested, therefore, that knowing what might be going on in an individual's mind in terms of invisible mental processes such as thoughts and consciousness is less important than understanding observable behaviors in relation to the environmental events surrounding them (Driscoll, 2005).

When applied to human learning, the behaviorist orientation suggested that learning is a process of carefully planned steps under the direction of an educator (teacher, instructional designer) who either succeeds or fails at creating the conditions necessary for student learning. Among the critical elements for assuring learning success from this behaviorist perspective was providing immediate reinforcement for student responses. The automated "teaching machine" (Pressey, 1926, 1927) that delivered programmed instruction (Crowder, 1960; Skinner, 1958) promised a solution to the problem of supplying learners with timely feedback on their progress. The idea was to automate the process of teaching by setting up, in advance, the conditions under which learning will inevitably occur and delivering those stimuli—or messages—via a mechanical device. The machine then provided feedback on the learner's response and, if correct, the learner went on to the next step. If incorrect, however, the learner reviewed the previous material until she got it right. The teaching machine concept advanced further with the advent of early computers in the 1960s and 1970s, as most computer-assisted instruction continued to reflect a behaviorist orientation. While computerized drill-and-practice programs and tutorials did capitalize on the new technology's enhanced displays and improved learner interactions, they still presented material in a step-wise fashion, provided immediate reinforcement for learners' responses, and assumed a strong degree of program control over learner control (Saettler, 1990).

By the early 1980s, at roughly the same time microcomputers were also being introduced to the market, the cognitive model of learning began to replace the behaviorist model in the educational technology literature. Cognitivists emphasized knowing rather than responding and viewed learning as an active process of acquiring, organizing, and constructing new understandings from incoming stimuli. In the cognitivist view, therefore, understanding how knowledge is represented in memory is key to the development of instructional theory. Among the key assumptions of the cognitive sciences at this time was the idea that humans receive, process, and store information in ways analogous to computers.

Human Information-Processing

Like the Shannon–Weaver communications model, Atkinson and Shiffrin's (1968) three-stage information-processing theory has been particularly influential over the years among cognitivist learning theory models. In this explanation of human memory, stimuli coming in from each of the five senses are first handled by a *sensory register*, which filters and then routes the incoming signals to a second, *short-term store*. Short-term store (also sometimes called *working memory*) holds information temporarily while it is being encoded as *schema* for permanent storage in the *long-term store*. *Encoding* is the process of building relationships and connections within new material or between new material and existing knowledge structures. Long-term store is both the place where we hold newly encoded schemas and the place from which we retrieve well-established memories.

Information-processing theorists maintain that learning occurs when information that has been transferred to and stored in long-term memory can be retrieved when needed (Atkinson & Shiffrin, 1971; Phye, 1997). It appears, however, that limitations in each of these operations may restrict the amount of data one can consign to long-term storage. For example, in order to acquire or make sense of the constant barrage of sensory information, an individual must decide, often unconsciously, which information to attend to and which to ignore (Broadbent, 1958; Treisman & Gelade, 1980). There is also a limit to the amount of information, or maximal cognitive load, an individual can process in short-term store at any given time (Paas, Renkl, & Sweller, 2003; Sweller, Ayers, & Kalyuga, 2011). And, while there is some evidence to suggest that once information has been moved to long-term store it remains there forever (Nelson, 1971, 1978), it is equally clear individuals certainly can lose access to memories over time (Ausubel, Robbins, & Blake, 1957; Norman, 1969; Postman, 1961).

From this view then, instructional message design should be focused on helping learners process information rather than merely initiating behavioral responses (Saettler, 1990). Winn argued in 1993 that designers had "failed to consider how messages affect what they mean to the individual who receives them in interaction with each person's knowledge of the world" (p. 75). Therefore, to facilitate learners' acquisition, processing, and later retrieval of new material, designers should work to manipulate the attributes of an instructional message to make clear delineations among salient features, organize presentations hierarchically to show relationships, and provide meaningful connections to learners' existing knowledge structures (Salomon, 1979/1994).

In this way, instructional message design emerged as a subdiscipline of instructional design from the intersection of communication and learning theory. And, over the years, principles derived from research in this area have supplied instructional designers with a wealth of useful information important to support "a designer's decision of form" (Smith & Boling, 2009, p. 4).

Current Issues

However, despite considerable changes over the last 50 years in communications and learning theory as well as the available interactive technologies, it appears the underlying instructional message design concepts have remained essentially the same. In fact, even recent compilations of research-based principles for instructional media designers still rely principally on empirical work done before 1995 (for example see Lohr, 2008; Morrison, Ross, Kalman, & Kemp, 2011). Molenda and Boling (2007) noted that the emphasis continues to be on optimizing the instructional communications system by finding the most effective ways to transmit material to be learned from the source (teacher or designer) to the receiver (learner), with little concern for the more dynamically social and reciprocal nature of most communication transactions. In effect, the assumption is that "meaningfulness" can be determined in advance and—given the right combination of message cues—transmitted successfully to all learners (Sless, 1981).

Philosophical Mismatch

While the shift from behaviorism to cognitivism in the first half of the last century was a sea change in perspectives on learning, both theories were still based on an objectivist belief that knowledge exists independently of learners and learning is the process of transferring that knowledge "from outside to within the learner" (Driscoll, 2005, p. 387). More recently, constructivists have argued that knowledge does not exist independently but is, instead, constructed by learners as they actively seek to make meaning from their experiences. Thus, constructivists view instruction as a process of supporting active knowledge construction rather than transmitting knowledge into an empty vessel. In fact, constructivists like Duffy and Cunningham (1996) have contended that we cannot be certain that "perfect communication" with wholly shared meaning between a sender and receiver is even really possible.

> We can only evaluate whether meaning is shared by testing the compatibility of our individual meanings: exploring implications, probing more deeply. Of course, no matter how much we probe, we can never be sure that the meaning is shared (p. 171).

Instead, the authors suggested we must actively seek to understand the communicators' different perspectives and, in a learning context, seek to understand and challenge the learner's thinking—eschewing the transmission approach to instruction.

So, about the same time many of the seminal works in instructional message design were being produced, Cooper (1993), Jonassen (1990, 1991), Kember and Murphy (1990), and others were arguing that if learners actively construct their own understanding through interactions between their existing knowledge structures and authentic experiences with the world around them, then the field must move away from models based on an objectivist epistemology that places responsibility for learning on "pre-packaged" messages didactically designed to deliver content through some communications medium to passive recipients. Jonassen (1990) contented:

> It matters little how we represent ideas and less how we present it. *What matters is how the learner is thinking*. Since knowledge is mediated by thinking and not by technologies, our goal should focus on providing cognitive tools for helping learners to construct knowledge, that is, to think more productively (p. 34).

According to Januszewski and Molenda (2008) this philosophical shift to constructivism dramatically changed the orientation of the field. Research interest moved away from "the design of prespecified instructional routines" to be delivered in a variety of communication formats and toward "the design of environments to facilitate learning" (p. 2). Jonassen, Lee, Yang, and Laffey (2005) summed up the growing philosophical mismatch by observing "…the most obvious effect of this influence has been a shift from emphasis on instructional communication systems to an emphasis on practice-based collaborative learning systems" (p. 247).

Definitional Problems

In addition to the growing philosophical mismatch, instructional message design has suffered from definitional problems as well. Some have taken a very broad view of the field as a "linking science" between learning theory and instructional practice (Dewey, 1900 as cited by Fleming, 1993) whereas others have taken a much narrower view, choosing to focus on media attributes and their affordances for improving—or impairing—learners' cognitive processing.

Syntheses of Generalized Principles

Among the first major works attempting to synthesize basic research into applied instructional message design principles was Fleming and Levie's (1978) *Instructional Message Design: Principles from the Behavioral Sciences*. In it, the authors took a very broad view of instructional message design as the bridge between learning theory research and instructional practice. According to the preface, this text set out to formulate "sets of generalizations stated as principles" from research in the areas of perception, memory, concept formation, and attitude change in an effort to "narrow the gap between research and practice in instructional message design" (p. vii). The idea was to provide a research-based conceptual framework that might "inform the creativity of designers/teachers" but "not replace or lessen the need for innovation in instruction" (p. xiii).

Fleming and Levie's first edition was roughly organized around the functions of instructional messages within the instructional communications system and, therefore, included chapters on perception principles (helping learners acquire messages), memory principles (helping learners process message content), concept learning principles (helping learners relate new constructs to existing knowledge structures), and attitude change principles (assuring the delivered message has the desired effect). Fifteen years later the second edition was updated to reflect "the pervasive change in the research literature from the earlier behavioral emphasis to the current cognitive orientation" (Fleming & Levie, 1993, p. viii). Nonetheless, the update retained the first edition's organization around message functions, changing the earlier memory principles chapter to learning principles instead and adding three more chapters on motivation, psychomotor, and problem-solving principles.

Works Focused on Media Attributes

While some of the principles suggested in Fleming and Levie's two editions specifically addressed the use of graphics, text, sound, and the like, most of what the authors proposed there were principles that might apply generally to the design of instruction regardless of medium. In contrast, others over the years have approached discussions of instructional message design from the more specific focus on some media attribute (text, sound, color, images) and explored optimally effective ways to utilize the inherent codes or symbol systems possessed by the medium to facilitate cognitive processes (Jonassen, Campbell, & Davidson, 1994; Moore, Burton, & Myers, 1996). Interest at the time in media attributes likely emerged from—and contributed to—the media debates of the 1980s and early 1990s over whether media (television, film, radio) could influence learning in-and-of-themselves (for a complete review, see Clark, 2001). Contributions to the field that have taken this media attributes approach have included Jonassen's *Technology of Text* (1982, 1985), Hartley's *Designing Instructional Text* (1986), Houghton and Willow's *The Psychology of Illustration* (1987). Additionally, the first two editions of this *Handbook* included instructional message design sections organized from a media attributes perspective with chapters on static and visual representations, text, audio/sound, and multichannel/multimedia (Jonassen, 1996, 2000).

More recently, Mayer (2001, 2003, 2005, 2008, 2009, 2011) and his colleagues have extended this work by very systematically exploring how the brain processes the attributes of multimedia instructional messages based on three major principles of cognitive theory: the dual channel principle, the limited capacity principle, and the active processing principle (see also Mayer's many collaborations with Clark, Johnson, Moreno, and others). Based on the findings from these studies, Mayer has argued that the three goals of multimedia instructional message design should be to minimize extraneous cognitive processing by eliminating irrelevant presentation elements, manage essential processing, and foster generative processing during learning. To date, Mayer's and others' empirical work has focused primarily on deriving principles for minimizing extraneous cognitive processing and managing external processing. (For a more thorough review of the work being done in multimedia learning, see Chap. 31). Having adopted the umbrella term "multimedia learning" to refer to the work being done in this area, it is not altogether clear whether Mayer and his colleagues intend this to be a subset of instructional message design or, rather, perceive this to be what instructional message design has evolved into—particularly given that most instructional messages now entail multiple media.

Methodological Concerns

Thus, the term "instructional message design" as a subdiscipline of instructional design does not appear to have ever had a precise meaning or a discrete set of descriptive parameters that formed the boundaries for inquiry. At the very least, it appears the research in this area has focused increasingly on highly constrained comparison studies of media attributes. And, while the findings from these studies have given message designers an empirically tested set of guidelines for understanding the potential cognitive processing ramifications of making poor multimedia presentation design choices, Boling (2010), Krippendorff (2006), and others have argued that the principles derived from this research falls short of telling designers specifically what to do in any given situation (see also Archer, 2004; Cross, 2007; Lawson, 2004).

Britt (1997) explained that—through simplification, explicitness, and reformulation—theory-based models derived from a traditional "scientific approach" to inquiry can provide an effective way to sort out the chaos of systems that are too complex to deal with directly, like instructional communications (see also von Bertalanffy, 1950, 1962, 1968, 1975). Because such models show the repeating patterns and relationships among the parts, they can help one understand the true complexity of the problem or situation. However, according Banathy (1991), dynamic social systems such as education appear to have too many interacting variables to be reduced easily to a set of linear, cause-and-effect relationships (see also Banathy, 1996; Banathy & Jenlink, 2004). Changes to one element in the system can influence, to different degrees, many other elements of the system as well. Therefore, from this *systems philosophy* perspective, the nature of each individual system element can be understood only by looking at how it functions in relation to the whole system of which it is a part. Stated differently, systems philosophers contend that, outside of the laboratory's experimental control, there is no such thing as an independent variable.

It was from this viewpoint that Rieber (2005) concluded "Generalization of the results from educational multimedia research to the 'real world' of learning and performing in schools and the workplace should be viewed with considerable caution" (p. 551). Sless (1981) and others have also argued that, in fact, we cannot ever hope to *predict* the consequences of a particular instructional message:

> "Scientific" procedures cannot work because the systems under investigation are governed by meanings and rules related to meaning which cannot be reduced to cause and effect contingencies. The only way such a system can be controlled is by regulating the meanings in the system and rules governing their usage. …control of meanings is diffused within the culture, refracted by personal experience and focused differently within different contexts, all of which are only marginally controlled by the education process (p. 173).

Rowland (2008) suggested that, instead, "a fully developed system of inquiry for educational contexts" will need to exist at the intersection of research and design, with each transforming the other (p. 7). Unfortunately, as Smith and Boling (2009) noted, to date very little applied work has been done to provide concrete guidance in how to translate the designer's specifications into the tangible attributes of an instructional message (see also Gibbons & Yanchar, 2010).

Potential Future Directions

In 2009 Gibbons contended that good designs do not serve a theory, but rather a metaphor. Further, he maintained that the appropriate design metaphor for instruction is conversation—making the design of messages "one of the very most important layers in the future of designer's thinking." If that is true then perhaps instructional message design does still have an important role to play in the future of our field despite the paradigm shifts, definitional issues, and methodological concerns. But what guiding framework should we be following? What is the definition of "message design" within this new context? What questions should we be focusing on now and how should we be pursuing the answers to those questions?

A New Guiding Framework for Message Design

As discussed earlier, instructional message design has traditionally existed at the intersection of learning and communications theories. But while foundational learning theory has shifted to more constructivist approaches, there has not been a similar evolution in our thinking as a field about the nature of communication. Message design remains firmly rooted in the transmission oriented communications model first proposed by Shannon and Weaver in 1949. While there have been many communications models proposed over the years since then, one that appears to hold the most promise for message design within a constructivist paradigm is *conversation theory*.

In 2004 Boyd suggested that educational technology needed to move away from "the conventionally understood psychology of the individual" and, instead, understand the instructional communication system as a conversation among "a collection of psychological individuals… whose presence is variable and hierarchical" (p. 179). Between 1966 and 1996 Gordon Pask developed "conversation theory" as a framework for exploring the complexity of interactions necessary for learners to construct meaning and make knowledge explicit within real life sociocultural environments. According to Luppicini (2008), conversation theory emerged in opposition to earlier theories that viewed learning as "a set of mental structures and processes that can be analyzed separately and applied to learning and instructional applications" (p. 3).

Pangaro (1996) explained that, at the simplest level, learning from a conversation theory perspective begins with one participant in a group uttering a word like "cup," which is likely to have rather different meanings for the other participants. In order to clarify and agree upon the meaning, a conversation among the participants is necessary. This begins with the first participant clarifying how a cup is used, what it is for, and how it looks. The other participants listen to these views, consider that perspective, and come as close as they can to understanding the first participant's meaning, then share their understanding with the group. If there are conflicts between the other participants' views and the first presented, their views are discussed and considered as well. Once there is consensus among participants' views of "cup," there is said to be "agreement over an understanding." Thus, effective conversation occurs not when meaning is shared, but rather "when beliefs are negotiated through interaction and evolve via goals" (Pangaro, 2008, p. 35).

But conversations need not be only among humans for learning to occur—conversations can also involve technology-based communication systems as well, particularly as the rapid growth of interactive multimodal and social networking technologies offer opportunities not previously possible (Luppicini, 2008). Thus, Boyd (2004) suggested that conversation theory can serve as a framework for the design of technology-based constructivist learning support systems. However, we can no longer conceive of these technologies as the deliverers of a series of previously designed instructional messages but, instead, as tools that must be able to "adopt a role similar to that of action researcher, continually observing, reflecting, and adapting the process" (De La Cruz & Kearney, 2008, p. 124).

A Broader Focus for Message Design

Movement away from an objectivist, linear paradigm of instructional message design and delivery and toward creating technology-facilitated environments that support conversations among learners will likely also require message designers to think, once again, more broadly about the field. That means allowing for the entire process of "conversation" (not just the sender to receiver transmission) and developing the necessary tools to make meaningful, interactive dialog possible for all participants. Stated differently, we need to find ways to create the technology affordances necessary for participants other than the educator (teacher/designer) to support and represent their thinking while engaged in the discourse.

Like Fleming (1993), Gibbons and colleagues have taken a broader view of design as a "linking science" between theory and practice that focuses on the product rather than the process of design (see Gibbons, 2003, 2009a, 2009b; Gibbons, Nelson, & Richards, 2000; Gibbons & Rogers, 2009a, 2009b). Gibbons observed that many design process models do not provide much in the way of actual operational principles for decision-making when creating a design, often glossing over the "miracle box" labeled "design instruction," "write instruction," or something similar. While Gibbons does not contextualize his ideas within a conversation framework, he does conceive of design within the miracle box as being made up of multiple layers of decision making about what will be the artifact's functions—the content, strategy, control, message, representation, media-logic, and management of the conversation. According to Gibbons & Rogers, 2009a, the *Content* layer involves decisions about subject matter, how it will be structured, organized, divided, and the like. The *Strategy* layer comprises the "space, time, event, social, and interaction structures that define occasions through with the learner can experience the content structures" (p. 18). In the *Control* layer, the designer makes decisions about affordances the learner will have available to participate actively in the exchange. The *Message* layer, in this sense, involves the ways in which the system will respond adaptively to the learner's activity—based on predefined message generation and construction systems. *Representation* involves "the rules for converting abstract structures from all of the other domains (layers) into representations that have sensory properties" (p. 19). The *Media-logic* layer involves decisions made about the actual delivery system employed in the execution of the representations. And, finally, the *Data Management* layer involves the underlying collection, storage, and data analyses activities needed to support adaptivity of instruction within the system. Each layer is characterized by a set of unique design goals, constructs, theoretic principles for the selection and use of design constructs, design and development tools, and specialized design processes.

According to Gibbons and Rogers (2009b), the design process in this view involves design by "successive constraint placement" on the system rather than strict adherence to some prevailing doctrine. And, while well-known instructional theories have had a great deal to contribute to providing guidelines and rules for the content, strategy, and to some degree the control layers, there are very few formalized guidelines for structuring the message, media-logic, or data management layers.

A New Research Paradigm for Message Design

In addition to redefining the field more broadly to comprise the design of technology affordances aimed at enabling all involved in the conversation to actively participate, message designers also will need to become more mindful of the non-cognitive factors that contribute to meaning-making in human conversation so that we can design adaptive systems that respond appropriately. Grunert (1997) argued that "We must seek frameworks that acknowledge, as the technical framework does not, the social, political, emotional, moral, imaginative, and aesthetic complexity of human interaction in the world" (p. 44). Wilson (2005a, 2005b) agreed and offered four "pillars of practice" that he suggested should underlie a broader view of instructional design research and practice in the future: individual cognition and behavior, social and cultural learning, values, and aesthetics. Wilson suggested these four levels of analysis "reflect more than an expanded view of learning outcomes" and become, instead, "an expanded view of design processes themselves and criteria for evaluating designed products" (p. 10).

The first pillar, *Individual Cognition and Behavior*, requires understanding the way learners think and acquire knowledge and skill. This level has been and continues to be thoroughly researched in instructional design and technology and relies heavily on much of the earlier instructional message design research that has been done over the years. Wilson's second level of analysis, *Social and Cultural Learning*, "turns to issues of cultural context and social support, including peer-to-peer interactions; group identity and motivation; and participation within communities of learning and practice" (Wilson, 2005b, p. 245). Like the first of Wilson's pillars, this area of inquiry has historically been a primary focus of the field under terms such as "learning communities" (Lave & Wenger, 1991); "situated cognition" (Brown, Collins, & Duguid, 1989); "cognitive apprenticeships" (Collins, Brown, & Newman, 1989; Wertsch, 1998); and the like. *Values*, Wilson's third level of analysis, is less well researched in the instructional design field and deals with exploring the underlying values and mores that are communicated in our designed materials. This pillar, as suggested by Krippendorff (2006) as well, "is a turn toward considerations of meaning—*a semantic turn*" (p. xv) that focuses our attention on questions of social justice and equity. Wilson's fourth pillar, *Aesthetics*, involves exploring both the "shape and form of the learning experience, as well as the design of messages within that experience" (Wilson, 2005b, p. 245). Drawing largely from the arts—particularly literary criticism—Parrish (2005, 2008, 2009, 2010) has been exploring the aesthetics of learning experiences and has come up with a set of principles and guidelines for thinking about message design, some of which suggest alternative approaches to the problems of cognitive load and avoiding split attention.

According to Sless (1981), understanding how learners respond to instructional conversations that are sensitive to values and aesthetics will require a different approach to empirical research that focuses more on the semiotic quality of the exchange and less on its psychophysical qualities. He added:

> …the skilled practitioner is more likely to make sound judgments on the basis of years of experience than the positivist researcher on the basis of precise research. It is therefore imperative that the cumulative knowledge of practice be nurtured (p. 178).

Claiming that precision may be a false goal for the social sciences, Freedman (1985, 1987, 1991) and others who have adopted the systems view over the years suggest an alternative research design (see Ling, 1983; Platt, 1964; Uslaner, 1983; Zeisel, 1982). Rather than attempt to emulate the precision of the natural sciences by making the constraining assumptions necessary to analyze large samples using multiple regression, systems methodology begins by formulating the properties of systems in abstraction, then observes specific cases to test the assumptions made. Freedman contended that although this approach is potentially less precise, it usually will generate answers to the right questions rather than solve the wrong problem. When answers are not forthcoming, one always can go back and modify the original assumptions.

While the systems view adopts a holistic strategy, the primary purpose of this approach to inquiry is to find ways to eliminate the discrepancy between a system's stated goal and that system's actual output (Kidd & VanCott, 1972). Senge (1990) suggested that the systems approach to inquiry is primarily the science of managing the problems that arise in "real world" situations outside of laboratory controls. The systems approach is a means to organize complexity into a coherent story that can help identify the important variables, illuminate the causes of problems, and indicate potential solutions. Thus, it appears that explicating those features of technology most effective for supporting learning may require that we embrace a systems inquiry approach to research in this area (Banathy & Jenlink, 2004; Boling & Smith, 2012; Gibbons & Rogers, 2009a, 2009b; Rieber, 2005; Smith & Boling, 2009).

Conclusion

Sless (1981) observed that "…education is parasitic on the modes of communication available in our culture" (p. 41). Even as we move away from objectivist epistemologies toward more constructivist approaches, it seems communication will still play a central role in the learning environment and, therefore, so too will message design. Reestablishing this area of inquiry as a valid subdiscipline of instructional design, however, will require following the paradigm shifts of the field and adjusting our definitions and research foci accordingly. It may also benefit from a name change.

In 1991 Grabowski differentiated between message design for *instruction* and message design for *learning*. Message design for instruction, she suggested, "deals with attention, perception, and comprehension, as well as, but not necessarily, retention and retrieval" (p. 204). Message design for learning, on the other hand, "addresses the cognitive processes required of retention and retrieval and therefore would be most concerned with the inductive composition of the message" (p. 204). She added that: "Message design for instruction deals with those external factors out of control of the learner which can facilitate learning, while message design for learning deals with those strategies which activate internal factors to have learning actually occur" (p. 205). Perhaps the next edition of this *Handbook* should include a new section called "Message Design for Learning?"

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Multimedia Instruction

31

Richard E. Mayer

Abstract

Multimedia instruction consists of instructional messages that contain words (such as printed or spoken text) and pictures (such as illustrations, diagrams, photos, animation, or video). The rationale for multimedia instruction is that people can learn more deeply from words and pictures than from words alone. Multimedia instruction began with the publication of Comenius' Orbis Pictus (The World in Pictures) in the 1600s, and has progressed to a wide array of computer-based multimedia learning experiences that are available anytime and anywhere. The science of learning—that is, a research-based account of how people learn—is necessary for designing effective multimedia instruction. Meaningful multimedia learning occurs when the learner engages in appropriate cognitive processing during learning, including attending to relevant words and pictures, organizing words and pictures into coherent representations, and integrating the representations with each other and with knowledge activated from long-term memory. Successful instructional methods for improving learning with multimedia include research-based principles for reducing extraneous processing during learning, managing essential processing during learning, and fostering generative processing during learning.

Keywords

Multimedia learning • Science of learning • Extraneous processing • Essential processing • Generative processing

Introduction

What Is Multimedia Instruction?

Multimedia instruction is instruction that includes words (e.g., printed or spoken text) and pictures (i.e., static graphics such as illustrations, diagrams, charts, maps, and photos, or dynamic graphics such as animation and video). Multimedia instruction can be presented on paper (e.g., as printed text and figures), on a computer (e.g., as narrated animation or annotated graphics), on a handheld device (e.g., as a game involving printed words and graphics), or face-to-face (e.g., as a narrated slide presentation). For example, Fig. 31.1 presents an annotated diagram aimed at explaining how a car's braking system works, and Fig. 31.2 presents frames from a narrated animation aimed at explaining how a car's braking system works.

Rationale for Multimedia Instruction

The rationale for multimedia instruction is that people can learn more deeply from words and pictures than from words alone—a finding that has been called the *multimedia principle* (Fletcher & Tobias, 2005; Mayer, 2009). For example,

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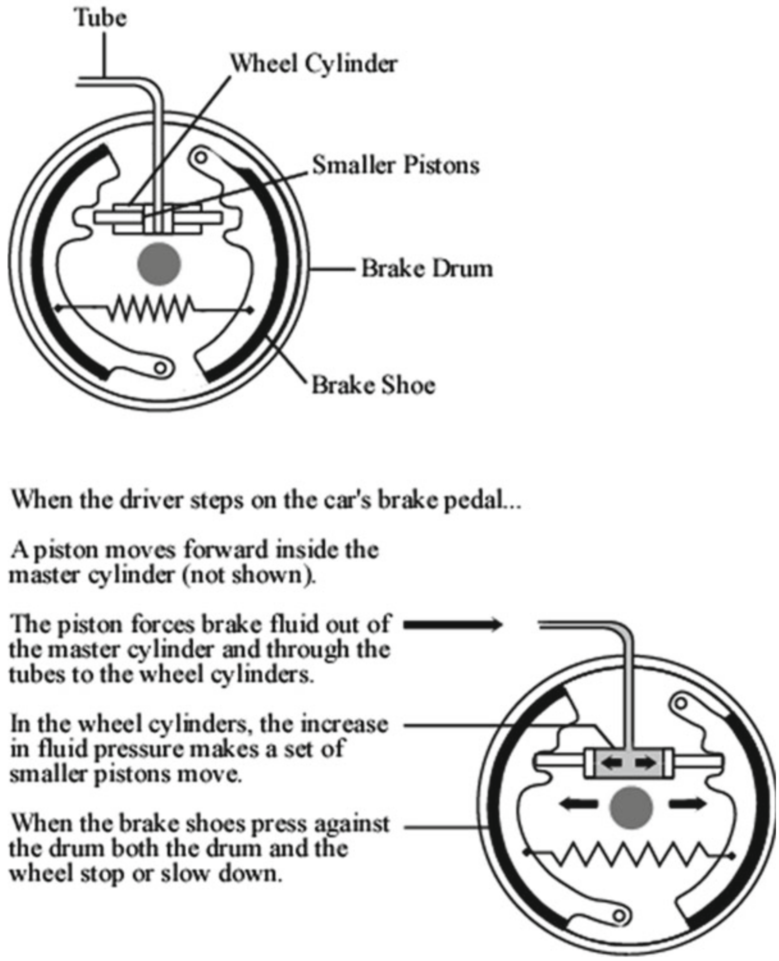

Fig. 31.1 Annotated diagram of a car's braking system

students who received text and illustrations explaining how a car's braking system works (such as in Fig. 31.1) performed better on a subsequent transfer test than students who received only the printed text (Mayer, 1989; Mayer & Gallini, 1990). Similarly, students who received a narrated animation explaining how a car's braking system works (such as in Fig. 31.2) performed better on a subsequent transfer test than students who received only narration (Mayer & Anderson, 1992). In short, under some circumstances, there is strong and consistent evidence that learning is improved when corresponding graphics are added to words (Mayer, 2009).

Not all multimedia lessons are equally effective, however, so research is needed to determine evidence-based principles for effective multimedia instruction. Some of these design principles are described in the third section of this chapter, and the underlying theory is described in the second section of this chapter.

Historical Overview of Multimedia Instruction

In the field of education, instruction has traditionally been based on verbal media, including spoken words (e.g., in lectures, discussions, or tutorials) and printed words (e.g., in textbooks). Yet over the past 350 years there have been visionaries who proposed an instructional approach that combined words and pictures, and scientists who investigated the effectiveness of such multimedia instruction for student learning.

The history of multimedia instruction has involved three major phases—the introduction of instructional illustrations beginning in the mid-1600s, the scientific study of learning with illustrations and text beginning in the mid-1900s, and the scientific study of multimedia learning in computer-based environments beginning in the late 1900s. The first phase is exemplified by the publication of John Comenius' *Orbis Pictus* ("The World in Pictures") in 1658—the world's first illustrated textbook. Each page consisted of an illustration of some aspect of the world ranging from birds of the field to bones of the human body to a bakery shop to a school, with a number next to each object in the illustration, along with a legend that gave the name and definition of each numbered object in Latin and in the student's native language. The editor of an English-language version of *Orbis Pictus* notes that "it was the first picture-book made for children and was for more than a century the most popular textbook in Europe" (Comenius, 1887).

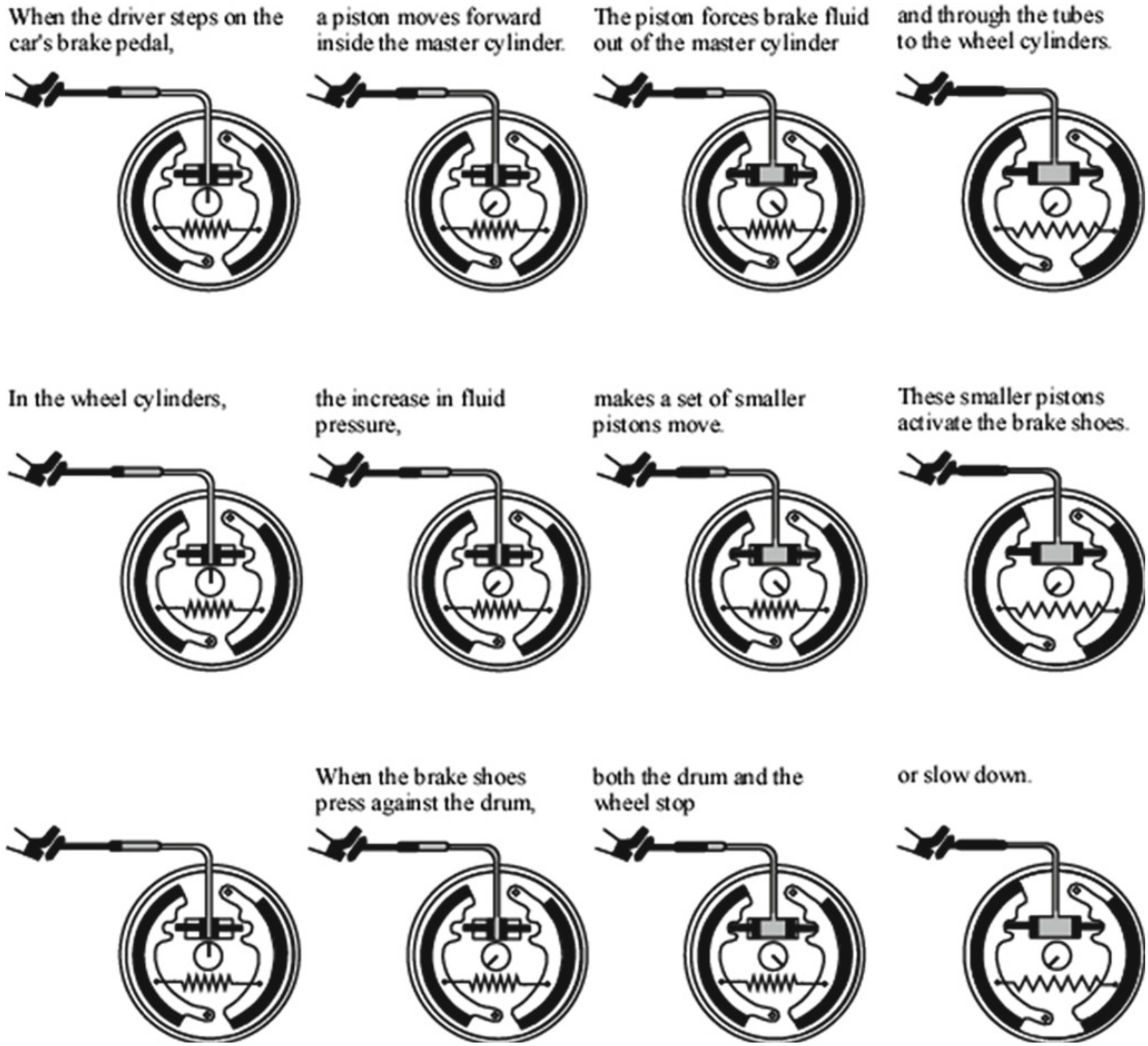

Fig. 31.2 Slides from a narrated animation of a car's braking system

In the field of engineering, machine books containing annotated illustrations of machines began appearing in the middle ages as a means of communicating between engineers and investors as well as between engineers and the artisans carrying out the work (Lefevre, 2004). In the field of business, William Playfield introduced the world's first books to use statistic graphics in 1786 and 1801 (Playfair, 2005), which revolutionized the way statistical information is communicated (Cleveland, 1985; Few, 2004; Kosslyn, 2006; Tufte, 2001).

Orbis Pictus, and other early books involving text and illustrations, can be seen as forerunners of today's textbooks, which devote up to half their space with graphics, though not as effectively as *Orbis Pictus* (Levin & Mayer, 1993; Mayer, Sims, & Tajika, 1995). Advances in technology enabled the spread of multimedia instruction in educational films in the 1920s, educational television in the 1950s, and computer-based instruction in the 1960s (Cuban, 1986). More recent advances in visualization technology have enabled the spread of multimedia instruction in e-learning environments (Clark & Mayer, 2008).

The second major phase in multimedia instruction involves the scientific study of how people learn with printed words and illustrations, which became popular in the mid-to-late 1900s (Flemming & Levie, 1993; Mandl & Levin, 1989; Moore & Dwyer, 1994; Paivio, 1971, 1986; Schnotz & Kulhahy, 1994; Willows & Houghton, 1987). For example, in a rigorous meta-analysis of the learning effects of adding illustrations to printed text, Levin, Anglin, and Carney (1987) reported a large effect size when the illustrations were designed to promote deep cognitive processing (with effect sizes greater than $d = 0.50$) but not when they served mainly to decorate the page (with effect sizes below $d = 0.00$). An important accomplishment of this work was the distinction between visual and verbal channels for processing information as depicted in Paivio's (1971, 1986) dual coding theory as well as preliminary design principles for using illustrations and text (Flemming & Levie, 1993; Moore & Dwyer, 1994).

The third major phase in multimedia instruction, which began in the late 1900s, extends the scientific study of how people learn to include computer-based multimedia instruction. For example, computer-based environments that support multimedia instruction include slide presentations, computer-based training, online multimedia lessons, narrated animation, hypermedia, interactive simulations, intelligent tutoring systems, animated pedagogical agents, virtual reality, and serious games (Atkinson, 2008; Clark & Mayer, 2008; Graesser, Chipman, & King, 2008; Kosslyn, 2007; Lowe & Schnotz, 2008). This third phase in multimedia instruction has both a theoretical goal of contributing to the science of learning by developing a cognitive theory of multimedia learning and a practical goal of contributing to the science of instruction by developed evidence-based principles for the design of multimedia instruction (Clark & Mayer, 2008; Mayer, 2005, 2009). The remainder of this chapter summarizes the progress being made in achieving these goals of building a theory of how people learn from multimedia instruction and compiling principles of multimedia instructional design.

Applying the Science of Learning to Multimedia Instruction

How Multimedia Learning Works

The science of learning is the scientific study of how people learn, that is, how the learner's experience causes a change in the learner's knowledge (Mayer, 2008, 2011). When applied to multimedia instruction, the goal is to understand how people learn from words and pictures. Three relevant principles about the human information processing system derived from research in cognitive science are as follows:

Dual channels—people have separate channels for processing verbal and pictorial material (Paivio, 1986, 2001)

Limited capacity—people can process only a few pieces of information in each channel at any one time (Baddeley, 1986, 1999; Sweller, 1999)

Active processing—meaningful learning occurs when people engage in appropriate cognitive processing during learning, including attending to the relevant information, mentally organizing it into coherent structures, and integrating it with other structures and with knowledge activated from long term memory (Mayer, 2009; Mayer & Wittrock, 2006; Wittrock, 1989)

Figure 31.3 presents a model of how multimedia learning works based on the cognitive theory of multimedia learning (Mayer, 2008, 2011; Mayer & Moreno, 2003). The model consists of two channels (i.e., a verbal channel on top and pictorial channel on the bottom), three memory stores (i.e., sensory memory, working memory, and long-term memory represented as boxes), and five cognitive processes represented as arrows (i.e., selecting words, selecting images, organizing words, organizing images, and integrating).

The learning process begins when the learner receives a multimedia instructional message—such as when the learner reads an illustrated textbook, attends a PowerPoint lecture, clicks on an online narrated animation, or plays an educational computer game. Spoken words and sounds impinge on the ears, resulting in their sounds being held in auditory sensory memory for a very brief period (i.e., <1 s); pictorial material and printed words impinge on the eyes, resulting in their images being held in visual sensory memory for a very brief period (i.e., <1 s). If the learner attends to the incoming sounds and images (indicated by the *selecting words* arrow and the *selecting images* arrow, respectively), some of the information is transferred for additional processing to working memory (which has limited capacity in each channel). In working memory, as indicated by the *organizing words* arrow, the learner arranges the incoming sounds into a coherent cognitive representation, which can be called a *verbal model*;

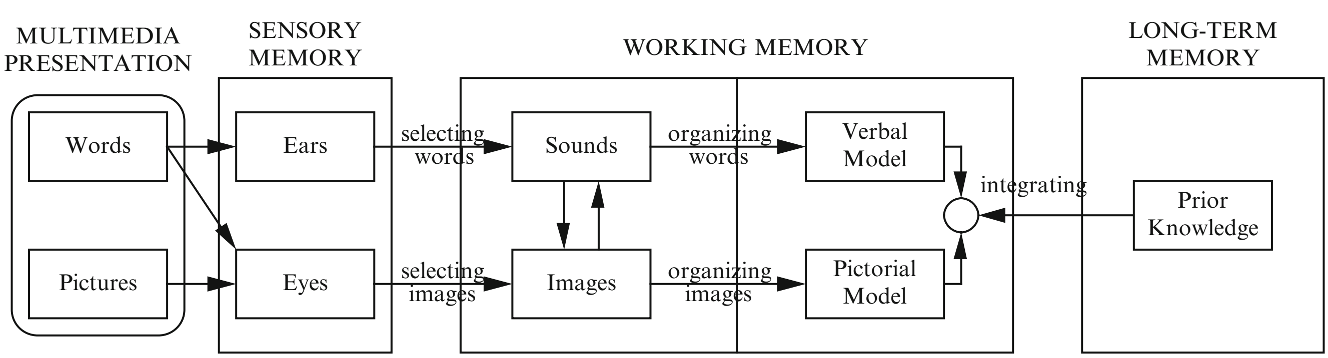

Fig. 31.3 A cognitive theory of multimedia learning

Table 31.1 Three demands on the learner's cognitive capacity during learning

Type	Definition	Cause	Arrows
Extraneous processing	Cognitive processing that does not serve the instructional goal	Poor instructional design	None
Essential processing	Cognitive processing for building a mental representation of the presented material as presented	Complexity of the material	Selecting (and initial organizing)
Generative processing	Cognitive processing aimed at making sense of the presented material	Learner's motivation to exert effort to learn	Organizing and integrating

and as indicated by the *organizing images* arrow, the learner arranges the incoming images into a coherent cognitive representation, which can be called a *pictorial model*. Finally, as indicated by the *integrating arrow*, the learner builds connections between corresponding aspects of the verbal and pictorial models and with relevant prior knowledge activated from long-term memory (which contains the learner's storehouse of knowledge). Once the knowledge is constructed in working memory, the learner can embed it in long-term memory for permanent storage. The learning process depicted in Fig. 31.3 also depends on the learner's motivation to want to make sense of the presented material and the learner's metacognition with respect to selecting, monitoring, and controlling appropriate cognitive processing during learning.

How to Design Multimedia Instruction that Fosters Multimedia Learning

The model of multimedia learning includes five cognitive processes for meaningful learning from multimedia instruction, as indicated by the five arrows in Fig. 31.3. Guiding these cognitive processes during learning is the primary focus of multimedia instruction. The major challenge for designing effective multimedia instruction is that meaningful learning requires that the learner engages in appropriate cognitive processing during learning, but the learner's capacity for processing information in each channel in working memory is extremely limited.

Drawing on Sweller's (1999, 2005; Brunken, Plass, & Moreno, 2010) cognitive load theory and Mayer's (2009; Mayer & Moreno, 2003) cognitive theory of multimedia learning, Table 31.1 lists three kinds of demands on the learner's cognitive processing capacity during learning. Extraneous processing is cognitive processing during learning that does not serve the instructional goal, and is caused by poor instructional design. For example, in a situation where an illustration is on one page and the text describing it is on a different page, the learner must engage in scanning back and forth between the corresponding words and graphics, which results in extraneous processing. Therefore, an important instructional goal is to design multimedia instruction in ways that reduce extraneous processing.

Essential processing is cognitive processing during learning that is required to mentally represent selected parts of the presented material as they were presented, and is caused by the inherent complexity of the material. For example, in a situation where a novice is learning a complicated concept, such as how a lightning storm develops, a great amount of cognitive processing is required to mentally represent the material. Therefore, an important instructional goal is to design multimedia instruction in ways that manage essential processing.

Generative processing is cognitive processing during learning aimed at making sense of the presented material by processing it more deeply, and is caused by the learner's motivation to exert effort to understand the material. For example, learners may explain a lesson to themselves, looking for inconsistencies with their prior knowledge. Therefore, an important instructional goal is to design multimedia instruction in ways that foster generative processing.

According to this triarchic theory, instructional designers must deal with situations in which learning tasks place three kinds of cognitive processing demands on learners (i.e., heavy processing demands) but learners possess limited capacity for cognitive processing during learning (i.e., limited processing capacity). Figure 31.4 summarizes three multimedia instruction scenarios, each requiring a different kind of multimedia instructional design solution.

In the extraneous overload situation (shown in the top of Fig. 31.4), the amount of extraneous, essential, and generative processing required for learning overloads the learner's available cognitive capacity (i.e., the amount of processing the learner can carry out at one time in working memory). If the learners are wasting precious cognitive capacity on extraneous processing, they may not have adequate capacity remaining for essential and generative processing, which are needed for meaningful learning. When an instructional scenario creates excessive extraneous cognitive processing, an important instructional goal is to design the lessons in ways that reduce extraneous processing.

In the essential overload situation (shown in the middle of Fig. 31.4), the need for extraneous processing has been eliminated or greatly reduced, but the amount of required essential processing still exceeds the learner's cognitive capacity. In this case it is not appropriate to reduce essential processing because essential processing is required for the

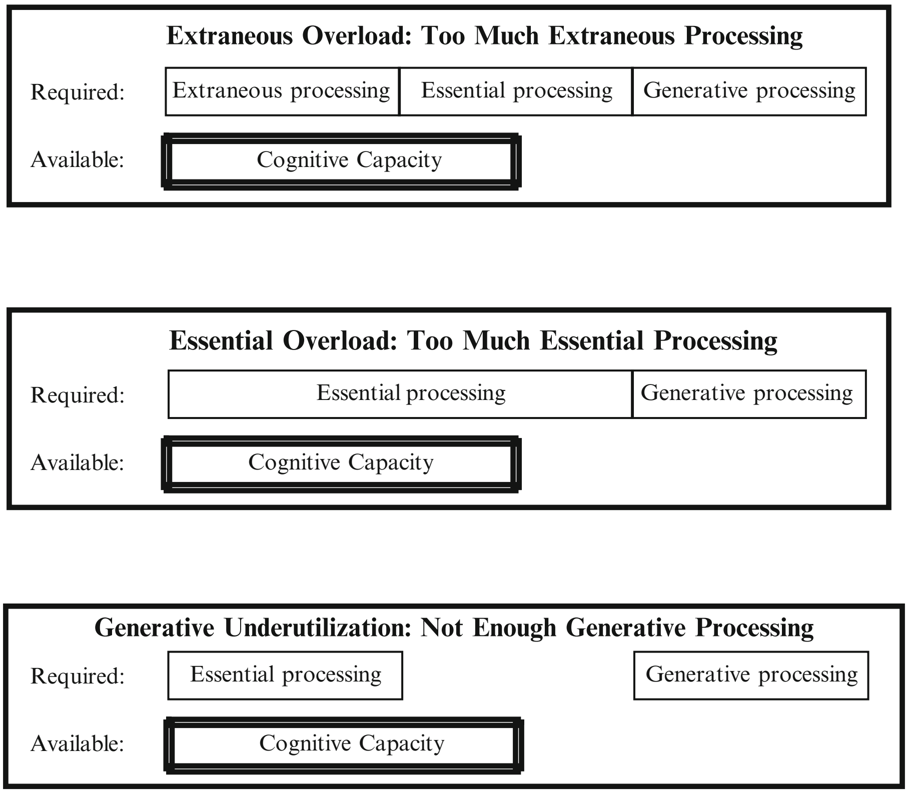

Fig. 31.4 Three demands on the learner's cognitive capacity during learning

learner to mentally represent the presented material (although with growing expertise learners will be able to chunk the incoming information in ways that minimize the demand for essential processing). When an instructional scenario creates excessive essential cognitive processing, an important instructional goal is to manage essential processing.

In the generative underuse situation (shown in the bottom of Fig. 31.4), extraneous load has been eliminated and essential load has been managed so the learner has cognitive capacity to engage in generative processing but chooses not to do so. In this case, an important instructional goal is to foster generative processing by designing instruction in ways that encourage the learner to engage in deeper processing (e.g., organizing and integrating) during learning.

Research-Based Principles of Multimedia Instruction

The triarchic theory suggests three instructional goals, each for a different instructional scenario—reduce extraneous processing for extraneous overload situations, manage essential processing for essential overload situations, and foster generative processing for generative underuse scenarios. This section explores some evidence-based principles for accomplishing each of these three goals. Most principles are based on research evidence as documented in one of three sources: (1) a handbook of research on multimedia learning (Mayer, 2005), (2) an Association for Psychological Science task force report on research-based learning principles applicable to education (Halpern, Graesser, & Hakel, 2007), and (3) a report issued by the US Department of Education on research-based learning principles applicable to education (Pashler et al., 2007). This section focuses on principles that consistently generate effect sizes greater than $d=0.40$, which Hattie (2009) argues is the level needed for practical relevance for education.

Principles for Reducing Extraneous Processing

Table 31.2 lists six principles for reducing extraneous processing—coherence, signaling, spatial contiguity, temporal contiguity, redundancy, and expectation principles.

The *coherence principle* is that people learn better from a multimedia lesson when extraneous material is excluded rather than included. For example, in a series of six experiments involving a multimedia lesson on lightning formation including both paper-based formats (Harp & Mayer, 1997, 1998) and computer-based formats (Mayer, Heiser, & Lonn, 2001) students performed better on a transfer posttest if they learned from a concise presentation than from an elaborated

Table 31.2 Evidence-based principles for reducing extraneous processing

Principle	Description	Example
Coherence (Halpern et al., 2007; Mayer, 2005)	Eliminate extraneous words and pictures	Cut out interesting but irrelevant anecdotes and cartoons
Signaling (Mayer, 2005)	Highlight essential words and pictures	Use an outline and headings; put key terms in bold font for a text lesson
Spatial contiguity (Halpern et al., 2007; Mayer, 2005; Pashler et al., 2007)	Place text next to the part of the graphic it describes	Embed each part of a caption next to the corresponding part of an illustration
Temporal contiguity (Halpern et al., 2007; Mayer, 2005)	Present corresponding graphics and spoken text at the same time	In a narrated animation, describe the events in audio at the same time they are depicted on the screen
Redundancy (Mayer, 2005)	Present graphics with spoken words rather than graphics with spoken and printed words	Do not add onscreen text to a narrated animation
Expectation (Halpern et al., 2007)	Present a preview of the test items or instructional objectives before the lesson	Before this section of the chapter, present the question: "What are the names, definitions, and examples of six principles for reducing extraneous processing?"

presentation containing added sentences, photos, or video clips that were interesting but not relevant to the explanation. The median effect size was $d=1.66$, which is large effect. In a follow-up study, students received a PowerPoint presentation on how a virus causes someone to catch a cold or on how the human digestive system works, which included inserted statements about the topic that were high or low in interest (Mayer, Griffith, Naftaly, & Rothman, 2008); the study showed that the low-interest group outperformed the high-interest group on a transfer posttest, with $d>0.80$ in both experiments.

Overall, these results are consistent with previous research showing that student learning from text is diminished when the text contains added *seductive details*—interesting but irrelevant sentences, such as amusing anecdotes or grizzly facts (Garner, Brown, Sanders, & Menke, 1992; Hidi & Baird, 1986; Mohr, Glover, & Ronning, 1984; Shirey, 1992; Shirey & Reynolds, 1988; Wade, 1992; Wade & Adams, 1990). For example, in a replication involving a text lesson on lightning formation, Lehman, Schraw, McCrudden, and Hartley (2007) found that adding interesting but extraneous sentences about lightning throughout a lesson resulted in significantly less learning ($d=0.88$) based on deep processing measures such as a holistic understanding score for student essays.

Adding background music or environmental sounds to a narrated animation on lightning or brakes also resulted in lowered transfer posttest performance, with a median effect size of $d=1.11$ based on two experiments (Moreno & Mayer, 2000a). Adding relevant factual or mathematical details to a multimedia lesson on how lightning works or how ocean waves work that are not needed to understand how the basic cause-and-effect system works also resulted in lowered transfer test performance, yielding a median effect size of $d=0.82$ across six experiments (Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Mayer & Jackson, 2005). Overall, there is strong and consistent evidence for the coherence principle based on well-controlled laboratory studies. The effect may be diminished for high knowledge learners (Ploetzner, Fehse, Kneser, & Spada, 1999) or for high working memory capacity learners (Sanchez & Wiley, 2006).

The *signaling principle* is that people learn better when the essential material and its organization are highlighted. Verbal signaling can take the form of putting essential printed text in bold font (or giving vocal emphasis to essential spoken text), adding an outline or graphic organizer containing the same words as in the text, adding headings that correspond to the outline, or including pointer words such as "first…second…third." Visual signaling can take the form of adding arrows, flashing, or a spotlight that grays out the nonessential areas. In a series of six experiments involving paper-based multimedia lessons on lightning or biology (Harp & Mayer, 1998; Stull & Mayer, 2007) and computer-based narrated animations on how airplanes achieve lift (Mautone & Mayer, 2001), students performed better on a transfer posttest when the presentation included verbal signals, yielding a median effect size of $d=0.52$. These results help extend earlier research on learning from text showing that verbal signaling improves students' retention of a text passage (Loman & Mayer, 1983; Lorch, 1989; Lorch & Lorch, 1996; Lorch, Lorch, & Inman, 1993; Meyer, 1975; Meyer, Brandt, & Bluth, 1980).

Visual signaling involving arrows was not found to be effective in promoting transfer posttest performance with animations on how airplanes achieve lift (Mautone & Mayer, 2001) and on how a toilet tank flushes (Hegarty & Kriz, 2007). In some cases transfer test performance was improved when online multimedia lessons included an onscreen agent who pointed to essential material in a worked example (Atkinson, 2002), when the appropriate portion of a worked example flashed on the screen as a narrator described it (Jeung, Chandler, & Sweller, 1997), and when spreading color was used to indicate the flow of activity in narration on piano mechanisms (Boucheix & Lowe, 2010). Spotlighting the appropriate portion of a narrated animation on the human heart as the narrator described it (by decreasing luminance outside the spotlight) improved transfer performance in one study (de Koning, Tabbers, Rikers, & Paas, 2007) but not in another (de Koning, Tabbers, Rikers, & Paas, 2010). Overall, there is moderate evidence for the benefits of verbal signaling but continuing research is needed to establish principles for visual signaling. The effect may be diminished for high-knowledge learners (Meyer et al., 1980; Naumann, Richter, Flender, Cristmann, & Groeben, 2007) or when the material is simple for the learner (Jeung et al., 1997).

The *spatial contiguity principle* states that people learn better when corresponding printed words and graphics are presented near each other on the page or screen. In a core set of five experiments carried out in our lab involving paper-based multimedia lessons on brakes and lightning (Mayer, 1989; Mayer, Steinhoff, Bower, & Mars, 1995) and a computer-based multimedia lesson on lightning (Moreno & Mayer, 1999a), students performed better on a transfer posttest if words describing each step in the process were placed next to the portion of the diagram they described rather than as a caption at the bottom of the diagram, with a median effect size of $d=1.12$.

Similar results favoring integrated presentation over separated presentation of printed words and graphics were found with paper-based lessons on mathematics (Sweller, Chandler, Tierney, & Cooper, 1990), engineering (Chandler & Sweller, 1991, 1992; Tindall-Ford, Chandler, & Sweller, 1997), and how the heart works (Chandler & Sweller, 1991), and with computer-based lessons on how a tire pump works (Bodemer, Ploetzner, Feuerlein, & Spada, 2004), statistics (Bodemer et al., 2004), and physics (Kester, Kirschner, & van Merrienboer, 2005). In a recent meta-analysis of 37 experiments on spatial contiguity, Ginns (2006) reported an average effect size of $d=0.71$ favoring integrated over separated presentation, and the effect size was $d=1.07$ for published studies that used posttest measures of transfer.

Overall, there is strong and consistent evidence for the spatial continuity principle involving both paper-based and computer-based multimedia lessons. The effect may be diminished for high-knowledge learners (Mayer et al., 1995), when the material is very simple for the learner (Ayres & Sweller, 2005), or when the graphic can be understood without accompanying words (Ayres & Sweller, 2005).

The *temporal contiguity principle* is that people learn better when corresponding spoken text and graphics are presented simultaneously rather than successively. Across eight computer-based experiments carried out in our lab, students who received simultaneous presentations (i.e., narration and corresponding animation, video, or slides at the same time) performed better on transfer posttests than students who received successive presentations (i.e., narration before or after animation, video, or slideshow), including multimedia lessons on tire pumps (Mayer & Anderson, 1991, 1992; Mayer & Sims, 1994), brakes (Mayer & Anderson, 1992; Mayer, Moreno, Boire, & Vagge, 1999), lungs (Mayer & Sims, 1994), and lightning (Mayer et al., 1999). The median effect size was $d=1.31$, which is a large effect.

These findings mesh well with classic studies in which students remembered more from a narrated movie on carnivorous plants (Baggett & Ehrenfeucht, 1983) or toy construction (Baggett, 1984) than one in which the sound track was misaligned from the movie. In a recent meta-analysis of 13 experiments on temporal contiguity, Ginns (2006) reported an average effect size of $d=0.87$ on learning outcome measures favoring simultaneous over successive presentation.

Overall, there is strong and consistent evidence for the temporal contiguity principle. The effects may be diminished when learners have control over the pace and order of presentation (Michas & Berry, 2000) and when the segments are very short (Mayer et al., 1999; Moreno & Mayer, 1999a).

The *redundancy principle* is that people learn better from graphics with spoken words than from graphics with redundant spoken and printed words. In a set of five computer-based studies involving lightning (Mayer et al., 2001; Moreno & Mayer, 2002a) and an environmental science game (Moreno & Mayer, 2002b), students who received a narrated animation (or narrated slideshow) performed better on a transfer posttest than students who received the identical presentation with on-screen text added as captions. The median effect size was $d=0.72$.

Similar results yielding similar effect sizes were obtained with computer-based lessons involving human memory (Jamet & Le Bohec, 2007), lightning (Craig, Gholson, & Driscoll, 2002), and electrical engineering (Kalyuga, Chandler, & Sweller, 1999, 2000) as well as paper-based lessons on temperature graphs (Leahy, Chandler, & Sweller, 2003) and math problems (Mousavi, Low, & Sweller, 1995). In a recent review, Sweller (2005) used a somewhat broader definition of redundancy, but also concluded that there was empirical support for the redundancy principle.

Overall, there is strong and consistent evidence for the negative consequences of adding redundant onscreen text to a narrated animation, video, or slideshow. The redundancy effect may be diminished when the onscreen text is shorted to a few key words that are placed next to the corresponding part of the graphic (Mayer & Johnson, 2008). When there are no graphics, presenting concurrent spoken and printed text can result in better learning than printed words alone when the verbal segments are short (Moreno & Mayer, 2002a) but not when they are long (Diao & Sweller, 2007).

The *expectation principle* is that people learn better when they are shown the type of test items in advance of the lesson. For example, when Mayer, Dow, and Mayer (2003) presented sample pre-questions before a narrated animation on electric motors, students performed better on a transfer posttest (with different transfer questions) than when students did not receive pre-questions, with an effect size of $d=0.83$.

Table 31.3 Evidence-based principles for managing essential processing

Principle	Description	Example
Segmenting (Halpern et al., 2007; Mayer, 2005)	Break a complex lesson into manageable parts	Break a continuous narrated animation into small segments, each controlled by an onscreen "Continue" button
Pretraining (Mayer, 2005)	Before a lesson, provide training in the names and characteristics of key elements	Tell people the name, location, and actions of each part in braking system before showing a narrated animation on how brakes work
Modality (Mayer, 2005; Pashler et al., 2007)	Present graphics with spoken text rather than with printed text	Present a narrated animation on lightning rather than an animation with onscreen captions

This finding meshes with classic research on adjunct questions in learning from text, in which pre-questions produced positive effects on retention (Boker, 1974; Rothkopf, 1966; Rothkopf & Bisbicos, 1967). Overall, there is promising initial support for the expectation principle, but more research is needed, including additional research on providing students with a statement of the instructional objective.

Principles for Managing Essential Processing

Table 31.3 lists three principles for managing essential processing—segmenting, pretraining, and modality principles. The *segmenting principle* is that people learn better when a complex lesson is presented in manageable parts. Learners can fully digest one segment of the lesson before moving on to the next segment. For example, Mayer and Chandler (2001) found that compared to viewing a continuous 2.5 min narrated animation on lightning formation, students performed better on a transfer test after viewing a narrated animation on lightning formation that paused after each of 16 segments until the learner clicked a "Continue" button. Similarly, compared to viewing continuous narrated animation on how an electric motor works, students performed better on a transfer test in two experiments if they could see the presentation broken into five segments, each started by the learner's mouse click (Mayer et al., 2003). Overall, across three experiments conducted in our lab, the median effect size across these three experiments was $d=0.98$, favoring the segmented group over the continuous group.

Similar results were obtained in which students learned better when worked-out examples were broken into manageable steps for solving probability problems (Gerjets, Scheiter, & Catrambone, 2006) and for solving algebra equations (Ayres, 2006), and in which students learned better when a complex graph was broken into parts (Lee, Plass, & Homer, 2006; Mautone & Mayer, 2007). Overall, there is a growing base of support for the segmenting principle, with a median effect size of $d=0.82$ across nine experiments. Concerning boundary conditions, Ayres (2006) provides some evidence that the effects of segmenting may be strongest for low-knowledge learners.

According to the *pretraining principle*, people learn better from a complex lesson when they receive pretraining in the names and characteristics of the key concepts. Less processing is required when the complex lesson is presented because the learner already knows about the key concepts. In a core set of five experiments carried out in our lab, students performed better on a transfer test when a narrated animation on brakes (Mayer, Mathias, & Wetzell, 2002) or tire pumps (Mayer et al., 2002) or a geology game about geology formations (Mayer, Mautone, & Prothero, 2002) was preceded by a brief introduction to the names and characteristics of each key component of the system. The median effect size was $d=0.85$, which is considered to be a large effect. Similar results with large effect sizes were obtained in computer-based lessons on statistics (Kester, Kirschner, & van Merrienboer, 2004) and electronics (Kester, Kirschner, & van Merrienboer, 2006), as well as paper-based lessons on electrical engineering (Pollock, Chandler, & Sweller, 2002) and mathematics (Clarke, Ayres, & Sweller, 2005). Overall, there is strong and consistent evidence for the pretraining principle across ten experiments, yielding a median effect size of $d=0.88$. Concerning boundary conditions, preliminary evidence suggests that the effects of pretraining may be strongest for low knowledge learners (Clarke et al., 2005; Pollock et al., 2002).

The *modality principle* is that people learn better from a multimedia lesson when words are spoken rather than printed. Removing printed words from the page or screen frees up capacity in the visual channel allowing more processing of the graphics, and providing spoken words offloads some on the processing demands onto the verbal channel, which has capacity available. In a set of 17 experiments on modality, my colleagues and I have found strong and consistent evidence that learners perform better on transfer tests when words in a multimedia lesson are spoken (as narrated graphics, for example) rather than printed on the screen (as captioned graphics), with a median effect size of $d=1.02$. The findings include computer-based lessons on lightning (Mayer & Moreno, 1998; Moreno & Mayer, 1999a), brakes (Mayer & Moreno, 1998), electric motors (Mayer et al., 2003), and biology (Harskamp, Mayer, Suhre, & Jansma, 2007) as well as an environmental science game (Moreno, Mayer, Spires, & Lester, 2001; Moreno & Mayer, 2002a, 2002b) and an aircraft simulation (O'Neil et al. , 2000).

Similar results with generally strong effect sizes have been reported in paper-based lessons on how to solve geometry

Table 31.4 Evidence-based principles for fostering generative processing

Principle	Description	Example
Multimedia (Halpern et al., 2007; Mayer, 2005; Pashler et al., 2007)	Present words and pictures rather than words alone	Present a narrated animation on lightning rather than a narration
Personalization (Mayer, 2005)	Put words in conversational style	Say "I" and "you" rather than only use third person constructions
Voice	Use human speech rather than machine speech	Use recorded sound files of human voice rather than machine-synthesized voice

problems (Mousavi et al., 1995), how to solve electrical circuit problems (Tindall-Ford et al., 1997), and graph reading (Leahy et al., 2003), as well as computer-based lessons on lightning (Craig et al., 2002), electrical engineering (Kalyuga et al., 1999, 2000), and solving math problems (Atkinson, 2002; Jeung et al., 1997). In contrast to 35 experiments favoring the modality principle, with a median effect size of $d = 0.88$, the modality effect was not obtained in a study in which the pace of the lesson was slow and under learner control (Tabbers, Martens, & van Merrienboer, 2004), thereby suggesting a possible boundary condition. In a meta-analysis based on 39 between-subjects comparisons, Ginns (2005) reported a mean effect size of $d = 0.72$ favoring the use of spoken words over printed words in multimedia lessons.

Overall, the modality principle has been more widely tested than any other principle, and has achieved a high level of empirical support. Some important boundary conditions that warrant further study include that the modality effect may be stronger when the material is complex (Ginns, 2005; Tindall-Ford et al., 1997), the relevant portion of the graphic is highlighted (Jeung et al., 1997), the words are familiar to learners (Harskamp et al., 2007), and lesson is fast-paced and under system control (Ginns, 2005; Tabbers et al., 2004).

Principles for Fostering Generative Processing

Table 31.4 lists three principles for fostering generative processing—multimedia, personalization, and voice. The *multimedia principle* is that people learn better from words and pictures than from words alone. The rationale is that multimedia presentations encourage learners to build connections between corresponding words and pictures, thereby causing them to engage in one of the key cognitive processes in meaningful learning—the process of integrating. Across 11 experiments conducted in our lab, students performed better on transfer tests when their lesson contained printed words and corresponding illustrations rather than printed words alone (Mayer, 1989; Mayer & Gallini, 1990) or spoken words and corresponding animation rather than spoken words alone (Mayer & Anderson, 1991, 1992; Moreno & Mayer, 1999a, 2002b), yielding a median effect size of $d = 1.39$. Similar findings were reported for a computer-based lesson on lightning (Moreno & Valdez, 2005) and for a lecture on learning principles (Moreno & Valdez, 2007; Moreno & Ortegano-Layne, 2008). Overall, there is strong and consistent evidence for the multimedia principle. Some possible boundary conditions are that the multimedia effect may be stronger for low knowledge learners (Kalyuga, Chandler, & Sweller, 1998, 2000; Mayer & Gallini, 1990) and for high-quality graphics (Schnotz & Bannert, 2003).

The *personalization principle* is that people learn better when the instructor uses conversational style rather than formal style. The rationale is that people try harder to make sense of the presented material (i.e., engage in the cognitive processes of organizing and integrating) when they feel they are in a social partnership with the instructor. Across 11 experiments carried out in our lab, students performed better on transfer tests when they received a multimedia lesson in which the words were in conversational style (such as using "you," "I," and "we") rather than formal style, including computer-based lessons on lightning (Moreno & Mayer, 2000b) and the human respiratory system (Mayer, Fennell, Farmer, & Campbell, 2004), and games on environmental science (Moreno & Mayer, 2000b, 2004) and engineering (Wang, Johnson, Mayer, Rizzo, Shaw, & Collins, 2008). The median effect size was $d = 1.11$, which is a large effect. The effect also applies to polite wording of feedback and guidance by online tutors in an engineering game (Wang et al., 2008), but was not obtained with online chemistry tutors in classrooms (McLaren, Lim, Gagnon, Yaron, & Koedinger, 2006). Continuing research is needed to pinpoint the conditions most suitable for using conversational or polite wording.

The *voice principle* is that people learn better when an online instructor speaks with a human voice rather than a machine voice. The rationale is that an instructor using a human voice is more readily accepted as a social partner (Nass & Brave, 2005), thereby fostering deeper cognitive processing during learning. In a set of three experiments involving computer-based lessons on lightning formation (Mayer, Sobko, & Mautone, 2003) and mathematics word problems (Atkinson, Mayer, & Merrill, 2005), students performed better on transfer tests when the onscreen agent spoke in a friendly human voice rather than a machine-synthesized voice, yielding a median effect size of $d = 0.78$. These results provide promising preliminary evidence for the voice principle, but a larger evidence base is needed. A potential boundary condition concerns the role of the match between the learner's and instructor's gender, race, ethnicity, or emotional state (Nass & Brave, 2005).

Complementary evidence across nine experiments shows that adding the instructor's physical image on the screen (such as a talking head or a motionless cartoon character) does not substantially improve learning (Atkinson, 2002; Craig et al., 2002; Mayer et al., 2003; Moreno et al., 2001), yielding a median effect size of $d = 0.26$. Thus, the available evidence does not provide strong support for what could be called the *image principle* (Mayer, 2009). One possible suggestion may be that the onscreen agent would be more effective if it engaged in human-like gesturing (Goldin-Meadow, 2003; Hostetter, 2011; Lusk & Atkinson, 2007), an intriguing idea that warrants further study and could be called the *embodiment principle*.

Finally, some other candidates for fostering generative processing—also relevant to non-multimedia environments (Mayer, 2011)—are the concretizing principle, the anchoring principle, the testing principle, the self-explanation principle, the worked-out example principle, the guided discovery principle, the questioning principle, and the elaboration principle. The *concretizing principle* is that people learn better when unfamiliar material is presented in a way that relates it with the learner's familiar knowledge, such as using concrete examples and analogies. Research on concrete advance organizers provides encouraging evidence that students learn more deeply from a text lesson when it is preceded with a familiar concrete model or analogy (Mayer, 2008). Research on the use of concrete manipulatives in mathematics instruction offers another source of encouraging evidence (Lillard, 2005). In a multimedia learning environment, for example, allowing students to move an onscreen bunny along a number line helped students learn about addition and subtraction of signed numbers (Moreno & Mayer, 1999b).

The *anchoring principle* is that people learn better when material is presented in the context of a familiar situation, such as embedding a lesson on algebraic functions within the context of running a pizza business (Brenner et al., 1997). Research on multimedia learning also shows that anchoring a mathematics lesson within the narrative of a realistic practical problem can enhance learning (Bransford et al., 1996).

The *testing principle* is that people learn better when they take a practice test on the material have studied. Research using noneducational materials provides promising evidence (Roediger & Karpicke, 2006), as do some preliminary findings using educational multimedia in a computer-based environment (Johnson & Mayer, 2009). The *self-explanation principle* is that people learn better when they are prompted to explain lesson elements during learning, an idea that has preliminary empirical support in multimedia environments (Johnson & Mayer, 2010; Roy & Chi, 2005). The *worked-example principle* is that people learn better when they are shown a step-by-step example of how to solve a problem, with commentary—a principle that has extensive support including some multimedia learning environments (Renkl, 2005, 2011). The *guided discovery principle* is that people learn better when they are allowed to solve problems while receiving appropriate guidance, a technique that has been successful with computer simulation (de Jong, 2005, 2011). The *questioning principle* is that people learn better when they must ask and answer deep questions during learning and the *elaboration principle* is that people learn better when they outline, summarize, or otherwise elaborate on the presented material (Mayer, 2011). Finally, providing high quality feedback has long been recognized as one the most powerful instructional techniques for skill learning (Hattie & Gan, 2011; Shute, 2008), so its role in multimedia instruction warrants further investigation (Ido, Aleven, McLaren, & Koedinger, 2011).

Conclusion

Multimedia instruction involves instructional messages that consist of words (e.g., spoken or printed text) and pictures (e.g., drawings, charts, photos, animation, or video). The science of multimedia learning is concerned with developing a research-based theory of how people learn from words and pictures. Three major principles for a cognitive theory of multimedia learning are that learners have separate information processing channels for verbal and visual material (i.e., dual channel principle), that learners can engage in only a small amount of processing in each channel at any one time (i.e., limited capacity principle), and that meaningful learning depends on the learner's cognitive processing during learning (i.e., active processing principle). The science of multimedia instruction is concerned with developing design principles for multimedia instruction that are consistent with research evidence and grounded in cognitive theory.

Three kinds of goals of multimedia instruction design are to minimize extraneous cognitive processing during learning (i.e., cognitive processing that does not serve the instructional goal), to manage essential processing during learning (i.e., cognitive processing needed to mentally represent the essential material), and to foster generative processing during learning (i.e., cognitive processing aimed at making sense of the material). Research on instructional effectiveness pinpoints the degree to which students perform better on subsequent transfer tests when multimedia instruction is based on instructional design principles. Some principles for reducing extraneous processing during learning are coherence, signaling, redundancy, spatial contiguity, temporal contiguity, and expectation. Some principles for managing essential processing during learning are segmenting, pretraining, and modality. Some principles for fostering generative processing during learning are multimedia, personalization and voice.

A logical next step would be to explore what makes the difference between extraneous processing and generative processing, that is, what determines whether added material is relevant to the instructional goal. In addition, continuing research is needed to determine the boundary conditions for each principle in multimedia instruction, such as the degree to which principles apply to different kinds of learners, learning objectives, and learning contexts.

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Authentic Learning Environments

32

Jan Herrington, Thomas C. Reeves, and Ron Oliver

Abstract

Authentic learning is a pedagogical approach that situates learning tasks in the context of future use. Over the last two decades, authentic learning designs have captured the imaginations of innovative educators who see the approach as a means to enable students to develop robust knowledge that transfers to real-world practice. Authentic learning has its foundations in the theory of situated cognition, together with other pedagogical approaches developed over the last two decades, such as anchored instruction. It offers an alternative instructional model based upon sound principles for the design and implementation of complex and realistic learning tasks. The technologies associated with technology-based learning provide ideal conditions for the implementation of the approach, both in blended and fully online courses. New Web-based technologies and mobile devices provide affordances—as both cognitive tools and delivery platforms—for dissemination of polished and professional authentic learning experiences. As educational institutions increasingly embrace the internet and Web-supported learning, the potential exists for authentic learning environments to be used widely to improve student learning. This chapter reviews the seminal and recent literature in the field, and provides a model of authentic learning for the design of learning environments across educational sectors.

Keywords

Authentic learning environments • Authentic assessment • Cognitive tools • Situated cognition

Introduction

> Learning methods that are embedded in authentic situations are not merely useful; they are essential. (Brown, Collins, & Duguid, 1989, p. 37)

Everyday life abounds with challenges, problems, risks and opportunities. In our personal and professional lives, we meet these challenges using the context and resources available to us—and in the process we learn. In everyday life, few successful problem-solving strategies ignore the context and limitations afforded by the real situation. However, in formal education settings, pedagogical strategies often ignore the real-world relevance of a learning context.

Authentic learning is a pedagogical approach that situates learning tasks in the context of real-world situations, and in

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so doing, provides opportunities for learning by allowing students to experience the same problem-solving challenges in the curriculum as they do in their daily endeavors. Over the last two decades, authentic learning has evolved from a situated learning model, and has captured the imaginations of innovative educators who see it as a means to facilitate the acquisition of robust knowledge that transfers more readily to real-world practice (Herrington & Herrington, 2007; Lombardi, 2007a, 2007b). The authentic learning environment model developed by Herrington and Oliver (2000) offers an alternative instructional model to a systems model such as Gagné's Nine Events of Instruction model (Gagné, Briggs, & Wager, 1992), by providing principles for the design and implementation of complex and realistic learning tasks. In 2010, Herrington, Reeves, and Oliver (2010) extended this model to e-learning environments.

Brief Account of Theoretical and Historical Foundations of Authentic Learning

Since Whitehead's *Aims of Education* (Whitehead, 1932), and Dewey's *Experience and Education* (Dewey, 1938) interest in realistic learning contexts has been strong. Such perspectives have provided a philosophical foundation for the general approach of "learning by doing". More recently, Fred M. Newmann and his colleagues at the University of Wisconsin in the USA (Newmann & Associates, 1996; Newmann, Marks, & Gamoran, 1996) have focussed on *authentic pedagogy* in the classroom and the importance of "real-world" activities and disciplined enquiry. Authentic learning as defined in this chapter has more specific origins in the theory of *situated cognition* or *situated learning* (Brown et al., 1989; Choi & Hannafin, 1995; Collins, Brown, & Newman, 1989), and *legitimate peripheral participation* (Lave & Wenger, 1991), together with other pedagogical models developed over the last two decades, such as *anchored instruction* (Cognition and Technology Group at Vanderbilt, 1990).

Theoretical Foundations of Authentic Learning in Situated Cognition and Legitimate Peripheral Participation

In the 1970s and 1980s, teachers and researchers in education began to investigate the notion of using apprenticeships for school-based instruction—the traditional model of master and apprentice that had been used for centuries—and to try to distinguish characteristics that were critical to its success in enabling learning. Their aim was to explore "cognitive apprenticeships", and to begin the process of developing a theoretical perspective based on the apprenticeship model, that cognitive science had, to date, not been able to explain. Brown et al. (1989) were the first to use the ideas to produce a proposal for a model of instruction that had implications for all sectors of education. In their model of situated cognition, Brown et al. (1989) argued that meaningful learning will only take place if it is embedded in the social and physical context within which it will be used. In its most simple form, situated learning was defined by Collins (1991) as: "the notion of learning knowledge and skills in contexts that reflect the way the knowledge will be useful in real life" (p. 122). During the 1990s, the further exploration of cognitive apprenticeships and situated learning (e.g., McLellan, 1996) coincided with rapid development in the educational uptake of multimedia, simulations, and eventually Web-based learning environments (Alessi & Trollip, 2001; Wilson, 1996).

In 1993, Brown and Duguid noted: "One of the most persistent educational questions following discussions of situated learning has been: How can these situated theories be operationalized?" (1993, p. 10). Although many people were writing in the area at the time (e.g., Carraher, Carraher, & Schliemann, 1985; Saxe, 1988; Scribner, 1984) and despite calls for a model of instruction to isolate those "critical elements" that made apprenticeships successful, no comprehensive model of the approach for classroom practice had emerged.

Other Related Work, Such as Anchored Instruction

Also in the late 1980s and early 1990s, researchers and developers at the Cognition and Technology Group at Vanderbilt University in the USA were exploring an approach to technology-based learning that they called *anchored instruction*, which develops specific content knowledge in the context of problem solving, and which places considerable emphasis on "creating an anchor or focus that generates interest and enables students to identify and define problems and to pay attention to their own perception and comprehension of these problems" (Bransford, Sherwood, et al., 1990, p. 123). Bransford, Vye, Kinzer, and Risko (1990) argued that this approach promotes transfer of knowledge by making it more accessible, and that students are able to distinguish between "knowing X" and "thinking to use X" (p. 391).

In designing their programs, the Cognition and Technology Group at Vanderbilt (1993) proposed that students begin with an information-rich resource which provides an effective starting point, not a final end point, for instruction. They also saw the process as a way to "equalize the preparation of the students" (p. 57), which was reminiscent of the concept of "bridging apprenticeships" proposed by Resnick (1987).

The well-known *Adventures of Jasper Woodbury* problem-solving series is a prime example of the kind of learning environment developed by the Cognition and Technology

Group at Vanderbilt (1997). Another is the Young Sherlock program (Bransford, Vye, et al., 1990) in which students use the feature-length film *Young Sherlock Holmes* as an anchor for investigating story writing, and the history of the Victorian era. Students investigate historical aspects such as contemporary inventions (Should Watson be riding in a carriage? Wasn't the car invented then?); scientific concepts such as the climate, weather and geography (Does it snow in December?); and literary elements such as grammar, plot and character development. Students use the video for a full semester to examine the film in detail often from multiple perspectives.

Numerous small and large-scale design studies were conducted to guide the development of the Jasper Woodbury Problem-Solving series that is the primary exemplar of anchored instruction. Extensive observational studies allowed the Vanderbilt team to derive design and implementation guidelines such as "…there are multiple ways to use Jasper, and that teachers need the freedom to adapt it to their own teaching styles" (CTGV, 1997, p. 62). Many small scale quasi-experimental "intervention studies" allowed the researchers to examine issues such as near and distant transfer from the problem sets in the Adventures of Jasper Woodbury Problem-Solving Series to other types of complex problems.

Eventually, the research team at Vanderbilt moved to large scale field trials of the Jasper materials. For example, a 1-year-long research project was conducted with the Jasper program in 16 schools in nine US states (Pellegrino et al., 1991). Comparing students in Jasper classes with those in traditional mathematics classes using quasi-experimental designs, the researchers investigated effects in terms of mathematical problem-solving and reasoning skills, specific mathematical knowledge and skills, standardized achievement test scores, and attitudes toward mathematics. The study used both quantitative and qualitative data collection methods. The results were generally favorable for the Jasper students. With respect to problem-solving, the Jasper students were more skilled in identifying problems and breaking them down into smaller components that would lead to solutions. Regarding specific knowledge and skills, the Jasper students outperformed the control students in areas such as decimals, fractions, and calculations of area, perimeter, and volume. The Jasper students also were better in solving three different types of word problems. Results were less positive in the attitude and achievement areas. Although the Jasper students had more positive attitudes toward mathematics at the end of the school year, they expressed no greater desire to study math than the control students. On standardized achievement tests, Jasper students tended to perform better than the others, but these particular results were not statistically significant.

The Cognition and Technology Group at Vanderbilt (1990) viewed anchored instruction as a practical application of situated cognition in formal educational settings. They acknowledged the logistical difficulties of placing learners into context-rich authentic environments within a formal schooling system, but argued that anchored instruction is a feasible way to provide context that is more manageable than organizing community-based projects (1993). Anchored instruction continues to provide a useful framework for the examination of scientific phenomena, particularly in the context of visual media within the realm of experience of the target students (Pellegrino & Brophy, 2008), and in relation to the wealth of video materials freely available on the internet, for example, on *YouTube* (Bonk, 2009, October 5).

A Framework of Authentic Learning

In response to the call by Brown and Duguid (1993) for a model of classroom practice to operationalize these theories, Herrington (1997) conducted a comprehensive review and analysis of the literature in these areas and proposed a model of critical characteristics of situated learning. Subsequently, a framework was developed in reference to the design of multimedia learning environments (Herrington & Oliver, 2000). This was later applied to Web environments (Oliver & Herrington, 2000), and then more generically to learning environments in higher education (Herrington & Herrington, 2006). A framework of authentic learning and authentic tasks was developed from this analysis, and was referenced to e-learning and technology-based learning in general (Herrington et al., 2010). This framework is described in more detail below.

Elements of Authentic Learning and Authentic Tasks

The characteristics that emerged to form a model of authentic learning from the research are listed below, together with a short but not exhaustive list of references of researchers who advocated each element. The framework proposes that an authentic technology-based learning environment employs the following characteristics:

An authentic context that reflects the way the knowledge will be used in real life: In designing technology-based learning environments with authentic contexts, it is not enough to simply provide suitable examples from real-world situations to illustrate the concept or issue being taught. The context needs to be all-embracing, to provide the purpose and motivation for learning, and to provide a sustained and complex learning environment that can be explored at length (e.g., Brown et al., 1989; Honebein, Duffy, & Fishman, 1993; Reeves & Reeves, 1997).

Authentic tasks: The learning environment needs to provide ill-defined tasks that have real-world relevance, and which present a single complex task to be completed over a sustained period of time, rather than a series of shorter disconnected activities (Bransford, Vye, et al., 1990; Brown et al., 1989; Lebow & Wager, 1994; Reeves & Reeves, 1997). The goal for completing such tasks comprises the creation of unique products to demonstrate achievement, even if there is an accepted and established procedure for solving the problem. Further research on characteristics of authentic learning tasks and activities (Herrington, Reeves, Oliver, & Woo, 2004) proposed further refinement of the nature of authentic tasks. Authentic tasks: are ill-defined, requiring students to define the tasks and subtasks needed to complete the activity; are investigated by students over a sustained period of time; can be integrated and applied across different subject areas and lead beyond domain-specific outcomes; are seamlessly integrated with assessment; create accomplished products valuable in their own right; and allow competing solutions and diversity of outcome.

Access to expert performances and the modelling of processes: To faithfully replicate the forms of support available to problem-solving in real-life contexts, authentic learning environments need to provide access to expert thinking and the modelling of processes, access to learners in various levels of expertise, and access to the social periphery or the observation of real-life episodes as they occur (Brown et al., 1989; Collins et al., 1989; Lave & Wenger, 1991). The facility of the Internet to create global communities of learners, who can interact readily via social networking, enables countless opportunities for the sharing of narratives and stories from experts and practitioners.

Multiple roles and perspectives: In order for students to be able to investigate the learning environment from more than a single perspective, it is important to enable and encourage students to explore the task from different perspectives, considering various points of view, and to "criss-cross" the learning environment repeatedly (e.g., Collins et al., 1989; Honebein et al., 1993; Spiro, Feltovich, Jacobson, & Coulson, 1991).

Collaborative construction of knowledge: Few complex problems in real-life are solved by people working independently. The opportunity to collaborate is an important element of an authentic problem-solving process. Consequently, tasks need to be addressed to a group rather than an individual, and appropriate means of communication need to be established. Collaboration can be encouraged through appropriate tasks and communication technology and is especially significant for students studying at a distance (e.g., Brown et al., 1989; Collins et al., 1989; Reeves & Reeves, 1997).

Reflection: Reflection is a critical element in the solution of authentic tasks. In order to provide opportunities for students to reflect on their learning, the learning environment needs to provide an authentic context and task, as described earlier, to enable meaningful reflection. It also needs to provide nonlinear organization to enable students to readily return to any element of the learning environment if desired, and the opportunity for learners to compare themselves with experts and other learners in varying stages of accomplishment (e.g., Boud, Keogh, & Walker, 1985; Kemmis, 1985; Schon, 1987).

Articulation: When students are required to articulate their ideas, the process strengthens their understanding and reasoning, and helps to identify any weaknesses or gaps in their thinking. In order to produce a learning environment capable of providing opportunities for articulation, the tasks need to incorporate inherent—as opposed to constructed—opportunities to articulate, collaborative groups to enable articulation, and the public presentation of argument to enable defense of the position (e.g., Collins et al., 1989; Edelson, Pea, & Gomez, 1996; Lave & Wenger, 1991).

Coaching and scaffolding: Students should not be left entirely to their own devices in authentic learning. Learning is best facilitated by the inclusion of deliberate coaching and scaffolding supports provided principally by the teacher but also by other means (e.g., a client for whom an authentic task is being undertaken). Authentic learning environments need to provide collaborative learning where, for example, more able partners can assist with scaffolding and coaching, and where teachers provide appropriate learning support (e.g., Collins et al., 1989; Greenfield, 1984).

Authentic assessment: The assessment in authentic learning settings needs to be tied directly to the successful solution of the task. As such, the learning environment needs to provide: the opportunity for students to demonstrate their effective performance with acquired knowledge, and to craft polished, performances or products in collaboration with others. It also requires the assessment to be seamlessly integrated with the activity, and to provide appropriate criteria for scoring varied products (e.g., Linn, Baker, & Dunbar, 1991; Reeves & Okey, 1996; Wiggins, 1993).

The elements of this framework are best considered as design guidelines rather than mandatory characteristics. In this sense, any learning environment or task can only be considered more or less authentic, so that elements are best viewed across a continuum (such as the method suggested by Reeves & Reeves, 1997 for gauging effective dimensions of interactive learning on the Web). Such a multidimensional approach would allow the overall trend of the

1. Higher-Order Thinking

lower-order thinking only 1... 2... 3... 4... 5... higher-order thinking is central

2. Depth of Knowledge

knowledge is shallow 1... 2... 3... 4... 5... knowledge is deep

3. Connectedness to the World Beyond the Classroom

no connection 1... 2... 3... 4... 5... connected

4. Substantive Conversation

no substantive conversation 1... 2... 3... 4... 5... high-level substantive conversation

5. Social Support for Student Achievement

negative social support 1... 2... 3... 4... 5... positive social support

Fig. 32.1 Five standards of authentic instruction (Newmann & Wehlage, 1993)

environment's authenticity to be gauged. Newmann and Wehlage (1993) used such a multidimensional approach to describe the five standards for authentic instruction illustrated in Fig. 32.1 (cf. Marks, 2000 who used this model to estimate student engagement; and Gulikers, Bastiaens, & Kirschner, 2004 who used it to explain the notion of authenticity as a continuum).

Other models of authentic learning have been put forth, although they have not been guided to an extensive degree by previous research. For example, Renzulli, Gentry, and Reis (2004) described four essential criteria for implementing authentic learning with middle school students. First, students should seek to solve a real-life problem to which they would attach an emotional commitment as well as a cognitive interest. Second, the problem should be sufficiently open-ended so that there are a variety of strategies for its solution. Third, the problem-solving strategies and the "solutions" developed should encourage students and other participants to change their actions, beliefs, or attitudes. Finally, the problem should have a real audience beyond the classroom. An example of authentic learning activity advocated by Renzulli et al. (2004) could involve students helping seniors at a local nursing home research their genealogical records. Callison and Lamb (2004) identified seven signs of authentic learning: (1) student-centered, (2) access to multiple resources beyond the school, (3) students working as scientific apprentices, (4) students collecting original data, (5) commitment to learning beyond the assignment, (6) authentic assessment of process, product and performance, and (7) team collaboration. Finally, Rule (2006) reviewed the literature on authentic learning and synthesized a model with the following four themes:

1. The activity involves real-world problems that mimic the work of professionals in the discipline with presentation of findings to audiences beyond the classroom.
2. Open-ended inquiry, thinking skills, and metacognition are addressed.
3. Students engage in discourse and social learning in a community of learners.
4. Students are empowered through choice to direct their own learning in relevant project work (p. 2).

It is possible to see similarities and consistencies among the different models describing the elements of authentic learning, with variations typically only in emphasis or how the ideas are expressed. The model we have researched provides further explanation and discrete elements to guide teachers in the design of authentic learning environments.

Authentic Learning in Practice

Well-designed authentic tasks can be used at multiple levels of education. Beginning in 1966, the Firefox project involved high school students in publishing a magazine about the folklore of the Appalachian Mountains (Wigginton, 1985). Today, authentic tasks are being used to guide learning in entire courses of study in colleges and universities around the globe (Herrington et al., 2010). In these courses, authentic tasks are not provided simply to enable students to practice skills that been taught in more didactic, content-focused ways. Instead, these tasks are integral to the way students engage with the course (Woo, Herrington, Agostinho, & Reeves, 2007). For example, learning the practices and conventions of critiquing was integral in a course on North American literature (Fitzsimmons, 2006), where students' first task was to write a guide for reviewing before they wrote literature critiques and reviewed each other's work. The students assumed the role of members of an editorial board, and they jointly selected the best papers for publication in an online journal.

In some cases, the affordances of a Web-based delivery primarily serve to strengthen the impact of an authentic task on student learning, if other elements of authentic learning designs are also in place, such as strong support provided by the teacher and collaborators. For example, Oh (2011) conducted a 2-year educational design research study of a graduate level evaluation course that was offered online to students in multiple universities. The primary pedagogical design was built around the authentic tasks of planning, conducting, and reporting an evaluation of an e-learning program for a real client. The course Web site provided multiple forms of scaffolding for the small groups of students responsible for completing these complex authentic tasks.

Creating an event that is able to instantiate learning in a particular area, and involve community beyond the student group, is a powerful way to incorporate authentic learning principles. For example, hospitality management students created and hosted the Appalachian Growers' fair (Deale, Elders, & Jacques, 2010) where students not only created a successful community event, but were also able to showcase local produce and model sustainable tourism.

Concerns About Authentic Learning Environments

As with any innovative pedagogical model, there are many arguments and discussions about authentic learning designs. For example, Merrienboer and Brand-Gruwel (2005) wrote: "authentic learning tasks must be carefully sequenced from simple to complex, that these tasks need to be performed in environments that gradually increase fidelity (i.e., similarity with reality) if learners acquire more expertise, and that learners' task performance is scaffolded by well-chosen means of problem solving support" (p. 414). However, there is much research to support the position that a less structured approach is more appropriate in dealing with complex problems. Table 32.1 lists some of the arguments and beliefs that have been reported in the literature (or anecdotally) to argue against the use of authentic learning designs in education, together with research that responds to these claims.

Although these objections will inevitably continue to be viewed by some educators as impediments to the effective use of authentic learning designs in education, they are primarily concerns about both the intent and the processes involved in authentic learning. Authentic learning is different from service learning or on-the-job training that is commonly conducted in real work settings. Authentic learning activities can be readily created and implemented in online as well as in classroom or blended settings. As educators increasingly embrace e-learning, the opportunities for authentic learning environments to be much more widely adopted increase considerably.

Issues in Authentic Learning Environments

The model of authentic learning has its foundations in the idea of authenticity, a construct that has many meanings and perspectives, and is open to interpretation. In this section, we wish to discuss four areas of interest and debate that have emerged in the literature.

Do the Context and Problems Need to Be Real?

Many educators believe that for a learning task or environment to be authentic, it must be real. Indeed, teachers have traditionally sought to provide real experiences through field trips, excursions, and internships that go beyond the walls of the classroom or lecture hall. Some researchers have urged teachers to ensure that when creating authentic learning environments, problems must be real. For example, Savery and Duffy (1996) stated three reasons why learning problems must address real issues:

> First, because the students are open to explore all dimensions of the problem there is real difficulty of creating a rich problem with a consistent set of information. Second, real problems tend to engage learners more—there is a larger context of familiarity

Table 32.1 Reported concerns about authentic learning designs and relevant research

Concerns	Relevant research
Students do not get their money's worth because there is no teaching	Oh (2011) found that the design and implementation of an effective authentic learning environment depend heavily on the engagement and feedback provided by the instructor
Students are left to their own devices without support to abstract meaning from the environment	In the context of hospitality education, Deale et al. (2010) found that knowledgeable, highly committed community partners and instructors could assist undergraduate students in planning, and conducting a successful festival
Finding real clients for students to work with is a difficult and time-consuming task for teachers	Clinton and Rieber (2010) describe an online system that allows clients to apply to have students enrolled in instructional design studio courses to complete real-world tasks for them
Authentic e-learning environments are expensive and time consuming to develop because they require realistic simulations with multiple possible outcomes	Meyers and Nulty (2009) describe how they provided environmental science students with authentic simulations derived from the actual data that the instructors were analyzing for their own research
Authentic tasks are suitable for vocational courses but not for higher education or personal growth areas like literature and the arts	Fitzsimmons (2006) gave students enrolled in his North American Fiction and Film course the authentic roles of Editorial Board Members of an online scholarly journal
For some courses there is no real-world application for the knowledge, so there can be no authentic task	For virtually any subject, students can learn through the authentic tasks of teaching others or designing instructional materials related to the topic (Herrington et al., 2010)
Students cannot perform complex and authentic tasks until they are taught the subskills required to complete it	Diamond, Middleton, and Mather (2011) describe how college level students worked as professional game developers to produce prototype learning games for clients from diverse disciplines and in the process learned the fundamentals of those disciplines

> with the problem. Finally, students want to know the outcome of the problem—what is being done about the flood, did AT&T buy NCR, what was the problem with the patient? These outcomes are not possible with artificial problems. (p. 144)

While Savery and Duffy (1996) described nonreal contexts and issues as "artificial problems", others have focussed more on the cognitive aspects of problem-solving activities to create a "cognitively real" learning environment. For example, Smith (1987) in his review of research related to simulations in the classroom concluded that the "physical fidelity" of the simulation materials is less important than the extent to which the simulation promotes "realistic problem-solving processes" (p. 409), a process Smith describes as the "cognitive realism" of the task. Luigi, Tortell, Morie, and Dozois (2006) also use the term "cognitive realism" to explain the use of sensory inputs in a simulation to reduce the necessity for photorealistic graphics.

Some researchers have found that spatial and physical representation of some elements in a learning environment can be beneficial, particularly for novice learners. For example, Chang, Lee, Wang, and Chen (2010) found that when robots were used instead of entirely virtual characters, younger students' perception of the authenticity of the task was enhanced, and they were more motivated to engage in the learning tasks.

However, highly realistic simulations of the kind used in training in the military, air pilot training, and in medical education are not necessarily efficient, nor indeed effective, in most educational settings. The physical verisimilitude to real situations is of less importance in learning than the cognitive realism, provided by immersing students in engaging and complex tasks (Herrington, Reeves, & Oliver, 2007).

Whose Authenticity? The Suspension of Disbelief

Authentic learning environments, of the kind we have described here, often require the willingness of students to "buy-in" to a scenario or problem explanation. For example, the task description might ask students to imagine that they are performing specialist roles such as: a member of a space agency team planning a mission to Mars (Reeves, Laffey, & Marlino, 1997), a professional lawyer working in a firm in a small town (Barton, McKellar, & Maharg, 2007), an accomplished researcher employed to investigate the closure of a school in a rural community (Angus & Gray, 2002); an expert consultant employed to investigate imbalance in an ecosystem (Brickell & Herrington, 2006); or a practising doctor conducting cervical screening tests (Keppell et al., 2003). Students can initially reject this predetermined role, yet, if they are to fully engage with the learning tasks, they need to commit to the environment and its parameters. This process was described by the early nineteenth century poet Samuel Taylor Coleridge as the "willing suspension of disbelief". The term has been applied to instances of human response to the arts, but it can be witnessed in learning contexts as well (Herrington et al., 2010).

While some argue that perception of authenticity is a personal response that is largely "in the eye of the beholder" (Gulikers, Bastiaens, Kirschner, & Kester, 2008, p. 401), there has been some research to indicate that a separation between real-world learning and its approximation can be accommodated in learning environments (Kantor, Waddington, & Osgood, 2000). For example, Petraglia (1998) contended that learners need to be *persuaded* that they are participating in an authentic learning environment, and that persuasion is "at the core of authentication" (Petraglia, 2009, p. 179). Further, Kantor et al., (2000) who, when referring to the kinds of goal-based scenarios they design, argued that their environments are as authentic as a staged production, that is, "to the degree that the staging of theatrical productions is authentic" (p. 222). As noted by Barab, Squire, and Dueber (2000) authenticity occurs "not in the learner, the task, or the environment, but in the dynamic interactions among these various components" (p. 38). Our research into the patterns of students' engagement as they suspend disbelief to engage in scenario-based learning environments (Herrington, Oliver, & Reeves, 2003) suggests that the use of authentic tasks encourages and supports immersion in self-directed and independent learning—an important success factor in online and technology-based learning.

While technology is increasingly providing opportunities for learning environments to create real products and real publications, there will always be a role for scenarios that situate a problem within a realistic rather than real context, and that enable students to explore problems with a range of resources available. Such learning environments provide opportunities for students to think and act like an expert, and it is in the design of these environments—we would argue—that the pedagogy resides.

Authentic Learning or Direct Instruction?

For decades, there has been a debate among educational researchers and learning theorists about the effectiveness of constructivist pedagogical approaches (Duffy & Jonassen, 1992). An especially provocative volley in the scholarly debate about constructivist learning theory and pedagogy was issued by Kirschner, Sweller, and Clark, long time proponents of direct instruction, when they published a paper titled *Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching* in the Spring 2006 issue of the journal *Educational Psychologist*. Their intentionally provocative article stimulated several rebuttal papers, and an edited volume: Tobias and Duffy's (2009) *Constructivist Instruction*: *Success or Failure*.

Kirschner, Sweller, and Clark (2006) defined learning as "a change in long-term memory" (p. 75) and maintained that the ineffectiveness of instructional models such as constructivism, discovery learning, problem-based learning, experiential learning, and inquiry-based learning stems from the failure to account for "human cognitive architecture." They declare that "Any instructional procedure that ignores the structures that constitute human cognitive architecture is not likely to be effective" (p. 76). It is not possible in this chapter to argue directly with the positions that Kirschner et al. (2006) have taken regarding the status of long-term memory as the bedrock of human cognitive architecture and the purportedly unassailable effectiveness of direct instruction. We leave such point-by-point debates to others such as Jonassen (2007) who has long argued convincingly that learning is more than a change in long-term memory.

However, it is unlikely to surprise anyone that the instructional model Kirschner et al. (2006) recommend is direct instructional guidance, defined as "providing information that fully explains the concepts and procedures that students are required to learn as well as learning strategy support that is compatible with human cognitive architecture" (p. 75).

Direct instruction is the antithesis of most instructional models that employ minimal guidance, but direct instructional guidance is regarded by Kirschner et al. (2006) as the only means to guarantee the transfer of knowledge and skills from experts to novices. The authors express disdain for instructional models that "challenge students to solve 'authentic' problems or acquire complex knowledge in information-rich settings based on the assumption that having learners construct their own solutions leads to the most effective learning experience" (p. 76). Kirschner et al. further conclude that any qualitative studies that purport to provide evidence of the impact of authentic or situated learning models are merely anecdotal in nature. They maintain that, by contrast, "Controlled experiments almost uniformly indicate that when dealing with novel information, learners should be explicitly shown what to do and how to do it" (p. 79). One problem with this contention is that few of the studies cited by Kirschner et al. deal with learning environments at the macro level of an entire semester-length course. Instead, the treatments used in their studies are more episodic and artificial, lasting from a few minutes to an hour. These studies do not generally examine long-term engagement in learning in which learners have a personal stake in achieving the outcomes, nor do they deal adequately with the challenge of learner motivation.

Kirschner et al. (2006) critiqued instructional models based on constructivism and social constructivism as too minimal in guidance and advised direct instruction. In fact, direct instruction may work best for novices in a field of study marked by fixed content and specific behavioral objectives. For instance, consider a novice Emergency Medical Technician (EMT) being trained as a Certified First Responder (CFR). It would certainly be inappropriate to recommend learning emergency medical protocols via discovery learning or any other minimally guided approach.

At the same time, direct instruction may be ineffective and inefficient when helping workers who have already developed some level of expertise and on-the-job experience. Consider an experienced first responder (police, EMT, firefighter) learning to deal with complex and potentially devastating weapons of mass destruction. Direct instruction would not be appropriate for such an audience. A social constructivist learning environment centered around authentic tasks is likely to be much more effective. In the light of our theoretical and practical perspectives concerning authentic tasks and evidence from a series of qualitative studies, we argue that there is still ample room for alternative conceptions of learning and creative constructivist pedagogical designs.

Affordances of Web 2.0 Developments as Both Tools and Delivery Platforms?

Over a decade ago, Gordon (1998) described three types of authentic learning challenge, with each level increasing in "authenticity, complexity, uncertainty, and student self-direction" comprising the following: academic challenges (the transfer of existing curricular material into a problem situation); scenario challenges (where students are given real-life roles); and real-life problems (where students provide real solutions for real clients). While we would argue that each of these types of learning environments is not part of a hierarchy, and each can be equally authentic (as we have defined it), there is a fourth authentic challenge that Gordon could scarcely have imagined: the creation of authentic products in a participatory Web environment.

Such authentic learning tasks engage students in the creation of genuine products that add to understanding and the documentation of a field. In a history context, the *Not just a name on the wall* Web site (Morrissey, 2006) encourages students not only to learn about history but to *be* historians, actively researching the life of a real soldier in World War 1 (selected from the names listed on war memorials). Students write historical accounts of soldiers and their battalions during the war. Similarly, in a large-scale project entitled the *Brisbane Media Map* (Collis, Foth, & Schroeter, 2009) students collectively map media and communication industry establishments in a large city, creating a database of over 600 organizations. Students collect information on each organization, effectively mapping not only physical location and services, but trends and issues across the sector. The products of such authentic learning tasks are not simply academic assignments that do not see the light of day beyond the teacher's desk, but are products of genuine worth of much interest to professionals and the general public.

Future Potential and Challenges

The future of education is interdisciplinary, and authentic learning will be an important component of that future. Knotts, Henderson, Davidson, and Swain (2009) describe their collaborative effort to involve their students in authentic interdisciplinary learning in subjects as diverse as art, drama, geography, and teacher education. Their authentic interdisciplinary learning designs were inspired by Bain's (2004) recommendations for new higher education teachers in his useful guidebook titled *What the Best College Teachers Do*. Although this type of learning collaboration among teachers from multiple disciplines can be enormously innovative and potentially quite effective, it is not without costs, especially for new tenure-track faculty members who might be admonished to spend more time on their discipline-focused research. One of the major issues that must be confronted in higher education by those promoting the renewal of high-quality teaching and learning (cf. Arum & Roksa, 2011; Palmer, Zajonc, & Scribner, 2010) is the balance between teaching and research.

There are many practical and theoretical questions that remain unanswered concerning the future of authentic learning designs in education. In particular issues such as the difficulty of designing convincing tasks to carry complex and sustained learning, and the role of participatory social technologies in facilitating the creation and publication of genuine products are significant major research areas. Further research in the practical use of authentic learning in universities (institutions that in turn have their own political and administrative restrictions) is also needed, such as the impact of restrictive administrative and assessment policies in higher education, and the means to reduce the high workload associated with e-learning student support especially in times of reduced funding and resources. The role of motivation in student accomplishment in authentic learning is another area of much interest that has not been fully explained.

The current research into authentic learning has provided teachers with a strong understanding of what elements are needed to create an effective and successful authentic learning environment. However, many teachers still find difficulty in designing an authentic learning environment. Further research into the description, sharing and reuse of learning designs will help to facilitate the application of authentic learning into mainstream teaching (Oliver, Herrington, Herrington, & Reeves, 2008).

These areas of research and other questions related to the design and implementation of authentic learning environments would be best addressed, we believe, through educational design research (McKenney & Reeves, 2013; van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). Educational design research differs from traditional experimental approaches that might be used to compare authentic learning designs with traditional direct instruction designs. At best, experimental studies can inform designers and researchers about which instructional mode (e.g., classroom instruction vs. authentic learning environment) leads to greater outcomes, although the most likely outcome is "no significant differences." Educational design researchers, on the other hand, seek to define differential outcomes explained by variance in the design features of different modes. Educational design researchers investigate design features, not just alternative instructional delivery systems, allowing them to identify which design feature is more effective than another with respect to a specific outcome, and why. Although educational design research is arguably still in its infancy as a research approach, it is being more widely adopted (Kelly, Lesh, & Baek, 2008), and it should be the method of choice for those who would advance the state-of-the-art of authentic learning environments.

Conclusion

Authentic learning as a pedagogical approach is especially appealing to educational technologists. It situates knowledge in realistic contexts, thereby contextualizing knowledge, and making it less likely to remain "inert" when needed to solve problems (Wilson & Schwier, 2009). The realistic tasks in authentic learning cognitively challenge learners to solve problems and to think in the same ways as professionals working in real-world contexts (Clinton & Rieber, 2010; Oh, 2011). Technology-based cognitive tools can be used to support both the processes and the products of learning in authentic environments (Kim & Reeves, 2007). In addition, the complex tasks implicit in the approach require the creation of real products and innovations, and are more worthy of the investment of time and effort in higher education than de-contextualized exercises and tasks (Herrington & Herrington, 2006).

Authentic learning may well be the defining pedagogical orientation of education in the twenty-first century, but this will not be accomplished without more and better collaborative educational design research by researchers and practitioners in the field of educational technology and communications.

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Feedback Models for Learning, Teaching and Performance

33

Elizabeth K. Molloy and David Boud

Abstract

This chapter focuses on the role of feedback in learning with particular emphasis on its effect on learner performance, motivation and self-regulation. The authors provide a critical account of definitions and models of feedback, tease out the conceptual roots of practice guidelines and highlight how individual, relational and environmental factors can impact on the utility of feedback as a performance changing device. Many of the conceptual models published in the literature draw on theoretical principles rather than empirical data to support the impact of feedback on learning/performance change. The empirical data from a diverse range of disciplines converge to a common finding—that written and verbal feedback in practice deviates considerably from principles of effective practice. The reasons for this theory–practice disjunction are explored, and the authors suggest that the lack of adoption of advocated principles may represent a need to look at feedback in a different way.

A constructivist view on feedback encourages learners and educators to view feedback as a system of learning, rather than discreet episodes of educators "telling" learners about their performance. Highlighting the need for a shift in conceptual framework is not enough however. What is limited in the feedback literature is how to achieve feedback encounters that are typified by learner engagement. We argue that contesting the traditional, behaviourist "feedback ritual" requires leadership from educators, and a deliberate commitment to curricular redesign with purposeful and structured opportunities for learners to engage in feedback episodes, to put into place changes triggered by feedback and finally to re-evaluate performance in relation to set goals. Such a "system-orientated" take on feedback design requires upskilling of both educators and learners and needs to factor in the influence of context, culture and relationships in learning.

Keywords

Feedback • Self-regulation • Learner agency • Behaviourist principles of learning • Constructivist principles of learning

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Part One: Feedback Origins, Purposes and Application

Introduction

Feedback is seen as a key process in learning, providing information on actual performance in relation to the goal of performance. There is a large body of literature arguing for

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the importance of feedback in learning, yet there is an accruing body of evidence pointing to an inability of feedback to perform its function in practice. In particular, learner surveys have indicated that feedback is one of the most problematic aspects of the student experience (Carless et al., 2010). Ironically, but not surprisingly, educators typically believe that their feedback is more useful than their students believe it to be (Shute, 2008). The educators' inflated perceptions of their own performance points to a key issue that lies at the heart of the "feedback problem"—that educators, like all learners, need feedback on their (feedback giving) skills in order to recalibrate and improve their practices.

There is mounting survey data to suggest that students are dissatisfied with feedback. The Course Experience Questionnaire (Krause, Hartley, James, & McInnis, 2005) and National Student Survey (Higher Education Funding Council for England, 2011) consistently report that graduates are more dissatisfied with feedback than any other facet of their programs. Even with this incoming data, educators seem to rationalise the reported dissatisfaction with factors inherent in learners. One rationalisation in the discourse is that learners do not understand what is meant by feedback (Hattie & Timperley, 2007; Shute, 2008) and therefore do not recognise "feedback" when it is provided. Another proposition is that learners are thirsty vessels for performance information and won't be satisfied regardless of the amount of attention given to them (Henderson, Ferguson-Smith, & Johnson, 2005). In both arguments, the "fault" is seen to reside with the learner, rather than stem from the skill of the educator, the appropriateness of the learning activity or the nature of the learning environment. This tendency for "deflection" happens frequently when there is a discrepancy between learners' internal perceptions (self-evaluation) and external teacher perceptions (feedback). Chinn and Brewer (1993) work suggests that when such a discrepancy arises, the receiver will reinterpret external feedback to make it conform with their own hope, intention or interpretation of their own practice. In the case above, educators may argue that there is nothing wrong with their actual feedback practice, but rather, the problem stems from learners' inaccurate interpretation of it.

This chapter critiques literature on feedback from a range of fields, including higher education and professional education, and focuses on untangling why feedback is seen as problematic. Part one will explore what is done in feedback in education, and part two will focus on how it might be done better. Our suggestions for improvement of feedback are not based on better spreading of the clear, and already established messages on how to "do feedback", but rather we call for a reconceptualisation of feedback that may be more effective and more conducive to uptake in practice. In presenting this alternative framework, we argue for less preoccupation in what educators "do" in giving feedback, such as how much information to give and at what time, and instead anticipate a shift towards a better understanding of how students seek, interpret and use data related to their learning and how programs are designed to foster this. It is hoped that an alternative framework, built on constructivist learning principles can encourage learners and educators to view feedback as a co-produced system of learning, rather than discreet, unconnected episodes of unidirectional "telling". Challenging traditional "feedback rituals" requires commitment to curricular redesign with purposeful and supported opportunities for learners to engage in feedback "episodes", to implement changes triggered by feedback, and to reassess their performance in relation to the target. Such a system-orientated view of feedback design dispels assumptions that "feedback is done to learners" and that "feedback ends in telling". The shift in conceptual framework and associated practices acknowledges that learning is co-produced by both learner and teacher, and is influenced by context and relationships. This shift in feedback ideology should translate to changes in learner and teacher approaches to feedback, and positions feedback as a process to build sustainable learning practices, rather than simply as a catalyst for immediate episodic behaviour change.

The Definition of Feedback

Feedback was discussed as a concept in the 1940s in the field of rocket engineering (Ende, 1983) and was defined as information that a system uses to make adjustments to reach a target or goal. Norbert Wiener, a researcher who helped create the science of cybernetics was one of the first to extend the concept to the social sciences. He stated that "Feedback is the control of a system by reinserting into the system the results of its performance. If these results are merely used as numerical data for criticism of the system and its regulation, we have the simple feedback of the control engineer. If, however, the information which proceeds backwards from the performance is able to change the general method and pattern of the performance, we have a process which may very well be called learning" (Wiener, 1954 p. 71).

Since this early conceptual declaration, feedback as a concept has had wide application in education, organisational psychology and business. Its purpose as a learning tool is to highlight discrepancies between actual performance and intended performance, with a motive to produce behaviour change. The premise behind the need for feedback is that novices, across any spectrum of knowledge or profession, have difficulty in understanding the performance target, and have difficulty in evaluating how their own performance matches up to the target. Feedback acts like a mirror, to reflect back to the learner "what their performance looks like". For some people, the external provision of feedback matches their own self-evaluation of performance. That is, there is good approximation of self-assessment of competence and the actual performed or displayed activity. Others rely on external feedback as a reference point to build the accuracy of their own self analysis. External feedback can be seen as a tool to encourage accurate self analysis. With this form of "data collection and comparison" over time, individuals can hone their self-evaluation skills to approximate external judgements. In other words, external feedback can help us to better judge the quality of our knowledge and work.

Interestingly, early experimental studies looking at the effect of feedback on performance attempted to eliminate the role of the internal, or self-evaluative function in feedback (Butler & Winne, 1995). Researchers focused on the effect of external provision of information on observable performance. In line with this behaviourist philosophy, psychologists have commonly employed a methodology focused on looking for relationships between treatments (stimulus) and behaviours (response) and hypothesise cognitive mechanisms behind these correlations. Harré and Van Langenhove (1999) argued that behaviourist psychology is not unlike chemistry methodology, where chemical reactions are observed and explanations are then sought in unobserved molecular processes. "The concept of person is secondary if it is invoked at all" (Harré & Van Langenhove, 1999 p. 43).

With more recent theoretical perspectives on learning, including constructivist ones (Mory, 2004; Price, Handley, Millar, & O'Donovan, 2010) that acknowledge the active role of the learner in co-producing knowledge, it appears that this behaviourist approach to studying and understanding feedback is severely limited, as it does not recognise the agency of learners. Despite the acknowledgement of these alternative and more recent theories to represent understandings about how people learn, much research in feedback, and many of the practice recommendations, continues to lean on a behaviourist view of feedback as external transmission of information. That is, the dominant view of feedback is that a more experienced person tells a less experienced person about their interpretation of what they did, and how to do things better (Butler & Winne, 1995). With this conception, it is not surprising that much of the feedback literature focuses on enhancing the teacher's capacity to deliver high quality information at appropriate junctures (Nicol & Macfarlane-Dick, 2006), rather than focusing on the role of the student in feedback.

Typically, as highlighted by Butler & Winne (1995), learners have rarely had explicit instruction or support in how to seek or use feedback, particularly when it might contradict or challenge their own internal view of how they see their performance. This observation leads us to think that in order to improve the effectiveness of feedback, we need to focus not only on improving the quality of the externally provided message but also on strengthening the self-evaluative capacity of learners (Boud, 2000; Nicol & Macfarlane-Dick, 2006; Yorke, 2003). This message about the need to shift focus to the role of the learner in engaging and using feedback, rather than focusing on the mechanics of the "sender's delivery" of feedback, forms the central premise in part two of this chapter.

Models to Explain How Feedback Works

There are a number of explanatory models available to aid understanding about how feedback works in learning. Some are linear and behaviourist in sentiment, some are circular to imply an iterative process, some ignore the internal capacities of the learner, and others represent the interplay between internal and external performance information and how this affects response or output.

Despite the variability in models, there seems to be consensus in the literature about three key components that constitute feedback in learning. That is, the prerequisite properties for feedback include: (1) information on the goal of performance, (2) information about how performance meets the goal, commonly referred to as the "gap" and (3) strategies to address the gap (Sadler, 1989). Similarly, Hattie and Timperley (2007) describe the three components of the process as the feed up (where am I going?), the feedback (how am I going) and the feedforward (where to next?).

A Mechanical Model of Feedback

The key premise of a mechanical or technological model of feedback, as applied to rocket engineering or the powering of steam engines is that information relating to current task/work is given to learners in order to change the quality of the subsequent task/work. This model implies that there needs to be detection of a change or influence in subsequent behaviour as a result of the information exchange. It also implies that there is a need for the teacher to do what is required in order to have an effect on student performance in the desired direction. In this model, the type of information that is most important is not that which relates to any aspect of the task itself, but rather, information that impacts on the conduct of subsequent tasks. Interestingly, studies that have examined feedback practices in situ, particularly in workplace learning, have indicated that only a small percentage of feedback content is dedicated to discussion of strategies for improvement in performance (Fernando et al., 2008; Molloy, 2009).

Feedback in a mechanical model means that feedback involves information used, rather than information that is transmitted. Ramaprasad (1983) aptly summarised this function in that "the information on the gap between the actual level and the reference level is feedback only when it is used to alter the gap" (p. 6). The most obvious downfall of this model in it's mechanistic roots, is that it assumes that the

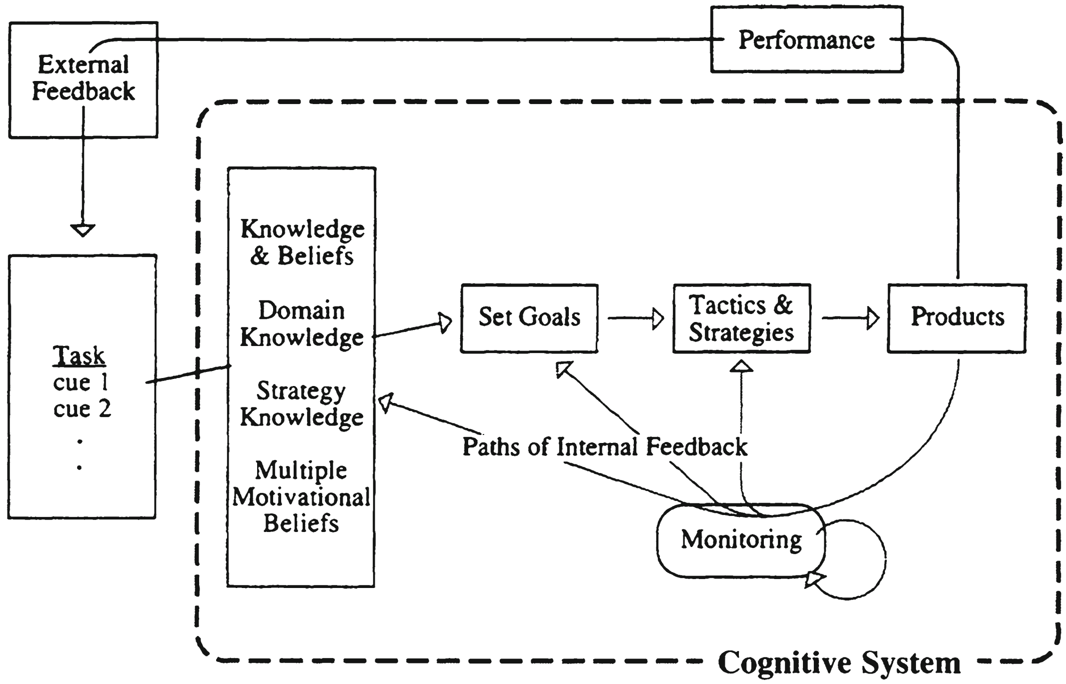

Fig. 33.1 A model of feedback as self-regulated learning. From Butler and Winne (1995) with permission

learner needs a teacher to provide the information that they need to learn and it assumes that the learner will respond to the "feedback intervention" in a predicable way. In the "messy" real-life context of education, where learners have the capacity to construct their own learning, and engage in activities with varying intention, the mechanical model of feedback does not hold up.

A Constructivist Model of Feedback

If learners are viewers as active players in constructing their own understanding, a constructivist model of feedback is more appropriate to represent the practice of seeking, giving, receiving and acting on feedback. The model acknowledges that feedback not only acts to improve subsequent performance of the task, but that the very process helps the learner to self-regulate. Under the constructivist framework, feedback is repositioned away from an episodic tool with a short term impact, to a process that builds skills over time. Boud (2000) wrote about the concept of sustainable assessment, and Hounsell (2007) extended this concept into "sustainable feedback" where feedback helps to promote student capacities in monitoring their own learning.

A model to explain the complex, multi-factorial workings of feedback where the student is central to the process (and not the educator's skill in collection and delivery of performance information), is provided by Butler and Winne (1995) (Fig. 33.1). The standout feature of this model is that feedback is conceptualised as intrinsic to self-regulation.

This conceptual model places the learner at the centre of the feedback process and explicitly acknowledges that the learner is actively making links between their goals in learning, the strategies or approaches they use to achieve this target and the performance outcomes. This comparative process, may cause the student to change their understanding of the goal, or may cause them to tweak or refine the strategies they chose to attempt to reach the goal. The educator (or external body which may constitute peer, practitioner or client) then provides additional external information that helps to further inform the "adjustment process". The internal and external feedback loops enable the learner to interpret a task's properties, and to design strategies or tactics to reach the desired goal. The model also acknowledges the impact of motivation on learning and performance.

Kulhavy and Stock (1989) examined the complexities of how external feedback may confirm, complement or contradict the internal feedback (or self-evaluation) of the learner. The researchers devised a "response certitude model" to explain how learners cope with a discrepancy between self-evaluation and external feedback. Chinn and Brewer (1993) and Butler and Winne (1995) also focused on how learners collect and make sense of internal and external information relating to performance. It is notable that these researchers focused on the role of the learner in seeking, interpreting and acting on feedback, rather than on the design or delivery mechanics of externally provided feedback. The "sustainable feedback" model respects students' agency and emphasises the development of students' dispositions for evaluative judgement that extend beyond the "formal education" period.

Butler and Winne (1995) identified six key ways that learners could interact with external feedback to render feedback ineffective. These "maladaptive responses to feedback" were observed and classified in the following ways; the learner can ignore the external feedback, reject the external feedback, view the feedback as irrelevant, perceive that there is no connection between the internal and external feedback, reinterpret the external feedback to make it align to the internal judgement (i.e. hear what they want to hear), and finally, act on the feedback in a superficial way to satisfy the assessor/feedback sender in contrast to making legitimate shifts in knowledge or practice on the basis of external feedback. In all these six instances, the influence of external feedback on behaviour change is likely to be minimal.

Students use internal and external feedback to assess the strengths and deficits in their performance, so that high quality characteristics or behaviours can be reinforced, and that less than optimal characteristics can be modified. Again, dominant conceptions of feedback emphasise that feedback is a tool for the learner's benefit. Sadler (1989) and Nicol and Macfarlane-Dick (2006) emphasise that feedback, as a system, also informs the educator about aspects of their teaching effectiveness. This less visible and discussed function of feedback is highlighted later in the chapter.

Effects of Feedback on Learner Performance and Motivation

Feedback is widely viewed as an intervention to improve learner performance. As reported by Pritchard, Jones, Roth, Stuebing, and Ekeberg (1988) "the positive effect of feedback on performance has become one of the most accepted principles in psychology" (p. 338). This was the accepted wisdom until the mid 1990s when a large scale meta-analysis on feedback was published by Kluger and DeNisi (1996) in *Psychological Bulletin*. In their analysis, the authors found that while on average, feedback improved task performance by 0.4 of a standard deviation, feedback in fact reduced performance in over one third of the cases. This finding led the researchers to explore the conditions or variables that rendered feedback either helpful or detrimental to performance. Hattie and Timperley's (2007) meta-analysis of feedback interventions also showed considerable effect size variability, supporting Kluger's claim that the approach used in feedback has a significant bearing on whether or not it is useful. A key proposition to emerge from the research is that feedback can have a debilitating effect on performance if it is delivered in a way that is perceived to threaten learners' "self" (Kluger & DeNisi, 1996).

This potential for feedback to debilitate rather than facilitate performance improvement is also a key thesis in papers by Shute (2008) and Nicol and Macfarlane-Dick (2006). Dweck (1999) explained the detrimental effect of feedback on motivation and performance in terms of the characteristics and world-view of the individual learner. Students who responded poorly to feedback, were seen as inhabiting a "fixed" or "entity" view where they saw their ability as finite and capped. In contrast, those learners who responded to feedback with subsequent positive behaviour/performance change were characterised as possessing an "incremental view" where they viewed their capacity as malleable and contingent on effort and motivation. Those learners with a fixed view of their own capacity had a tendency to interpret feedback relating to failure at task as failure of self and this response served to demotivate action.

Like all issues relating to feedback design, delivery and uptake, two parties are involved in the "feedback dance" and it is too simple to claim that a learner's disposition alone creates the predicted response above. The motivational beliefs of learners can be generated and/or influenced by the way educators provide feedback. For example, a common "feedback guideline" for educators is to phrase feedback in a way that emphasises behaviours related to task, rather than overarching or personalised characteristics such as overall ability or likeability or intelligence (Ende, 1983; Nicol & Macfarlane-Dick, 2006). Feedback that deviates from task and focuses on fixed qualities of "self" are likely to have a negative effect on motivation and performance (Butler, 1987; Narciss, 2008; Shute, 2008).

Kluger and Van Dijk (2010) have ventured further into the "feedback puzzle" in an attempt to understand the variable capacity of feedback for both good and harm. Rather than focusing on the self-efficacy of the learner, the researchers investigated how the nature of the task itself can interact with the utility of external feedback. The authors have postulated that people approach tasks or performances with two mind sets; either with a promotion focus or prevention focus. This regulatory focus of the learner determines whether positive (affirming) or negative (corrective) feedback is going to be more effective in soliciting behaviour change. In simple terms, a promotion focus involves things "people want to do" and a prevention focus is applied when "people have to do" tasks. A promotion-focused task is often based on problem solving and searching for new understandings, and a prevention-focused task is typified by vigilance and adherence to rules in order to avoid failure.

In their experimental study, Kluger and Van Dijk (2010) found that under a promotion focus, people are more responsive to positive feedback, whereas negative feedback tends to be more effective for people under a prevention focus. This research suggests that a one size fits all model on "how to give feedback" is not appropriate. It takes skill for the educator to judge the regulatory foci of the learner, and therefore, the type of feedback that will support the desired change. The findings also challenge educators to examine the properties of their own teaching and learning environment (Molloy, 2010). For example, in practical placements in medical education, error avoidance is important in protecting and optimising the patient's health—the learner (novice doctor) is operating in a high stakes environment, where their actions have potentially "life and death consequences". There are other professional cultures that value and thrive on creativity and innovation, and within these learning cultures, a promotion focus may reign over prevention. This research highlights the complexity of feedback in learning, and the centrality of context in influencing effective feedback practice. The role of the learner's history, cognition, and self-efficacy, along with the nature of the task in question, appears to influence the impact of the message. Such research prompts us to question the value in rolling out generic best practice feedback frameworks, which seem destined to collapse under loading in authentic practice.

Effects of Feedback on the Educator

Typically, feedback is viewed as a tool to help the learner. The less discussed function of feedback is as a mechanism to help the educator. Yorke (2003) reported that "the act of assessing has an effect on the assessor as well as the student. Assessors learn about the extent to which they [the students] have developed expertise and can tailor their teaching accordingly" (p. 482). An example of such feedback is in collating written test results. If a large number of students fail to answer a particular question correctly, the teacher may use this information as a surrogate for the quality of their teaching of the content knowledge.

Another example to illustrate how feedback can provide benefits to the educator, is when the learner receives feedback on their performance, and is then provided with an opportunity to make the suggested changes in performance. This subsequent performance loop can be analysed to assess the extent to which the advice is translated to a change in behaviour. The educator needs to structure a subsequent "practise opportunity" post-feedback to allow for the student to exercise any new knowledge gains. As an example, if a teacher observes a student-teacher in action with a class full of children and notes that the student-teacher has difficulty in controlling childrens' behaviour, they may provide feedback such as "… one thing that helps me in this situation is to do A, B and C …" It is important that the supervisor observes a subsequent class to see whether this strategy has indeed been effective in changing the class dynamic. If there is no change in dynamic, the supervisor is challenged to evaluate their own advice and collectively the learner and educator need to generate alternative ideas or strategies to help the learner achieve the goal. In summary, the learner's post feedback response provides the educator with "data" to evaluate the appropriateness or effectiveness of their own feedback and advice on performance improvement. It could be argued that without knowledge of the effect of any inputs on actual learning, as revealed through performance on subsequent tasks, no feedback has occurred, merely information that the teacher believes would be valuable.

Factors Impacting on Feedback Quality

Content

Sadler's seminal (1989) paper identified three essential properties in order for students to experience benefit from feedback. Students need to (1) have an understanding of the goal of performance, or reference point, (2) engage in an act of data comparison between the goal of performance and the actual performance and (3) attempt to close the gap between desired performance and actual performance using action or strategy. Much of the observational approaches to feedback research highlight the lack of time that educators spend on explicating performance targets and providing strategies to address the performance gap (Molloy, 2009; Nicol & Macfarlane-Dick, 2006). That is, students often do not understand the objectives of learning/performance and educators often do not spend time discussing tangible strategies for improvement (Hattie, Biggs, & Purdie, 1996). As Sadler (1989) eloquently reported, if educators do not provide information on the gap between the actual and reference level, and do not help devise strategies to alter the gap, we simply have a construct called "dangling data" (p. 121). It could well be that the dissatisfaction surrounding feedback is reflective of the dangling data that students can't use.

There are ample guidelines published on how educators should structure feedback messages, particularly in relation to how much time should be devoted to affirmation of performance, and criticism of performance. Kluger & DeNisi (1996) research on the interaction of "feedback sign" (positive versus negative) with the regulatory foci of the learner is an exception within the ocean of guidelines that are crafted on the basis of claiming to protect the self-esteem of the learner. A prime example of a model that is frequently advocated in educator training on feedback is the "Feedback Sandwich" (Henderson et al., 2005). In such a model, the educator is assigned the task of softening the blow when providing constructive feedback on performance, so that the information on deficits in performance becomes the meat in the sandwich, wedged between two slices of carbohydrate flattery. The ensuing conversation takes a predictable path that both educators and learners learn to navigate. Rather than a useful framework, this model can be seen as reductionist, tokenistic and paternalistic (Molloy, 2009). The learner anticipates the "important message" in the middle, and learns to disregard the complements on performance as part of a mandated linguistic ritual.

Many authors on feedback have honed their focus on to the impact of feedback on self-concept formation, and the tendency for learners to react defensively to feedback. The speculation regarding the "damaging impact" of feedback has led to the formulation and dissemination of simplistic models that in fact deviate from the original purpose of feedback, as conceptualised in cybernetics. That is, rather than feedback acting as a mirror—to reveal performance, gap in performance, and strategies to bridge the gap between desired task performance and actual task performance, it becomes a social convention of apparent honesty wrapped up in nicety, that the learner has to negotiate and decode through time.

The tension for educators in giving feedback oscillates between acting with sensitivity and delivering with honesty. This presents a challenge to educators across all sectors of higher education. Ende (1983, 1995) studied how doctors/supervisors gave feedback to students in medical education and observed that these supervisors went to great lengths to avoid upsetting learners. Ende coined this observed phenomenon "vanishing feedback" where, in an attempt to avoid a negative emotive reaction, educators disguised or avoided the constructive or corrective information, so that the learner was not privy to the important message, and consequent potential for performance improvement. As reported by Higgs et al., (2004) "Giving feedback that preserves dignity and facilitates ongoing communication between the communication partners, but that also leads to behavioural change, is a challenge." (p. 248).

Feedback characterised by "disguised corrective strategies" is fraught with danger. Students may not pick up on errors in their learning or practice, and may leave the learning encounter with an inflated sense of mastery (Ende, Pomerantz, & Erickson, 1995; Ilgen & Davis, 2000). This has implications not only for their immediate skill base, for example, essay writing ability or competence in a technical "hands on" task, but also impacts negatively on their self-evaluative capacity, as it is through the provision of external feedback that learners calibrate their own internal judgements.

Rather than engaging in models of feedback designed to soften messages, what would happen if we stopped underestimating learners' ability to process and act on truthful feedback? What if we took an alternative route and instead channelled energies into better orientating learners to the purpose of feedback, and provided them with frequent opportunity to seek, listen and respond to honest feedback, and align this to their own self-evaluation, throughout their programs?

Other guidelines for educators on the provision of effective feedback include the focus on behaviours and specific performances, not generalisations (Shute, 2008). And that observable decisions and actions are highlighted, rather than educators' own hypotheses around the student motivations or intentions behind performance approaches (Ende, 1983). Assuming a learner's intentions, without asking them for an explanation about their chosen approach to task is one way of devaluing their agency as a learner, and depriving them of the opportunity to self-evaluate and reflect. This practice positions the educator as the expert, and the learner as the passive recipient of information. A descriptive study by Latting (1992) suggested that educators from a psychology or health background have a tendency to adopt a diagnostic role (hypothesising causes of under performance) in feedback as a "hang over" from their clinical knowledge paradigm. "Clinically trained clinical educators who have developed skills in assessing the underlying causes of behaviour may be especially prone to offer their interpretations of a subordinate's behaviour" (Latting, 1992 p. 426). Good educators, like good learners, are those who engage in critical reflection and examination of their patterns of engagement in feedback; looking for historical, social cultural and pedagogical influences that might shape their habits.

Timing

The majority of generic feedback models available to teachers advocate that feedback is most effective when delivered immediately post-task engagement (Ende et al., 1995; Hattie & Timperley, 2007). However, delving into the feedback research reveals a more complex picture in relation to timing (Kulik & Kulik, 1988; Shute, 2008). Clariana, Wagner, and Roher Murphy (2000) found that there is merit in delaying feedback on complex tasks that involve greater degrees of processing. In such cases, delaying feedback can provide the learner with reflective space to evaluate performance and consider alternative ways to approach similar subsequent tasks. The immediate atmosphere of the learning environment and the emotional state of the learner may also determine the optimal time to engage feedback encounters. For example, in workplace learning scenarios such as in a classroom or a hospital, it may not be productive or appropriate to provide the "learner" with immediate feedback on their performance if pupils, patients or colleagues are present. Capacity for receptivity to external feedback is also diminished if the learner is highly emotive due to the nature of the task engagement (i.e. working with an unwell or dying patient) or is disappointed with their performance on the task (Molloy, 2009).

Qualities (and Perceived Qualities) of the "Teacher"

The perceived status of the feedback provider carries significant weight to the feedback message. Novices value feedback from their superiors, because of their perceived expertise (Asghar, 2009; Liu & Carless, 2006; Molloy & Clarke, 2005; Poulos & Mahony, 2008). The perceived ability and experience of teachers builds a case for trust and credibility, and therefore, learners are more likely to "listen to" and "act on" the feedback messages.

This interpretation of the status of the sender may impact on the use of peers in providing meaningful feedback to learners. In principle, a learner's peers are in a prime position to give meaningful performance information. Research in both university and workplace learning settings has indicated that student peers can often serve as the most accessible, and often, most invested, parties in the learning experience (Falchikov, 2002; Fantuzzo & Riggio, 1989; Ladyshewsky, 2010). It is for these reasons that they offer great potential to provide feedback to each other. The benefits of receiving feedback from different and additional sources is often written about, but less so, is the benefit that students gain from the act of giving feedback to others, as a result of the peer interaction (Ladyshewsky, 2010). This benefit occurs as the "peer tutor" must observe the tutee task/performance, think about how this relates to the goal of the task/performance (and therefore engaging in task/performance expectations) and reorganise and explain the material in accessible terms to the "peer tutee" (Fantuzzo & Riggio, 1989).

Peers are free from the constraints inherent in evaluation or summative assessment, and therefore, there is potential for disclosing honest information relating to deficits in learning, knowledge and performance. They often tend to be more available than teachers and may frame observations, gaps in performance and recommendations in language that is more accessible and meaningful (Ladyshewsky, 2010). However, despite these advantages, peers are commonly viewed as lacking expertise, and therefore, their feedback, despite how sophisticated and accurate, may not have the same reach as an equivalent message delivered by an expert in the field (Falchikov, 2002). This observation points to the potential value of peer feedback in areas in which peers manifestly have expertise. That is, they can have particular value in revealing whether the learner has clearly communicated to them.

Often mixed with the concept of expertise, but not a direct result of content/context expertise is the use of an authoritative or judgemental voice in feedback. This mode of delivery of performance information implies that the viewpoint cannot be contested—that is, the feedback is stated as fact, rather than positioned as a subjective construct that can be negotiated with the learner. The danger of feedback delivered in such a tone is that it can discourage the learner from self-evaluation or exploring an alternative view on the episode or performance in question. Carless et al., (2010) discusses the "terseness" or "finality" of one-way written or verbal comments, that do not invite any addition or modification or contesting by the learner. This mode of feedback delivery does not provide the learner with a sense of agency in their learning. This use of final vocabulary (Rorty, 1989) leaves the learner no room for manoeuvre: it closes options whether offered in positive or negative form, and discourages self-regulation (Boud, 1995).

Part Two: Creating a Learner Disposition to Seek and Use Feedback?

Disparate Educator and Learner Perspectives on How Feedback Is Given and Used

As highlighted in the introduction, educators typically rate the quality of feedback provided higher than learners' equivalent ratings. In particular, learner surveys have indicated that feedback is one of the most troublesome aspects of the student experience (Carless et al., 2010; Krause, Hartley, James, & McInnis, 2005). Students report deficits in the amount of feedback provided and in the quality of feedback provided. Observational studies in higher education seem to confirm students' self-reported dissatisfaction with the delivery of feedback, in that students often do not act on feedback to improve the quality of their work. A review by MacDonald (1991) concluded that many students do not read written feedback provided by educators, and those who do are not guaranteed to act on the messages. This finding was supported in a later study by Sinclair and Cleland (2007), revealing that less than half the students in the study collected the formative information made available. These results point to two key messages; (1) educators need to start responding to feedback about their feedback practices and (2) the focus in the feedback research and discourse is inappropriately centred on the role of the educator in "transmitting feedback" rather than on how students seek and use it.

Another finding from the research on feedback is that educators and students may have a shared conception of what "good quality" feedback *should look like*. However, the view of what feedback *actually looks like* is a different proposition. Molloy's (2009) study of learners and supervisors in feedback in clinical education revealed this disjunction. In phase 1 of the study, both parties emphasised the importance of a dialogue, as opposed to an educator-led monologue, and the provision of invitations or opportunities for student self-evaluation. In Phase 2 of the study, analysis of 18 feedback sessions between student and educator in clinical education showed that there was minimal input from students in the sessions. On average, the feedback interactions lasted for 21 min and the students' contribution accounted for less than 2 min of the "conversation". In the post-feedback session interviews, educators acknowledged the unidirectional nature of their feedback, despite "good intentions" and attributed this monologic tendency to time constraints, lack of trust in students' insight to formulate accurate self-evaluation, and complying with students' expectations of a transmissive exchange of knowledge from expert to novice. The findings suggest that educators may be focused on the short term benefits of feedback (i.e. the effect of the message on immediate performance) rather than the long term benefits of increasing students' capacity to self evaluate and self correct.

A Relational View of Feedback

Educators and learners may be able to parrot with accuracy "principles of effective feedback", yet researchers are accruing data to suggest that feedback is not carried out in accordance with these principles (Fernando et al., 2008; Krause, Hartley, James, & McInnis, 2005; Shute, 2008). One hypothesis for this lack of translation into practice, is that the models, or guidelines are not fit for practice. That is, they cannot be readily taken up by those involved.

The evidence supporting the lack of uptake in practice does not necessarily forecast the probability of doom and gloom in the landscape of feedback in higher education. Like any "feedback", this gap or incongruence between idealised practice and actual practice can provide an impetus to improve what is done. The incongruence can be seen as an avenue for re-examining what we think constitutes good feedback for learning. The remedies for poor feedback practice are not as simple as "spreading the word" to educators, or "saying the same message, but saying it louder" or refining mechanics in the process. As Carless et al., (2010) state, "tinkering with feedback elements such as timing and detail, is likely to be insufficient. What is required is a more fundamental reconceptualization of the feedback process" (p. 2).

To summarise, empirical evidence suggests that feedback is complex and that it can have both positive and negative effects on performance, depending on characteristics of the learner, the task and the learning setting. The interrelationship between the learner, the educator, the environment, the practice/knowledge culture and the specific task mean that a one size fits all model on "how to do feedback" is likely to fall down on many levels in application. Not only do the results point to an over-simplification of conceptions of feedback practice, but they also suggest that current feedback conceptions and practices may be overly informed by a unilateral and behaviourist view of education (Biggs, 1993). The observations of feedback in situ, and the collection of learners and educators' perceptions on intention and action indicate that feedback is commonly seen as a tool for the student, delivered by the educator, and for the purpose of improving the student's immediate performance on an equivalent or directly related task (Nicol & Macfarlane-Dick, 2006). Observational studies of verbal feedback reveal didactic provision of information from educator to learner. This model of practice positions the educator as the expert and the learner as the dependent and passive recipient of information who must take whatever is given.

Most guidelines on feedback imply that we know what to do to improve the effectiveness of feedback, and that improvement (and consequent improvement in student satisfaction ratings) will result from urging teachers to be more prompt in providing comments to students, and to provide this information more frequently. The most common institutional response is simply to mandate the frequency of verbal feedback delivery (i.e. once/day or once/week in the workplace setting) or to make rules about the speed of return of comments on written submissions of work. Such a response again appears to be leaning on behaviourist principles of learning, and ignores the role of the student in feedback episodes.

The importance of learners developing self-evaluative capacities through feedback is starting to gather momentum within the higher education literature (Boud, 2000; Boud & Falchikov, 2007; Carless et al., 2010; Hounsell, 2007; Nicol, 2009). This movement in feedback, as seen through a constructivist learning lens, pivots off Boud's (2000) notion of "sustainable assessment" where learners and educators work together to produce practices to meet immediate assessment requirements without compromising the knowledge and skills important for ongoing and independent learning. Carless et al., (2010) furthered this concept in the context of feedback research and refers to "dialogic processes and activities which can support and inform the student on the current task, whilst also developing the ability to self-regulate performance on future tasks" (p. 3).

Carless et al., (2010) view of a better way to do feedback, underpinned by the theories of constructivist learning (Price, Handley, Millar, & O'Donovan, 2010), puts (1) the student at the centre of the feedback experience, and (2) frames feedback as an iterative, continuous *part of learning* that helps the learner to develop independent skills in self-monitoring and self-regulation. Through providing external information on how performance matches up to goals of performance, educators are modelling critical reflection skills that help learners to calibrate capacity for their own internal appraisal. The learner's continuing comparison between internal and external information, and heightened trust in self-evaluation over time, is strengthened through regular opportunities for learners to self-evaluate. As Riordan and Loacker (2009) comment "the most effective teaching eventually makes the teacher unnecessary" (p. no). Sadler (1989) also commented on the value of actively engaging learners in self-assessment and therefore developing sustainable learning practices.

How Did We Get from Cybernetics to Sandwich Making?

One of the questions that begs to be answered is how has the original concept of feedback, as first discussed in cybernetics

(1954) evolved into the dominant practice we see in contemporary higher education? On a conceptual level, it is easy to see the advantages of controlling a system through reinserting into the system the results of its performance. The situated and social nature of learning (Harré & Van Langenhove, 1999) means that simple information provision to humans about performance can have an impact beyond its intent. Research in organisational psychology has demonstrated the multiple factors that can influence learners' receptivity to, and use of feedback, including both their own self-concept and the regulation foci of the specific task. Awareness of these sensitivities have manifested in "rules" about how to conduct fair and balanced feedback (Molloy, 2010). These rules of engagement may help create better learners or may in fact generate a teaching and learning encounter that departs from the original purpose for which it was designed. For example, there are times when students' performances do not warrant affirmation, and yet some models of feedback advocate that praise is a feature at the start and at the end of the feedback communication. Another example of potential deviation from purpose, is the idea that feedback should relate to the episode observed, and should not relate to past performance. This convention stems from principles of fairness and protecting the student from cognitive bias in assessment. This preservation of fairness is good in theory, but in practice, changes feedback from a continual and iterative process promoting looping between performance standards, performance, advice/remediation and subsequent task performance. In giving the student "a clean slate", feedback has morphed into a catalyst for immediate behaviour commentary and change, rather than an as a process to build sustainable learning habits.

Implications for Program Design

As a one-size-fits-all model such as the "feedback sandwich" fails in practice, we are loathe to present a list of instructions or prescriptive guidelines on how to do feedback under a constructivist framework, particularly when these claims are not substantiated through multiple research studies. There are, however, key overarching principles that might help generate healthy educational habits in both learners and teachers, and strategies to incorporate within the curriculum to support these ideals.

1. *Creating learner disposition for seeking feedback*
   If students are made aware of the advantages of feedback through suitable task design and sequencing, and have frequent opportunities to engage in productive, dialogic exchanges with multiple others, they are more likely to see feedback as a tool for "them" rather than as a destabilising or debilitating act "done to them" by those in authority. Generating this disposition is largely about providing regular opportunities to seek, listen to and act on feedback and to be provided with "sanctioned space" to both reflect on performance criteria and to reflect on how internally and externally generated feedback support or contradict each other. Henderson et al., (2005) commented that this provision of regular opportunities to practise feedback would mean that students would start to see engagement in feedback as habit, rather than as "an act of bravery". Another important strategy for reducing the emphasis on feedback as a one-way transmission from teacher to student is to involve peers and/or consumers in feedback provision (Ladyshewsky, 2010). Reaching for feedback sources outside the traditional teacher-learner relationship affirms the status of the learner as one with "agency" who makes knowledge rather than receives knowledge.
2. *Orientation to the purpose of feedback in learning*
   Both students and educators need to see feedback as a system of promoting learning through fostering active learners, not as individual acts of information provision and reception. That is feedback is not viewed "as telling" and "does not end in telling". Equally it is not a process that is *done to* students, *by* educators. All stakeholders in the environment need to be explicitly orientated to the purpose of feedback, and to view it as a means to increase skill in self-monitoring and self-regulation.
3. *Explicit*, *nested*, *iterative tasks*
   Students and those providing feedback need reminders that it is necessarily an ongoing loop linking (1) performance targets, (2) actual performance, (3) strategies for improvement to bridge the gap and (4) observation of opportunities for subsequent change in performance. Students report that they do not have a clear understanding of assessment goals or criteria and educators can work hard to explicate the standard or reference point. (Rust et al., 2003). Sadler (1983) promotes the use of student exemplars in order to develop an improved personal knowledge of what constitutes "quality work". Likewise, more professions are using videotaped exemplars of "best practice" in technical or practical skill execution, so that students have a readily accessible bank of performance targets by which to compare their own performance. Formative assessment tasks need to be positioned within the curriculum so that students have subsequent opportunities to enact the changes stimulated by feedback. For example formative feedback may be provided on tasks throughout a semester. Feedback at the end of a semester is less likely to be formative as learners are much less have an opportunity to utilise useful information in their immediate work. Without this subsequent practice opportunity loop, students are not able to see the benefits of feedback as a tool that changes practice, and educators are not able to judge the effectiveness of their interventions.
4. *Practising judgement*
   Early in the curriculum, students should have opportunities to judge their own performance, and to see how this

appraisal "stacks up" to external appraisal. This may constitute regular activities to assess students' content knowledge or it may take the form of criterion referenced assessment processes that learners engage in following written or practical skill performance. In the case of verbal feedback exchanges (for example post-oral presentation or post-workplace learning placement), educators can scaffold students self-monitoring capacity through asking questions about the student's own account of the performance. Clarifying or exploratory questions posed by the educator can encourage learners to think further about their learning, and help the learner to "own" their insights, rather than being told. Questions such as "how do you think you went?" "is this feasible?" "can you explain what you mean by?" serve as prompts for students to exercise their judgements. The subsequent provision of educator opinion may then validate, contest or calibrate the learner's internal evaluation, strengthening knowledge about the relationship between task goal and execution.

These four pillars of program design are likely to afford conditions favourable to effective feedback provision and uptake. The propositions include, but extend beyond the mechanics of feedback content and delivery, and are directed at higher levels of curricular design and implementation. The innovations designed to improve feedback processes in higher education need to be shared, and robustly evaluated for the effect on both learners and educators. These instances of "program level" changes need to be the focus of the next wave of feedback research. We already have plenty of data to reveal the widespread discontent with current processes.

Conclusion: Feedback and Self-Evaluation as Habits for Sustainable Learning

This chapter has outlined key research into feedback in an attempt to distill the properties that render it useful for learning. Students consistently rate feedback provision as problematic, and educators are starting to acknowledge that what they think they should do in feedback differs to what they enact in practice. The didactic nature of feedback exchanges, and the lack of engagement of students in the messages, points to a need to reorientate thinking on feedback for learning. A revolution, sparked by the observations and ideas of Boud, Price, Nicol and Carless, is starting to hit higher education. The challenge for educators is to embody these ideas, to depart from the traditional role as "director" of feedback and to focus on how to create a student disposition that seeks and uses multiple forms of feedback. The drive towards sustainable feedback practices requires commitment and skill from both learners and educators, and a progressive withdrawal of didactic performance information from the educator as students demonstrate skill and confidence in self-monitoring. Generating a discourse based on constructivist learning principles and the sharing of program design "wins and failures" should help align goals of, and practices in, feedback. The innovations designed to generate these sustainable learning habits, and the accompanying evaluation data, needs to be the focus of the next iteration of this chapter. That is the feedforward.

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34 Advanced Technologies for Personalized Learning, Instruction, and Performance

Mieke Vandewaetere and Geraldine Clarebout

Abstract

The inclusion of computer technology in education has led to increased attention for personalized learning and instruction. By means of personalized learning, or adaptive learning, learners are given instruction and support directly, adjusted to their cognitive and noncognitive needs.

This chapter aims at giving an overview of the current research that addresses advanced technologies, models, and approaches to establish personalized learning, instruction, and performance. In order to provide this, relevant learner and learning characteristics need to be measured or inferred and incorporated in learner models. These learner models provide the basis from which personalization can occur and have to be considered as the core of personalized learning environments.

In order to provide dynamic personalized learning, learner models need to be adjusted and updated with new information about the learner's knowledge, affective states, and behavior. To do so, the fields of artificial intelligence and educational data mining provide advanced technologies that can be applied for fine-grained learner modeling. First, the field of artificial intelligence in education has largely supported the development of intelligent tutoring systems. Second, educational data mining is indispensable for providing information about the learning process and learner behavior.

The integration of artificial intelligence and educational data mining in the learner modeling research provides a firm basis for effectiveness research on personalized systems. This chapter is concluded with the call for educational technologists to use advanced technologies as a method to support personalized learning and not as a goal when developing adaptive learning environments.

Keywords

Artificial intelligence (AI) • Artificial intelligence in education (AIED) • Learner modeling • Educational data mining (EDM) • Personalized learning • Adaptive system

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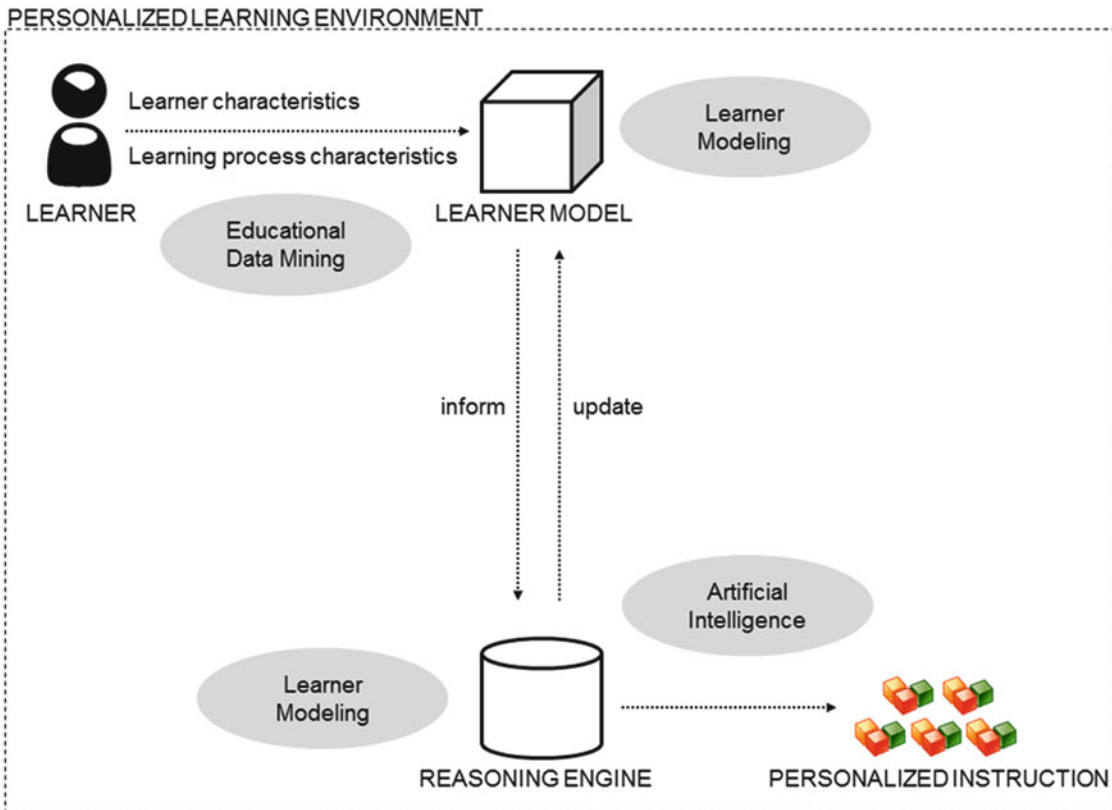

Fig. 34.1 Structure of a personalized learning environment—learner model and reasoning engine

Introduction

Personalized instruction was originally presented by Keller, with his personalized system of instruction (PSI; for a discussion, see Lee & Park, 2008; Lockee, Larson, Burton, & Moore, 2008, in the previous edition of this handbook). In 1974, Keller discussed 10 years of research on PSI and shot a glance at the future of personalized instruction. Keller (1974, p. 8) stated, "we need technology and we need reform, and there is no good reason why they cannot work together." Furthermore, Keller stated: "Such evidence as we have today makes me believe that personalized instruction is going to survive—that the days of traditional group education may be numbered. I foresee some major attacks upon the plan when its impact is more widely felt and its implications are better understood, but I have no doubt about the outcome. PSI, or something very much like it, is here to stay" (Keller, 1974, p. 8).

The current research and methods available for personalized learning, by means of adaptive and intelligent technologies, demonstrate that the words of Keller were somewhat understated. In the previous edition of this handbook, Shute and Zapata-Rivera provided an extensive overview of adaptive technologies and discussed why instruction should be adapted to learners (Shute & Zapata-Rivera, 2008). Also in the previous edition, Lee and Park (2008) thoroughly reviewed the approaches to adaptive instructional systems.

This chapter presents an overview of advanced methods and technologies for the development of personalized learning, by means of adaptive and/or intelligent systems. The distinction between adaptive and intelligent is rather historically situated and has become less pronounced with recent computational advances. In short, originally it was stated that adaptivity in a system does not make that system intelligent, or the other way around. Although adaptive and intelligent technologies are two different notions, there is no clear-cut distinction between adaptive and intelligent systems (Brusilovsky & Peylo, 2003). Adaptive systems take into account the learner-related information in the learner models and thereupon behave differently for different students or groups of students; intelligent systems apply artificial intelligence (AI) techniques to provide more and better support or instruction for their learners. As presented in Fig. 34.1, the challenge for both adaptive and intelligent systems is first to have an effective learner model that measures and captures the relevant learner and learning process characteristics. Secondly, there should be an appropriate reasoning engine that links the values of the features in the learner model with appropriate adjustments in the instructional system.

The answer to these challenges can be found in the domains of AI and educational data mining (EDM), both providing advanced technologies to extend learner modeling and provide adaptive and intelligent systems. In what follows, the research on learner modeling is discussed first. This overview is followed by a discussion on how research on AI in education and EDM research can enhance the traditional learner modeling approach in personalized learning. Each section describes the use of the technologies for personalized learning and concludes with a discussion of the technology's challenges and potential for the future.

Learner Modeling for Personalized Learning

Learner modeling research is also known as user modeling (UM; in hypermedia and Web applications research) and student modeling (in intelligent tutoring research). Generally, the user model is the heart of an adaptive system providing personalized learning. The more (relevant) information a model contains, the more adaptive the system is and the more personalized the learning can be. Learner models can contain a variety of information, depending on the goals of the instructor or the developer.

Static or Dynamic Approaches to Learner Modeling

Learner models range from very basic models, including one or more learner characteristics (e.g., prior knowledge, learning styles, and motivation) to which a system can adapt, to more advanced, highly dynamic models. When the learner model is built before a learner enters the learning environment, this model can be considered as static (Vandewaetere, Desmet, & Clarebout, 2011). Adaptation is then based on pre-task measurements of learner characteristics and takes place before the instruction starts. Such learner models contain more general information (Rich, 1979) and allow that learners can be classified into several groups or stereotypes. Based on this classification, an instructional strategy is chosen. This approach is a typical example of the aptitude–treatment interaction-based research (Shute, 1992). Triantafillou, Pomportsis, Demetriadis, and Georgiadou (2004) presented this approach by selecting a specific instructional style based on the learner's cognitive style as measured in terms of field (in)dependency. A major disadvantage of this approach is that context effects are ignored and that not all learner characteristics are equally relevant to be included in the learner model. For example, there is no adequate evidence base to justify personalization based on learning or cognitive styles (Pashler, McDaniel, Rohrer, & Bjork, 2008). Next to this, computational power has largely increased in the last decades and has instigated more advanced models, for at least the effectiveness of adaptive instruction may vary for different instructional contexts (Park & Lee, 2003). Context is determined not only by characteristics that differ between learners but also by intra-individual differences (e.g., several learning moments). As a consequence, a dynamic approach of modeling has become viable and advisable.

An example of this is feature-based modeling, a more fine-grained and dynamic modeling approach that has been the dominant approach in Web-based adaptive systems (Brusilovsky & Millán, 2007). Individual learner characteristics are captured in feature-based learner models. Such models are able to dynamically track changes in the learners' individual characteristics so that an updated model can be delivered during the learner's interaction with the environment.

The combination of stereotype models and feature-based models combines the best of both modeling approaches and is considered as a promising direction in learner modeling research (Brusilovsky & Millán, 2007). In this approach, the learner is first classified according to a stereotype where after an individual feature-based model is initiated (Tsiriga & Virvou, 2003). In this way, adaptive systems can easily deal with the typical "new user" or "new learner" problem, where no profile information of the learner is available and the modeling process has to start from scratch (Brusilovsky & Millán, 2007).

Methods and Techniques for Learner Modeling

Dynamic UM and, hence, learner modeling research typically uses AI and machine learning techniques for dynamically creating learner models. Such techniques can be applied to recognize patterns in learner characteristics and behavior and to integrate the patterns in a learner model. Soft computing technologies have been presented as a highly promising approach to environments in which learners are not able or willing to give feedback on their actions or in which it is important that learner characteristics are measured unobtrusively (Frias-Martinez, Magoulas, Chen, & Macredie, 2005). Methods such as fuzzy logic enable to easily represent the way human tutors evaluate learners (Fazlollahtabar & Mahdavi, 2009; Jeremic, Jovanovic, & Gasevic, 2009; Nasraoui & Petenes, 2003; Xu & Wang, 2006). A second technique focuses on neural networks that are able to predict learner's responses and errors and are therefore able to offer adaptive learning paths based on predicted responses of learners (Beck, Jia, Sison, & Mostow, 2003; Beck & Woolf, 2000). Each technique of the soft computing technologies captures a specific aspect of learner behavior. The task of the researcher is thus in selecting the most appropriate method for developing the most optimal learner model.

Next to soft computing approaches, applications of Bayesian probabilistic approaches have been reported by different authors (Conati, Gertner, & vanLehn, 2002; Nokelainen, Tirri, Miettinen, Silander, & Kurhila, 2002; Shute, Graf, & Hansen, 2005). Bayesian networks can deal with a broad range of variables, as demonstrated in the work of García, Amandi, Schiaffino, and Campo (2007), who proposed a Bayesian network for detecting students' learning styles. In the research of Conati et al. (2002), successful implementations of Bayesian networks in order to create student models were demonstrated in the Andes tutoring system.

All approaches mentioned in this paragraph are related to dynamic modeling and may give the impression that static modeling is not appropriate anymore or even superseded. Recent research demonstrates that this is not the case by presenting an adaptive system with two sources of personalization information (Tseng, Chu, Hwang, & Tsai, 2008). Initially, the learning style of a student is determined and a first personalization occurs based on learning style. Next, learner behavior is modeled (such as concentration degree and learning effectiveness) and a second personalization of presentation style and difficulty level is offered to the learner.

UM Challenges and Potential for the Future

Learner models serve as a good starting point for the development of adaptive and intelligent personalized learning environments. However, learner modeling has been widely recognized as one of the central problems in personalized learning environments (Mitrovic, Mayo, Suraweera, & Martin, 2001). We cannot expect learner models to be fully able to represent the learner's cognitive, affective, and behavioral characteristics. Learner modeling comes in many forms and has been applied in a variety of systems, often well tailored to a particular domain or teaching strategy. As a consequence, comparing the effectiveness of different approaches and technologies for learner modeling remains nonexistent. Student modeling has even been considered as an intractable problem, as the title of John Self's work indicates (Self, 1990). Self then argues that researchers should "adopt more realistic aims, then solution for some aspects of the student modeling problem are practically attainable and useful" (Self, 1990, p. 109).

Self also advised to rethink the role of a learner model and challenged researchers to make learner models open to the learners. As such, learners' self-reflection may be promoted. Research of Bull and colleagues acted upon Self's advice by the development of open learner models (OLMs) (Bull, Abu-Isa, Ghag, & Lloyd, 2005; Bull & Kay, 2007). An OLM "opens" the content of the learner model to the learner. It refers to making the learner model explicit to the learner so as to provide more information for self-assessment, reflection, and responsibility for the learning process (Bull et al., 2008). OLMs can be represented by the use of skill meters and graphs, a tree with prerequisites and lecture structure, animations, or even haptic feedback (Bull et al., 2005). Some OLMs permit interaction with the student and hence offer more control on the learner model by the learner itself. Mitrovic and Martin (2007) have shown that simple OLMs like skill meters can have a positive effect on the students' learning and metacognition, while studies conducted by Bull, Mabbott, and Abu-Issa (2007) and by Lazarinis and Retalis (2007) show that skill meters are an adequate representation for sharing learner models with peers and instructors.

To conclude, the techniques and approaches to learner modeling often reflect researchers' preferences. As such, a learner model is not necessarily the most appropriate for a given domain, instructional strategy, or group of learners. The major shortcoming in learner modeling research is that there is no general framework available on which techniques are best applied for certain learner modeling goals. Learner models for adaptive learning will have a different approach compared to learner models in intelligent tutoring systems (ITSs), and open learner models may be only suited for a certain group of (advanced) learners. What we need now is the instigation of empirical research that compares the effectiveness of learner modeling methods in order to avoid a larger proliferation of ad hoc constructed learner models.

Artificial Intelligence for Personalized Learning

After five decades of research, the field of AI remains enigmatic and no widely accepted definition is available (Fogel, 2006). Rather than pursuing a generic definition of AI, a more appropriate attitude can be to consider AI as a set of computational techniques, or even a set of methods. Because human intelligence as such has many faces, for instance problem solving, learning, classification, induction, language processing, and knowledge, the field of AI is at least a highly varied research domain. Originally, the goal of AI could be described as "to develop techniques which simulate human intelligence" (Dillenbourg, 1994, p. 13). The focus of AI was to reason as the learner and to simulate the human reasoning processes, or, at least, the outcomes of the reasoning processes. However, since human intelligence cannot longer be viewed as static, but is now considered as a dynamic knowledge structure, the focus of AI moved from reasoning as the learner to reasoning with the learner (Dillenbourg, 1994). The role of AI in education is hence to provide a large set of applications that can automate the design of learning at several levels.

The research on ITSs provides excellent examples on how AI techniques aid the development of adaptive systems and personalized learning experiences.

The major part of research on ITSs shows positive effects regarding the effectiveness of ITSs (Shute & Psotka, 1996), but as Shute (1992) cautioned, these results might be misleading due to several shortcomings in the research. In the earlier days of research on ITSs, the systems were too much evaluated in terms of AI criteria ("does it work?") and not in terms of pedagogical or instructional effectiveness criteria ("does it work efficiently?"), resulting in inappropriate evaluations of AI in education (Corbett, Koedinger, & Anderson, 1997, Chap. 37). A first overview of empirical studies on the effectiveness of ITSs was presented by Shute and Psotka (1996). The authors stressed the lack of agreement on a standard approach for the design and assessment of ITSs, resulting in few evaluations of pedagogical and instructional effectiveness. Based on a review of six ITSs, Shute and Psotka concluded that "the general positive trend is viewed as encouraging" (Shute & Psotka, pp. 590). Together with the publication of the state-of-the-art work of Shute and Psotka (1996), there was a focus shift towards the educational impact of ITSs. This resulted in numerous studies that demonstrated the pedagogical and instructional effectiveness of ITSs (Anderson, Corbett, Koedinger, & Pelletier, 1995; Mitrovic et al., 2001; Mitrovic, Koedinger, & Martin, 2003; vanLehn et al., 2005). As a consequence, ITSs are to be considered as a breeding ground for the implementation of several AI techniques. In what follows, several AI applications are discussed, starting with ITSs, because these systems comprise the majority of research on AI in education. Next, the scope is broadened from cognitive modeling to affective and behavioral modeling.

AI for Knowledge-Based Intelligent Tutoring Systems

To create personalized learning experiences, an ITS applies and integrates AI techniques to three components (Akhras & Self, 2002; Corbett et al., 1997). First, there is the learner model, representing the learner profile. The content of this profile, and which learner characteristics are included, is still subject of much debate in UM research. An overview of learner characteristics that are considered in the development of adaptive learning environments is given in Vandewaetere et al. (2011). Second, the domain model of an ITS holds a representation of the learning content or the knowledge to be taught, as well as the relationships between the different domain elements. A last component of an ITS is the instructional model or tutoring model. Elen (2000) considers this component as the didactical component of an ITS since it comprises the rules that form the teaching or the instructional strategy. It is the instructional model that largely defines the type of ITS. In what follows, several types of ITSs are discussed.

Model-Tracing Cognitive Tutors

The goal of model-tracing tutors is to check as many as possible student responses. Each step in a problem solving process is denoted in a cognitive model or problem-solving model, in order to ensure that the learner goes through all relevant content (vanLehn et al., 2005). The learner's actions are then compared against the expert model of problem solving. Cognitive models can be developed by specifying a set of production rules that overview all possible strategies and misconceptions that learners may have. Anderson's ACT and ACT-R theory of cognition provide a means for creating such production rules representing the cognitive skills to be taught (Anderson, 1993). As a consequence of the detailed representation of the knowledge that should be acquired by the learner, model-tracing tutors provide intense interaction and feedback (Blessing, Gilbert, Ourada, & Ritter, 2009). Comprehensive overviews of model-tracing cognitive tutors, such as the Algebra Tutor (Singley, Anderson, Gevins, & Hoffman, 1989), the Geometry Tutor (Koedinger & Anderson, 1993), and the LISP Tutor (Anderson & Reiser, 1985), have been provided by several authors (Anderson, Boyle, Corbett & Lewis, 1990; Anderson et al., 1995; Koedinger & Corbett, 2006).

Constraint-Based Tutors

A well-known example of a constraint-based tutor is the SQL-Tutor (Mitrovic & Ohlsson, 1999). Other examples are CAPIT, a tutor for teaching basic rules of English capitalization and punctuation, and KERMIT, a system that tutors database modeling (Mitrovic et al., 2001). In constraint-based tutors, the domain model consists of constraints or rules that all learner solutions should meet. Hence, the learners' behavior is interpreted and evaluated with respect to a predefined set of constraints. Constraint-based modeling is based on the theory of learning from performance errors (Ohlsson, 1996). Constraint-based tutors represent the domain model as a set of state constraints or equivalent problem states. If a learner has obtained a correct problem solution then none of the constraints is violated. And if a constraint is violated, this represents an error due to incomplete or faulty knowledge (Mitrovic et al., 2001). Learner modeling then takes place based on the violated constraints. Compared to model-tracing tutors, constraint-based tutors are much easier to develop, because constraints are much easier to formulate than production rules (Ohlsson & Mitrovic, 2007). On the other hand, their learner model is weaker because for some (ill-structured) domains it might be impossible to identify problem states and constraints that sufficiently present a learner's understanding (Kodaganallur, Weitz, & Rosenthal, 2006; Ohlsson, 1994).

Example-Tracing Tutors

Instead of general production rules (model-tracing tutors) or a set of constraints (constraint-based tutors), model-tracing tutors used generalized examples of problem-solving behavior. Generalized examples must be viewed as "behavior graphs," in that they indicate solution paths that are acceptable for a given problem or task (Aleven, McLaren, Sewall, & Koedinger, 2009). In that way, the tutor is able to recognize a broader range of correct learner behavior, compared to the listing of solution steps that are provided in other tutors. The main difference between example-tracing tutors and other tutoring systems is that no formal procedures or constraints must be defined. Instead, general acceptable solution paths are presented in behavior graphs. An example-tracing tutor that has been extensively evaluated is the Stoichiometry Tutor (McLaren, Lim, & Koedinger, 2008a, b).

All types of tutoring systems presented in the previous section focus on learning as a process of knowledge building. This resulted in ITSs focusing on cognitive modeling, by model-tracing, by formulating constraints, or by general problem-solving examples. In recent years, attention has shifted from purely modeling knowledge to modeling situations, interactions, and affordances, in line with a more constructivist view on learning (Akhras & Self, 2002). Also, affective and behavioral modeling has gained attention in research on AI in Education.

AI for Affect Recognition in Intelligent Tutoring Systems

Modeling the affective states of the learners is a highly promising research field in which learning environments with affect management capabilities are designed. The role of AI is in the automatic affect detection and recognition, hereby overriding the disadvantages of classical obtrusive measurements such as the use of questionnaires and think-aloud procedures (Craig, D'Mello, Witherspoon, & Graesser, 2008). Measurements that have been used to automatically detect affect are electroencephalography (EEG) for the measurement of brain activity (Blanchard, Chalfoun, & Frasson, 2007); electromyography (EMG) for sketching the facial muscle activity (Liu, Rani, & Sarkar, 2005); galvanic skin responses (GSR) for measuring stress and arousal (Blanchard et al., 2007; Liu et al., 2005); gesture analysis (GA) which analyzes body movements by means of a digital camera (Sebe, Cohen, & Huang, 2006); and facial expression recognition that incorporates a computational framework to infer a learner's state of mind (Arroyo et al., 2009).

Since emotion plays a central role in human cognition, affect recognition models are of growing importance. The automatic detection of student motivation (de Vicente & Pain, 2002), frustration and stress (McQuiggan, Lee, & Lester, 2007), and self-efficacy (Beal & Lee, 2005) has led to new ways of developing learning environments or systems with high levels of adaptation and hence, personalization (Conati & Maclaren, 2005). Examples of such learning environments are AutoTutor for the acquisition of Newtonian physics, computer literacy, and critical thinking (D'Mello, Craig, Witherspoon, McDaniel, & Graesser, 2008; D'Mello & Graesser, 2011; Graesser et al., 2008) and the Chrystal Island learning environment, used for teaching microbiology (Robison, McQuiggan, & Lester, 2009). Research studies with AutoTutor demonstrated that affect-sensitivity can be effective for learning (Lehman, D'Mello, & Graesser, 2012) and that affective tutoring improves (deep) learning for learners with low domain knowledge (D'Mello, Lehman, & Graesser, 2011). The Crystal Island learning environment showed substantial benefits for motivation, self-efficacy, interest, and perception of control, although learning gains were less pronounced as compared to traditional instruction (McQuiggan, Rowe, Lee, & Lester, 2008).

AI for Agent-Based Intelligent Tutoring Systems

Agent-based research in AI provides the means to develop learning companions or computer-simulated characters, with humanlike characteristics. Typical for such learning companions is that they play a non-authoritative role in the learning environment (Chou, Chan, & Lin, 2003). In agent-based systems, a pedagogical agent receives input from the environment and subsequently carries out actions in the environment (Poole & Mackworth, 2010). Learning companions and pedagogical agents can take several roles: an expert-tutor, a peer tutor, a competitor, a collaborator, a tutee, or a troublemaker (Chou et al., 2003).

The way learners interact with such agents, for instance by monitoring the cohesiveness of learner and tutor dialogues, can be related to behavioral patterns for the learning companion. Each behavioral pattern then can support a specific pedagogical strategy (D'Mello, Dowell, & Graesser, 2009).

To capture the characteristics of learner and tutor dialogues, a growing amount of (agent-based) systems applies natural language processing (NLP) techniques. NLP is a collective for AI techniques that explore how natural language of humans can be processed by computer-based systems. Also, NLP focuses on how such systems can interact with learners by means of natural language generation. Examples of such systems are Autotutor (Graesser et al., 2008) and ReportTutor, applied for training pathologists (El Saadawi et al., 2008).

AI Challenges and Potential for the Future

One major challenge for AI in education is the development of ITSs. Mitrovic and Koedinger (2009) stated that for 1 h of ITS instruction, 100–1,000 h of authoring time are needed. Authoring tools for ITS creation are, for example, ASPIRE for the development of constraint-based tutors (Mitrovic et al., 2009) and CTAT, for creating example-tracing tutors without programming (Aleven et al., 2009). Murray (2003) overviews several other authoring tools and provides strengths and limits per category of authoring tools.

Next to the development process as such, the long-term implementation of AI techniques can become a second challenge. Applications of AI techniques in UM, for instance, require sophisticated algorithms and sufficiently high computing memory. When ITSs become too sophisticated, they risk that their initial goals (i.e., engage the learner in a sustained reasoning activity and provide interaction based on a deep understanding of the learner's behavior; Corbett et al., 1997) are overridden by the technological constraints of schools and classes.

A third, and perhaps most genuine, challenge in ITS research is what Self (1990, p. 363) described: "The real opportunity for the next decade is to tie together the two threads—to design systems that care about students and have a degree of computational precision—and thereby provide a unique scientific and technical contribution." Rather than demonstrating the unlimited possibilities of AI in education, researchers should go back to the initial goal of using AI techniques in education: providing adaptive systems and personalized learning environments. This raises the question whether adaptive systems should be intelligent (strong hypothesis of AI) or whether they should act if they were intelligent (weak hypothesis of AI). Two decades after Self expressed his concern about ITS development, his words keep their vigor and relevance.

Educational Data Mining for Personalized Learning

Research on EDM is a relatively recent and emerging field in the area of personalization and adaptive learning. EDM research can be described as "developing methods for exploring the unique types of data that come from educational settings, and using those methods to better understand students, and the settings in which they learn in" (Baker & Yacef, 2009, p. 2). Although EDM stems from traditional research on knowledge discovery in databases, the applied methods are often different due to the specific characteristics of educational data (Baker, 2010). For example, educational data are often nested (students within classes within school) and are hence part of a multilevel hierarchy. The typicality of educational data results in EDM methods that are drawn from a broad range of other research fields, such as machine learning, psychometrics, social network analysis, Web mining, and other fields in which large databases form the subject of research.

In the next section, a selection of EDM methods is discussed. Recently, several authors provided extensive reviews of valid EDM methods (Baker, 2010; Romero & Ventura, 2007, 2010; Romero, Ventura, Pechenizkiy, & Baker, 2011).

Data Mining in Education: Techniques

Basically, EDM methods can be classified into four categories. A first category, prediction, aims at inferring a single aspect of the data (dependent or outcome variable) by means of a combination of independent variables (or predictors). Prediction methods can focus on detecting which features (or variables) are important in explaining the prediction of the outcome variable, or they can focus on predicting mediating or moderating factors first. Baker (2010) describes three types of prediction methods: classification, regression, and density estimation. Moore (2006) provides detailed information on these methods.

A second group of EDM methods comprises clustering techniques. As such, the goal is to find data points (e.g., learners, learner characteristics, schools, student actions) that form natural groups. Clusters can be very fine-grained, for instance when student actions have been clustered in order to find behavioral patterns (Amershi & Conati, 2009), or coarse-grained, for instance to investigate (dis)similarities between schools (Van de gaer et al., 2009).

A third group comprises relationship mining techniques, focusing on the discovery and strength of relationships between variables in data set with a large number of variables. This can be done by association rule mining in which if–then rules are formulated (i.e., *if variable x occurs, then variable y occurs*); by correlation mining (i.e., *variable x correlates positively with variable y*); by sequential pattern mining, in which student behavioral patterns are defined that lead to the actual learning event of interest (i.e., *to reach level 4, a student must go through chapter 1, do exercises 1–4, and ask for support*); or by causal data mining to infer causality (i.e., *if y occurs, this is caused by x*).

In the last category, discovery with models, a model is developed and validated, and is in turn used as input for another analysis, such as prediction mining. Discovery with models is an increasingly popular technique in EDM and answers questions like which learning materials (e.g., different types of practice) certain groups of students will benefit from most (Beck & Mostow, 2008); how different types of student behavior impact student learning (Cocea & Weibelzahl, 2009); and how variations in ITS design (e.g., metacognitive prompts) impact student behavior over time (Jeong & Biswas, 2008).

An additional category of text mining techniques was added by Romero and Ventura (2007). Text mining can, among others, be used for identifying groups of documents as a basis for knowledge extraction in e-learning environments (Hammouda & Kamel, 2007), or for analyzing and assessing discussion forums in learning content management systems or Web-based courses (Dringus & Ellis, 2005; Ueno, 2004).

Data Mining in Education: Applications for Personalization

EDM offers two key applications that aim to develop personalized learning environments (for an overview of all key applications, see Baker and Yacef (2009)). First, there is the improvement of learner models. The application of EDM methods has led to more sophisticated learner models and has enabled researchers to make higher level models about learner characteristics and learner behavior. Two examples of this are in the field of students' gaming behavior and help-seeking behavior. When students engage in "gaming the system," they fully exploit and misuse the system's help, hints, and support functions rather than actually genuinely process the learning materials (Baker et al., 2006; Baker, Walonoski, et al., 2008). Based on EDM techniques a model was created of which student behaviors, motivations, and emotions were associated with the gaming the system behavior. As such, several patterns could be extracted that are associated with gaming behavior (Baker, de Carvalho, et al., 2008) and new systems have been developed that adapt to when students engage in gaming behavior (Baker, de Carvalho, et al., 2008).

A second key application of EDM in personalization is the study of adaptive or personalized support. A well-known method for studying the effectiveness of support is learning decomposition (Beck & Mostow, 2008). With this method, a student's later successes (e.g., acquiring a certain knowledge level) are related to the amount of each type of support that was provided to the student or that was requested by the student. As a consequence, for each type of support, the relative effectiveness for learning can be sketched.

Although Baker and Yacef (2009) defined two key applications, the number of applications is more numerous. For instance, learners' sense of community was investigated by comparing different interaction patterns in online learning environments (Shen, Nuankhieo, Huang, Amelung, & Laffey, 2008). Other research focuses on estimating learners' engagement to the learning materials and detecting disengagement behavior by log file analysis (Cocea & Weibelzahl, 2009). Romero, Ventura, and Garcia (2008), finally, provide a thorough overview and tutorial of EDM methods applied to an online learning management system.

EDM Challenges and Potential for the Future

EDM research cannot be considered as a fully mature area yet. Much more specialized work is needed in order to largely implement EDM techniques (Romero & Ventura, 2007). Not all traditional data mining techniques can be applied for educational effectiveness research, since educational data often have specific characteristics that require the development of new techniques.

This development is largely supported by the emerging availability of public datasets and log files. Existing Web-based learning environments and content management systems provide rich databases that serve as a playground for EDM researchers to develop and test new EDM techniques. A major advantage of such databases is that they are easily accessible and provide ecologically valid data from a broad range of learners and for varied instructional strategies (Baker, 2010). In addition to that, the existence of such varied data (i.e., different context) allows for studying the influence of context factors, both by cross-sectional and longitudinal research methods.

A major challenge for EDM research is providing mining tools for educators and nonexperts in data mining (Romero & Ventura, 2007). After some years of using learning content management systems or Web-based education, educators have a rich database at their disposal, which can provide ecologically valid information on the learning content, the learner behavior, and the effectiveness of learning environments. However, due to the current complexity of applying data mining techniques, much of this information stays hidden, hereby leaving the treasures of educational data raveled. Hence, developers of adaptive systems should try to incorporate EDM methods and integrate these methods as authoring tools.

Summary and Conclusion

Wedding the power of computational intelligence with the aims of personalized learning involves major challenges, but also provides great potential. The technologies discussed in this chapter demonstrate that there are nearly no limits anymore with respect to modeling and learning technologies. AI, UM, and EDM technologies each provides highly sophisticated methods for the measurement, inference, and implementation of learner data in the development of personalized learning environments.

However, personalized learning and adaptive systems are much broader than only the technology they use. Figure 34.2 represents a four-dimensional view on adaptive learning and focuses on the following components:

1. Source of adaptation ("adapt to what?"): One can decide to solely focus on learner parameters, such as learner characteristics (e.g., learning style, see the chapter of Graf in this handbook) and learning outcomes (e.g., time on task, learning gains). Another source of adaptation could be that the interaction between learner and system is taken into account, hereby focusing on the behavior of the

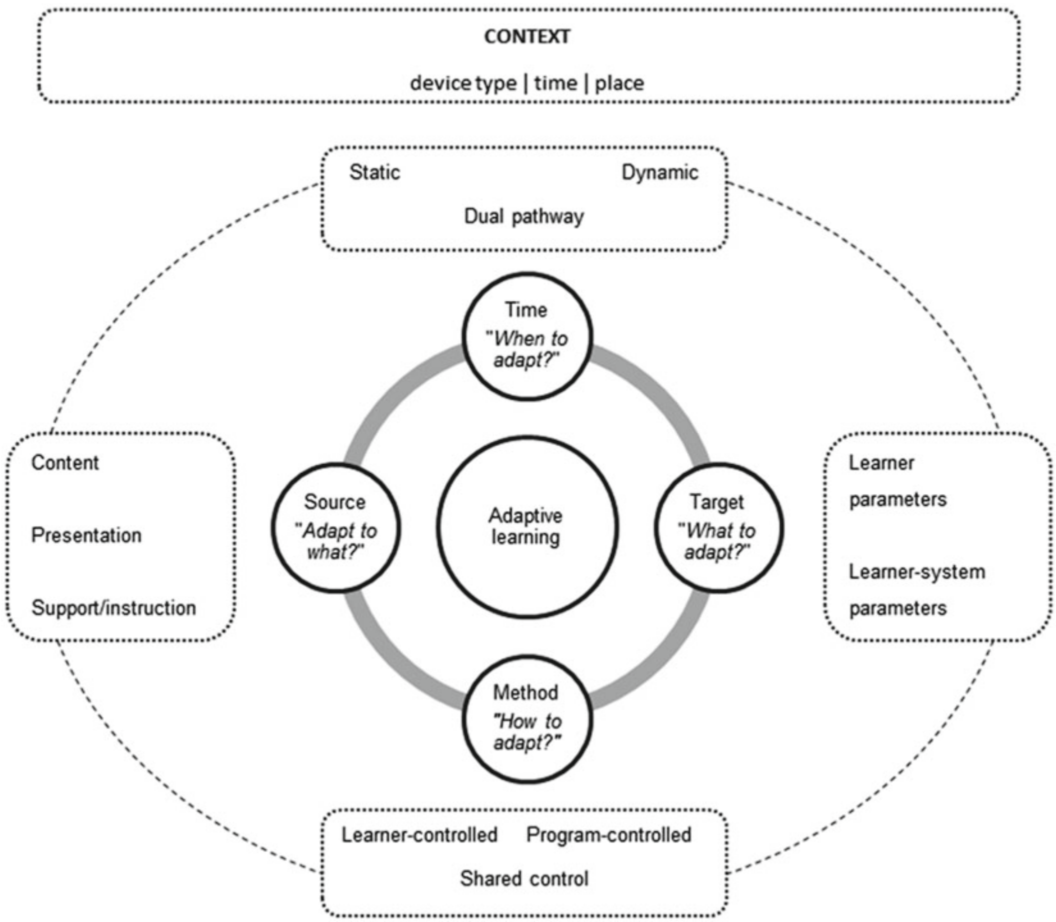

Fig. 34.2 Four-dimensional perspective on adaptive learning

learner when interacting with the system (e.g., gaming the system behavior; Baker, de Carvalho, et al., 2008).

2. Target of adaptation ("adapt what?"): The target of adaptive instruction is threefold and focuses on what can be adapted in the system. Either the content can be adapted, for instance by differentiating the difficulty level of the tasks, or items (Wauters, Desmet, & Van den Noortgate, 2010). Another way is to adapt the presentation format of the learning content, for instance by hiding or highlighting links (Brusilovsky, 1996). A third way is to adapt the degree of instruction and available support by methods for indirect guidance and map adaptation (Brusilovsky, 2001).
3. Time of adaptation ("adapt when?"): A third dimension of adaptive learning refers to the time of adaptation or when the adaptation will take place. This chapter discussed the difference between static and dynamic UM and has provided some examples of both types. A dual-pathway approach can also be implemented in which a first adaptation occurs after a single measurement of learner characteristics after which further modeling and adaptation occur based on learner-interaction parameters.
4. Method of adaptation ("adapt how?"): This last feature of adaptive learning distinguishes between learner-controlled adaptation, system-controlled adaptation, and the combination of both. System-controlled adaptation is adaptation that is defined by the developer or the instructor, as is the case in most ITSs. Learner-controlled adaptation, in contrast to system-controlled adaptation, imposes that the learner has full control over the environment and learning content. Both methods of adaptation have drawbacks and benefits (for a discussion, see Corbalan, Kester, & van Merriënboer, 2008, 2009; Elen, 2000; Williams, 1996). As a consequence, the notion of shared control was developed by Corbalan and colleagues (Corbalan et al. 2008, 2009). With shared control, the system first selects an appropriate set of learning materials or tasks, taking into account learner characteristics to adapt for. After that, the learner is able to freely choose within this set of materials or tasks.

The four-dimensional view on adaptive learning can assist developers and instructors to keep in mind the complexity and richness of personalized and adaptive learning. It also focuses on the fact that adaptive instruction can be offered in many more ways than the single integration of sophisticated algorithms. Indeed, the core curriculum of instructional technology research is the facilitation of learning and the improvement of performance by means of appropriate technological processes and resources (Richey, Silber, & Ely, 2008, p. 4). Approaches such as UM and technologies such as AI and EDM should serve as a means for improving education, a method to develop appropriate adaptive and intelligent systems. Future research in educational technology should compare the effectiveness of different methods and evaluate them by their costs and benefits on several levels: the development and implementation of such technologies for developers; the ease of use of tutors or school teachers; and the relevance for providing tailored instruction. A great potential for future research is in the field of nonformal education. While most adaptive and intelligent technologies are now applied in formal education, new research lines can focus on the interoperability of learner models in special education, vocational training, lifelong learning, and long-term approaches to personalization. Also, the domain-(in) dependency of learner models and learner modeling technologies should be investigated in order to create a generic set of advanced technologies for personalized learning.

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35 Computer-Supported Collaborative Learning: Instructional Approaches, Group Processes and Educational Designs

Peter Goodyear, Chris Jones, and Kate Thompson

Abstract

This chapter reviews research on computer-supported collaborative learning (CSCL). Its scope includes learning that takes place face to face (F2F), remotely and in blends of F2F and remote activity. It considers learning in groups of various sizes (from dyads to learning communities). It considers a range of approaches intended to promote and support collaborative learning, including instructor-led methods, scripted methods and methods that open up space for the autonomous, creative, productive work of the collaborating learners.

The chapter builds upon and updates related chapters in previous versions of the handbook. It provides the reader with links to broad-based, landmark reviews and summaries of this area and some of the core texts on the role of technology in CSCL. The chapter reviews selected research contributions from the last 5 years, identifying some emerging themes and highlighting important unresolved issues. It provides a conceptual orientation to the nature and potential educational benefits of CSCL. It summarises research results concerning real-time (synchronous) CSCL, blended designs for CSCL and CSCL using Web 2.0 technologies. It identifies some key issues in the methodology of CSCL research and also provides an overview of recent research on CSCL design using scripts and design patterns.

Keywords

Computer-supported collaborative learning (CSCL) • Networked learning • Collaboration script • Design pattern • Participation

Introduction

This chapter provides an introduction to the field of research on computer-supported collaborative learning (CSCL). It builds on related chapters in previous versions of the handbook (e.g. Johnson & Johnson, 2008; Romiszowski & Mason, 1996, 2004; Satwicz & Stevens, 2008). It also provides links to broader based reviews of research on collaborative learning (e.g. Johnson & Johnson, 1999; Slavin, 1990; Webb & Palincsar, 1996) as well as to some key texts on CSCL (e.g. Dillenbourg, 1999; Dirckinck-Holmfeld, Jones, & Lindström, 2009; Koschmann, 1996; Koschmann, Hall, & Miyake, 2002; Stahl, Koschmann, & Suthers, 2006; Steeples & Jones, 2002; Strijbos, Kirschner, & Martens, 2004). That done, the chapter provides a review of selected research contributions from the last 5 years, identifying some significant themes and areas of opportunity for future research.

The chapter's scope includes CSCL that takes place face to face (F2F), remotely and in various blends of F2F and remote activity. It looks at synchronous (real-time) as well as

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asynchronous interaction. It covers learning in groups ranging in size from dyads to learning communities. The chapter also reviews recent literature on the analysis of group processes in CSCL. Its closing sections focus on design for CSCL, with an emphasis on collaboration scripts and design patterns.

Collaborative Learning

Johnson and Johnson (2008) distinguish co-operative and collaborative learning from competitive and individualistic learning. In individualistic learning, students work by themselves to accomplish learning goals. In competitive learning situations, they work against each other to achieve a goal (such as a rank in the class). Johnson and Johnson use the terms co-operative and collaborative learning interchangeably, to denote situations in which students work together to maximise their own and each other's learning. Dillenbourg (1999) and others distinguish between co-operative and collaborative learning. *Co-operative* learning is used to denote situations in which students (can) divide up a group task and tackle the parts with a substantial element of independence. *Collaborative* learning requires the group to complete the task together, through dialogue and joint action. Collaborative learning provides learning opportunities that are sidestepped in co-operative learning. Guidance from the instructor, but also task design, can make the difference between a learning situation being tackled collaboratively rather than co-operatively—or even, individualistically (Paulus, 2005).

CSCL

CSCL refers to situations in which computer technology plays a significant role in shaping the collaboration. The term has had some currency since the late 1980s/early 1990s, though there is a slightly longer history of educational research into (co-present) group work with computers (e.g. Eraut & Hoyles, 1988) and into networked learning using online forums and email (e.g. Levin, Riel, Miyake, & Cohen, 1987).

In some cases, CSCL involves learners who are working at a distance from each other and the computer technology is their primary means of interacting, providing valuable flexibility in the use of time and space. But "CSCL" is also used to describe situations in which learners are co-present, as long as the technology plays a significant role in shaping the nature of their interactions with each other and supporting their collaborative activities. It is also important to recognise that some designs for CSCL include situations that interleave periods of working at a distance with working F2F, and may include mixtures of synchronous and asynchronous collaboration (e.g. a live F2F event, followed by an online discussion).

Technology can play a variety of roles in CSCL, e.g. it may provide a visual representation of the task or the product on which the students are working, or of some key aspects of their collaboration process (e.g. Kay, Yacef, & Reimann, 2007; Suthers & Hundhausen, 2003). Computer support may also take the form of scaffolding—as when structuring devices are used to help with the development of argumentation and/or in knowledge-building (e.g. Lu, Lajoie, & Wiseman, 2010; Marttunen & Laurinen, 2001; Scardamalia & Bereiter, 2006).

Networked Learning

"Networked learning" is "learning in which ICT … is used to promote connections: between one learner and other learners, between learners and tutors; between a learning community and its learning resources" (Goodyear, Banks, Hodgson, & McConnell, 2004, p. 1). The term is sometimes used as a synonym for forms of CSCL that largely or exclusively involve remote rather than F2F collaborations. Within the literature of networked learning (see, e.g., de Laat, 2006; Dirckinck-Holmfeld, Hodgson, & McConnell, 2011; Dirckinck-Holmfeld et al., 2009; Steeples & Jones, 2002) there is a sense that the term connotes collaborations involving medium to large numbers (tens to hundreds of participants, rather than (say) dyads).

The Educational Potential of CSCL

Meta-analyses and systematic reviews have established the general case that the outcomes of collaborative learning are superior to those of individualistic and competitive learning situations (Hattie, 2009; Johnson & Johnson, 1999; Slavin, 1990; Webb & Palincsar, 1996). Johnson and Johnson (2008) concluded that F2F CSCL outperforms comparable individualistic and competitive technology-based learning situations—whether the outcomes measured are the volume or the quality of work accomplished, mastery of factual information, ability to apply factual knowledge or success in problem solving. Collaboration can expose each learner to multiple perspectives on, and explanations of, phenomena. It can provoke belief revision, and provide external monitoring of, and feedback on, problem-solving performance.

For F2F CSCL, there is evidence to suggest that dyads and small groups perform better than larger groups (Lou, 2004; Lou, Abrami, & d'Appolonia, 2001)—within larger groups there are fewer opportunities for each student to articulate and examine their own beliefs. However, this potentially detrimental size effect can be countered by good design and/or group moderation (see scripting section below).

This body of research, impressive though its findings may be, tells less than the whole story about CSCL. For example, it applies a paradoxically restricted sense of learning—through testing the *acquisition* of knowledge by *individuals*. There is more to learning than the acquisition metaphor implies (Paavola, Lipponen, & Hakkarainen, 2004; Sfard, 1998). Much research and practice in CSCL have roots in Vygotsky and are inspired by ideas of learning in social interaction and knowing as distributed across minds, tools and artefacts. Opportunities to participate in social practices are valued in their own right, irrespective of what might later be measurable as an individualistic learning outcome. CSCL in this view is concerned with meaning, and meaning-making, mediated by digital artefacts in the context of joint activity (Jones, Cook, Jones, & De Laat, 2007; Koschmann, 2002). The opportunity to participate in core practices of the times—such as collaborative knowledge-building—achieves an intrinsic value (Bereiter, 2002; Paavola et al., 2004; Stahl, 2006).

Consequently, a significant vein of CSCL research has focussed on argumentation skills—the ability to participate in an argumentative discourse; to make defensible claims (providing warrants, qualifications, etc.); to test the claims of others; to draw appropriate inferences, etc. (e.g. Andriessen, Baker, & Suthers, 2003; Marttunen & Laurinen, 2001; Scheuer, Loll, Pinkwart, & McLaren, 2010; Weinberger & Fischer, 2006; Weinberger, Stegmann, & Fischer, 2010). Participation in CSCL does not automatically confer the benefits of learning to argue, or learning through arguing. It is not enough for a student to be allocated some group work, or for them to have access to some supportive technology. Rather, the situation in which they find themselves needs to provoke certain kinds of productive social interactions, which in turn stimulate appropriate mental activities with some chance of lasting benefits (Dillenbourg, 1999; Dillenbourg, Jarvela, & Fischer, 2009; Goodyear, 2002; Summers & Volet, 2010; Wegerif, 2006).

This implies a proactive role for the teacher/instructor and/or well-executed up-stream design.

CSCL in Real Time: Face-to-Face and Online

Much of the theory-driven research carried out in CSCL has involved asynchronous collaboration, using data from discussion boards in tertiary, online learning environments. More recently, some attention has been given to CSCL in real time: F2F CSCL and (usually remote) synchronous online CSCL.

Face-to-Face, Synchronous CSCL

F2F CSCL research investigates collaboration as it occurs around a shared piece of technology or educational program, such as mobile devices (e.g. Zurita & Nussbaum, 2007), virtual worlds (e.g. Girvan & Savage, 2010), simulation models (Sins, Savelsbergh, van Joolingen, & van Hout-Wolters, 2011), interactive whiteboards (e.g. Kershner, Warwick, Mercer, & Kleine Staarman, 2010; Warwick et al., 2010), or interactive tabletop devices (e.g. Falcão & Price, 2010). The collection and processing of data associated with F2F CSCL can be time-consuming compared to that associated with synchronous, online CSCL. Recent studies such as those using a MUVE (Thompson, Kennedy-Clark, Markauskaite, & Southavilay, 2011) use video to capture the computer screen, computer usage, gestures between students and the direction that the students face, in addition to high-quality audio, and log files of sequences of actions on the computers. In addition, the artefacts produced, or around which collaboration occurs, are also collected (Jeong, Chen, & Looi, 2011). These additional streams of data are adding to our understanding of CSCL environments, and the roles that the tools play. Studies using specific tools do have implications for other forms of CSCL. These include the ways in which students are able to collaborate around such devices, and the role of the instructor, in particular scaffolding techniques and the design of activities (Kershner et al., 2010), and their presence in student groups (Warwick et al., 2010).

The Interactive Whiteboard (IWB) provides learners with a different perspective on their learning environment due to its large screen and orientation. Kershner et al. (2010) investigated "how the IWB's affordances to support learning were employed by the children to *think collectively*" (p. 362). They used Mercer's (2004) *sociocultural discourse analysis* as a theoretical lens through which to view the experiences around the collaboration—identifying disputational, cumulative and exploratory group talk. The continued focus on exploratory group work was very important in achieving productive interaction—without collaboration skills, students had trouble interacting at the IWB, and this affected learning outcomes. Specifically, it was found that students need a joint understanding of the task, they need positive motivation and to take responsibility for their own learning and they need to engage in active support for each other, which relate more to general classroom dynamics than to the IWB.

Productive collaboration was also disrupted by technical difficulties (Kershner et al., 2010). Some groups, when faced with technical issues, engaged in discussion that helped to bond the group and developed a collective self-efficacy. Falcão and Price (2010) address this issue of interruption, or interference, in collaborative processes suggesting that interference could provide a trigger for argumentation and co-construction of knowledge. Their results showed that what could be thought of as "ideal" collaboration—organised, coordinated and planned interaction—meant that students reduced the level of exploration, and the moderator was required to stimulate further inquiry.

The design of tasks within which students collaborate around a shared device is important when considering the success of CSCL in these classroom environments. For the IWB, recommended tasks are those that allow students to engage with screen objects, physically engage with the screen, take control of elements of the lesson, represent ideas, access alternative possibilities or refocus and refer to previous knowledge (Kershner et al., 2010; Warwick et al., 2010). Similarly, for tabletop learning environments, design of tasks that take advantage of the affordances of the tool—using multiple resources, simultaneous multiple inputs, dependency on one physical-digital resource, dynamic digital feedback and shared visual field, and the creation of opportunities for spontaneous and productive collaborative situations have all been recommended (Falcão & Price, 2010).

Synchronous Online CSCL

Synchronous online CSCL has features of both F2F and asynchronous CSCL. Research has focused on aspects of understanding and managing the synchronous CSCL environment, such as decision-making (Reimann, Frerejean, & Thompson, 2009) or social presence (Weinel et al., 2011). Some work has focused on the way in which learners co-construct their shared understanding of working in CSCL environments (Holliman & Scanlon, 2006). Some research focuses on the role of the moderator in synchronous e-discussions, informing moderation techniques or development of tools to support moderation (see Asterhan & Schwarz, 2010; De Groot et al., 2007; Wichmann, Giemza, Hoppe, & Krauss, 2009). In order for synchronous online collaboration to be successful, the role of the moderator is vital, and challenging (Wichmann et al., 2009). The design of the collaborative tasks is also important (Holliman & Scanlon, 2006).

Teacher moderation is an important issue in synchronous environments because teacher support for students relies on online knowledge about collaborative discussions (Asterhan & Schwarz, 2010). The authors used Lund's (2004) taxonomy of human supportive roles in CSCL and suggest that a distinction can be made between generic and content-specific instruction within pedagogical support. They found that students expect moderators to scaffold their reasoning and their knowledge construction and keep the discussion focused. Overall, students expected moderators to be actively involved in the discussion while still allowing construction of knowledge by the students. Asterhan and Schwarz (2010) were able to identify two types of moderator scaffolding prompts—generic (low content) and non-generic (content specific). They decided that Lund's distinctions were not useful for analysing discrete moderation moves within a discussion and that the non-generic scaffolds were more successful. It may be that other purposes/tools may be better suited to generic scaffolds, but if it is the case, then this would be a design decision that needs to be made. They conclude that instructional practices used effectively in other formats—asynchronous or F2F—should not be simply transferred.

Tools have been developed to aid teachers in managing synchronous learning environments, and some of this work also generates real-time data that can be used for research and support. Asterhan and Schwarz (2010) used a tool called Digalo, in which the communication is visually organised and threaded. The ARGUNAUT approach (De Groot et al., 2007) supports moderation by automatically monitoring ongoing discussion while simultaneously deriving situation indicators. Trials of awareness support tools (Wichmann et al., 2009) found them to be helpful during the moderation of multiple e-discussions, and allowed better understanding of the students' activities. Some research is investigating ways to automatically infer when students are collaborating from the application and audio traces of interaction (e.g. Martinez et al., 2011).

Similarities in the issues that face those managing CSCL environments exist across the F2F and synchronous online settings discussed in this section. The role of the instructor is vital, the design of the tasks is important and matching appropriate tasks with expected outcomes is necessary in order to obtain successful learning outcomes.

Blending Face-to-Face and Online Collaboration

There are good educational arguments for *well-designed* combinations of F2F and online collaboration, where the logistics of the learners' study situation allows (So & Bonk, 2010). Reisslein, Seeling, and Reisslein (2005) report that students who have been asked to work in online groups state that they would prefer to be able to meet F2F beforehand. It is not uncommon for "blended" designs to involve an F2F meeting at the start, a period of online collaboration and a final F2F meeting for purposes of group presentation, assessment and project closure. Other designs can involve more frequent meetings—for example, with a weekly F2F discussion followed by a week-long online discussion (Ellis, Goodyear, O'Hara, & Prosser, 2007; Ellis, Goodyear, Prosser, & O'Hara, 2006) or with computer-supported PBL groups that meet once or twice a week and co-ordinate their group activity online in between meetings (e.g. Lu et al., 2010). Further design variations blend synchronous and asynchronous online activity. For example, Michinov, Michinov, and Toczek-Capelle (2004) show how synchronous chat sessions can be used to help create a sense of belonging at the start of an online program, as a substitute for F2F kick-off meetings. Conversely, Dietz-Uhler and Bishop-Clark (2001) found that initial online discussions had a beneficial effect on subsequent F2F collaborative work. Michinov and Michinov (2008) have investigated the effects of a *midpoint* F2F meeting, premised on the view that the midpoint of an online program of collaboration can be a period of instability and change. They found beneficial short-term effects on online participation just after the F2F meeting, but then saw a decline in task-oriented interactions and a rise in negative affect.

CSCL with Web 2.0 Technologies

CSCL faces a challenge in the context of new technologies described as Web 2.0 because Web 2.0 involves large-scale network effects and the ability to interact in, and contribute to, large groups (Kafai & Peppler, 2011). A practice perspective on Web 2.0 in CSCL was outlined by Dohn (2009) in this way:

- Collaboration and/or distributed authorship
- Active, open-access, "bottom-up" participation and interactive multiway communication
- Continuous production, reproduction and transformation of material in use and reuse across contexts
- Openness of content, renunciation of copyright, distributed ownership
- Lack of finality, "awareness-in-practice" of the "open-endedness" of the activity
- Taking place on the WWW, or to a large extent utilising Web-mediated resources and activities

The idea of Web 2.0 is intentionally imprecise and the definition provides a delimited core and a less precise periphery and it is often clarified by illustration, using contrasting examples of the Web and Web 2.0. Despite this lack of clarity Web 2.0 is a term that has been absorbed into CSCL literature (for example, Cress & Kimmerle, 2008; Dohn, 2009; Glassman & Kang, 2011).

Many Web 2.0 technologies blur the distinction between synchronous and asynchronous communications by incorporating both features in a single interface. Web 2.0 however is primarily an asynchronous medium because asynchronous communication is most amenable to scale. Web 2.0 places emphasis on user-generated content and participation, focused on the generation, manipulation and sharing of content. Applications of Web 2.0 in education have taken a variety of forms and include a number of different media. Empirical studies have reported on the collaborative use of blogs (Ducate & Lomicka, 2008; Farmer, Yue, & Brooks, 2008), wikis (Minocha & Thomas, 2007), virtual worlds (Konstantinidis, Tsiatsos, Terzidou, & Pomportsis, 2010) and mobile social media (Lewis, Pea, & Rosen, 2010). For a recent review, see Dohn (2010).

An area of connection between the literature on Web 2.0 and collaborative learning has been the focus on participation and participatory culture in Web 2.0 environments (Jenkins, 2009). Clear links have been drawn between Web 2.0 technologies and the participation metaphor of Sfard (1998), the knowledge building approach of Scardamalia and Bereiter (2006) and the knowledge creation metaphor of learning found in Paavola and Hakkarainen (2005). Participation was strongly associated by Sfard (1998) with the emergence of social and situated views on learning, and the ideas of learning as a process, legitimate peripheral participation and learning in a Community of Practice (Lave & Wenger, 1991). However Sfard counselled against merging the participation metaphor with a social view of learning, noting that the more psychological views of collaboration suggested a process of internalisation that sat more comfortably with an acquisition rather than a participation metaphor (Sfard, 1998).

Dohn argues that Web 2.0 and educational practices implicitly represent divergent understandings of knowledge and learning and that education implicitly embodies the acquisition metaphor whereas Web 2.0 embodies the participation metaphor (2009). This opposition between Web 2.0 and education is drawn too sharply and education, as Sfard noted, requires the use of both participation and acquisition metaphors. Web 2.0 can be seen as tilting the balance towards participation but in a way that is not in contradiction with educational practice. For example, Lewis et al. (2010) argue for the application of social theories of learning for design in participatory media. They argue that the power of social media for learning may lie in their potential to foster collaborations, on a scale and in tighter time cycles than has been seen before (Lewis et al., 2010). On this view, the logic of Web 2.0 can be mobilised for educational purposes by using crafted interactional affordances to support shared experiences and meaning-making.

Web 2.0 poses a challenge to CSCL in the way it places a priority on large-scale network effects. The architecture of participation is an architecture of scale and Web 2.0 suggests that the value of a service increases with the number of users that share that service. Design in Web 2.0 may take place at a meta-level in which systems allow users to create content but in addition users can also modify the behaviour and components of the system at the time of use. Meta-design of this type takes place at the level of the social and technical infrastructures in which participatory cultures and new forms of collaboration take place (Fischer & Giaccardi, 2006). CSCL has often concerned itself with tool and application development, whereas Web 2.0 processes would suggest changing focus to whole infrastructures and the provision of large-scale or universal services. Jahnke (2009) observed that Web 2.0 applications "transform social systems (e.g. social groups, universities) into socio-technical systems, where socially and technically supported relationships are highly interwoven" (Jahnke, 2009, p. 287). Key issues for future work in CSCL in relation to Web 2.0 concern infrastructures and the levels between micro-level interactions and macro-level social and technical conditions (Jones & Dirckinck-Holmfeld, 2009; Jones, Dirckinck-Holmfeld, & Lindström, 2006).

Assessing Group Processes

In the last 5 years, our ability to measure, and to appreciate the complexity of, the processes of CSCL has benefited from advances in methodologies used and in computational power. As should be expected with the uptake of new methods of analysis, there are concerns about the rigor with which this research is conducted (De Wever et al., 2006). Within CSCL particularly, research examining the processes involved suffers from an incoherent approach: each coding scheme used builds on a particular element of a different theory of learning and cognition. These theories include argumentation (Ding, 2009; Weinberger & Fischer, 2006); relationships between interactive, cognitive and discursive dimensions of knowledge-building (Schrire, 2006); knowledge sharing, knowledge construction and knowledge creation discourse modes (Van Aalst, 2009) or designing for co-construction of knowledge and negotiation of meaning, measuring participant dialogue (Hull & Saxon, 2009). Research addresses both synchronous (Ding, 2009) and asynchronous collaboration (for example, Hull & Saxon, 2009; Weinberger & Fischer, 2006), but few address both. The participants examined in this field of research are learners at various stages, including university students (Weinberger & Fischer, 2006), teachers (Hull & Saxon, 2009) and high school students (Ding, 2009). The units of analysis are different in each study, because they depend on the question asked (Schrire, 2006). Some studies segment the data over multiple levels (for example, Weinberger & Fischer, 2006), and others use additional elements to make sense of the process (such as the artefacts produced by collaboration (Ding, 2009)). Processes of collaboration do tend to be measured by content analysis of chats or discussion boards, and standard reporting of this type of analysis is followed (De Wever, Schellens, Valcke, & Van Keer, 2006). Some also analyse log file data (Reimann, 2009). Very few studies replicate other work or even use the same coding scheme, and there is no overarching theory within which all can be placed. The findings sit disjointed, and the reader is left to imagine how they may fit together. Clarà and Mauri (2010) begin to address the problem of reconciling studies, using an individual, group, context framework. They maintain that the differences are necessary and important and that the tensions provide the space for further development in CSCL. Regardless of the approach, studying processes in CSCL involves choices of theory, measures and analysis.

Some of the research reviewed for this chapter incorporates multiple measures of process, such as that by Weinberger and Fischer (2006), Schrire (2006), Van Aalst (2009), Ding (2009), and Evans, Feenstra, Ryon, and McNeill (2011). Such studies allow the identification of interaction effects (Weinberger & Fischer, 2006). Schrire's work indicates a relationship between collaborative interaction and socio-cognitive processes, discovering interaction pattern types, which she suggests could be used as indicators for characterising knowledge building. Ding's (2009) study identified individuals' patterns of knowledge elaboration and used these to explain the dyad's dynamics and the learning outcomes. The identification of interactions between multiple processes and patterns adds to our knowledge of how collaboration tools, such as scripts, work and in turn inspires discussions around designing effective CSCL environments. At this point, however, researchers are finding patterns to explain learning outcomes (Schrire's instructor- and synergistic-centred patterns within discussion board threads, Ding's three patterns of knowledge elaboration), rather than empirically testing the relationship between them. An issue when using multiple measures is how to visualise the way in which the measures fit together. A tool designed to do this is Tatiana (Trace Analysis Tool for Interaction ANAlysis) (Dyke, Lund, & Girardot, 2009). The group has demonstrated the way in which one data set was analysed from the perspective of knowledge building, the uptake of representational practices and a cognitive perspective of group understanding (Dyke et al., 2011). The main advantages of this tool are concerned with identifying similarities and differences between the analytical approaches, rather than finding links between them. Multimodal coding is the term used by Evans et al. (2011), who incorporate cognitive, perceptual, verbal and non-verbal elements to examine children's contribution to knowledge building activities. They use a linguistic annotation software tool called ELAN as well as Excel, allowing them to visualise the complex data over time.

Accounting for temporal patterns in processes of learning is a recent development in this field. Reimann's formative paper (2009) discusses the use of data, sequence and process mining to identify patterns for cases in which the collaborative process has been designed. These event-based approaches can sit alongside variable-centred approaches, adding a layer of information to our understanding of processes that focuses on long-term (days, weeks, months) changes in groups and takes into account the order of events. Reimann (2009) goes beyond the individual/group/context and also accounts for the group's learning history. The event-centred approach allows changes in group processes that are not easily quantified, such as when a member leaves a group, to be taken into account during the analysis. While some researchers have applied methods of analysis to process data such as heuristics mining (Reimann et al., 2009), others question the likelihood that processes in CSCL environments should be fit to linear, consistent models of interaction (Goggins, Laffey, & Amelung, 2011). Other methods used include Lag-sequential analysis to identify transition patterns between process categories (Kapur, 2011), and multilevel, ordered logistical regression to create an explanatory model (Wise &

Chiu, 2011). Factoring in of time, and the acknowledgement that group processes change over time, has inspired a range of exciting new research questions and methods.

The purpose of researching the processes involved in CSCL is to be able to relate processes to learning outcomes (Schrire, 2006; Weinberger & Fischer, 2006), to design learning environments so as best to encourage appropriate CSCL (Schrire, 2006; Van Aalst, 2009) and, once armed with an appropriate pedagogy, to further provide instructors with the tools necessary to manage these environments in real time (Schrire, 2006). Thus far the studies investigating processes in CSCL have been carried out in narrow fields (for example, Weinberger & Fischer, 2006), and the processes have to be manually coded and analysed, which are time-consuming (Reimann, 2009; Weinberger & Fischer, 2006). Links with learning outcomes tend to stand alone, not adding to a larger theory.

Also relevant to this discussion is the use of social network analysis in CSCL and networked learning (e.g. De Laat & Lally, 2004; de Laat, Lally, Lipponen, & Simons, 2006, 2007; Haythornthwaite & De Laat, 2010). Social networks are composed of nodes or actors and the ties or connections between them. Nodes can be individuals, organisations, communities or other kinds of collectives and in principle actors or nodes can be of different types, including non-human actors. Currently there is little work that includes non-human actors or hybrid forms such as humans interacting through networks that include other non-human nodes. From a social network perspective the research interest is in the nature of ties between participants and whether they are weak, strong or latent (Haythornthwaite, 2002; Jones, Ferreday, & Hodgson, 2008). However it is not always clear what might be sufficient to say that there is a tie between pairs (De Laat & Lally, 2004). Partially in response to this De Laat (2006) has argued for a combination of social network analysis with a timeline analysis to understand the relationship between engagement with learning and peer support and the ways they evolve.

Research in this area needs replication of existing studies to validate instruments with larger, empirical studies (De Wever et al., 2006), and a focus on hypothesis testing (De Wever et al., 2006; Reimann, 2009). Further to this, Reimann (2009) calls for shared online collections of annotated sequence data so that they can be analysed by many, with a variety of methods and tools. Exciting breakthroughs are being made, such as the automatic identification of reasoning displays and idea co-construction contributions in speech data (Gweon, Agrawal, Udani, Raj, & Rose, 2011). Gweon et al. have been able to show that a statement can be classified as either reasoning or non-reasoning, not based on textual input, but on acoustic and prosodic features of the speech, such as levels of pitch, intensity of speech, amount of silence and duration of speech. Examining the processes of CSCL contributes to the development of theory in the learning sciences, but overarching frameworks are still sorely lacking.

Designing for CSCL

Persico and Pozzi (2010) boil down CSCL design to three crucial elements: tasks, teams and time. To these we would add tools—making a "four Ts" model. Design may specify the nature of the task, how it could be broken down into sub-tasks and how these might be scoped and sequenced, how the work could be divided up amongst team members, the internal structure of a team (size, heterogeneity, etc.), how team members might interact and what tools and resources they will need (Goodyear, 2005; Laurillard, 2008; Pozzi, 2011). Design theorists of different persuasions may vary the verbs in the previous sentence: some insisting on "might," "could" or "may" while others prefer "ought," "should" or "must" (c.f. Dillenbourg & Tchounikine, 2007).

Collaboration Scripts

A script for collaboration may capture a number of these design elements, but is typically held to focus on some combination of (a) role definitions, and (b) guidance about the sequence of activities to be undertaken by each of the role-holders (De Wever, van Keer, Schellens, & Valcke, 2010; O'Donnell & Dansereau, 1992). Interest in the educational benefits of collaboration scripts flows from a recognition of the fact that spontaneous interaction within F2F learning groups rarely results in the depth or the richness of cognitive engagement that is necessary if the potential benefits of collaboration are to be secured (e.g. King, 2007).

One can distinguish a scale level in scripting: for example, designs that focus on roles and activity sequences are sometimes referred to as "macro-scripts," to distinguish them from "micro-scripts" that are intended to prompt a single move or a small number of turns in (say) an argument (Dillenbourg et al., 2009; Morris et al., 2010). Scale considerations have also been explored in the analysis of roles. For example, Strijbos and de Laat (2010) distinguish between micro, meso and macro roles, where the first is (normally) associated with carrying out a single task, the second with carrying out a cluster of tasks and the third with a more generalised stance or attitude towards participation in a collaborative activity. Scripts can be thought of as external, internal or both. That is, a script may be produced as an explicit description or prescription for some collaborative activity; or it may be an internal (metacognitive) resource that helps someone participate effectively in a CSCL activity. People may learn to become better at CSCL by internalising scripts that they first encounter as external representations (Kollar, Fischer, & Slotta, 2007).

Research on scripted collaborations in CSCL has created a substantial body of findings (Dillenbourg et al., 2009;

Fischer, Kollar, Mandl, & Haake, 2007; Weinberger, Kollar, Dimitriadis, Makitalo-Siegl, & Fischer, 2009; Weinberger et al., 2010). Within this literature, there is an emerging view that some scripting is better than no scripting, but that overuse or over-reliance on scripts can be counterproductive (Dillenbourg, 2002; Makitalo, Weinberger, Hakkinen, Jarvela, & Fischer, 2005). Tighter resolution of this argument depends upon what outcomes are valued. For example, over-scripting might be held to inhibit transfer, or the emergence of self-regulatory abilities, even if it boosts immediate performance on the task at hand or as captured in post-tests of knowledge acquired (Diziol, Walker, Rummel, & Koedinger, 2010; Kapur, 2008; Strijbos & Weinberger, 2010; see also Gressick and Derry (2010), who place particular value on emergent patterns of leadership in online groups).

However, even in relation to these "shorter range" targets, scripting does not guarantee success. For example, Weinberger, Ertl, Fischer, and Mandl (2005) tested the efficacy of two types of scripts: social scripts (which aim to guide students about how they should interact with each other in a CSCL situation) and epistemic scripts (which aim to help students focus on and complete each stage in an epistemic task). In short, epistemic scripts focus on the "what" of a learning task; social scripts focus on the "how." Such scripts may be implemented and used in a variety of ways, so it is hard to generalise about their intrinsic qualities. However, while Weinberger et al. were able to show positive benefits with their social scripts, they found deleterious effects with their epistemic scripts.

While research on the effects of collaboration scripts is still active, it is clear that effective scripting is a complex, dynamic problem that is unlikely to be tackled successfully through the imposition of rigid, a priori designs. This makes (software-based) dynamically adjustable scripting/scaffolding of collaboration a particularly interesting area for future R&D (see e.g., Dillenbourg & Tchounikine, 2007; Diziol et al., 2010). In a complementary way, it also favours further R&D on tools that groups can themselves use to visualise and monitor their own collaboration processes, and negotiate adjustments to working methods accordingly (Bodemer & Dehler, 2011; Kay et al., 2007). An associated line of R&D in the area of real-time orchestration of collaborative learning (by classroom teachers) is similarly investigating the ways in which tools and artefacts in the environment can help with the monitoring and management of CSCL processes (see e.g., Alavi, Dillenbourg, & Kaplan, 2009). Underpinning this, we need a way of theorising the relationships between learners' agency and the structuring effects of tasks and tools such that instructors and designers can provide appropriate forms and levels of support and guidance (Goodyear, 2005; Stubbs, Martin, & Endlar, 2006).

Design Patterns and Pattern Languages

Design patterns and pattern languages have emerged as an area of interest in CSCL in the last decade. A design pattern is a structured text which states the essence of a design *solution*, linking it to the *contexts* in which the solution is applicable, and providing a rationale that connects solution, problem and context (Goodyear & Retalis, 2010). It is a way of capturing and sharing design experience. A pattern language is a structured set of patterns aligned with the requirements of a complete design task. Design patterns and pattern languages have been created in both networked learning (e.g. Goodyear, 2005; Goodyear, de Laat, & Lally, 2006) and CSCL contexts (e.g. Hernández-Leo, Asensio-Pérez, Dimitriadis, & Villasclaras-Fernández, 2010; Villasclaras, Hernandez-Leo, Asensio-Perez, & Dimitriadis, 2009). They are seen as ways of supporting the work of "teacher-designers," particularly in the area of specifying CSCL tasks and roles.

Hernández-Leo et al. (2010) show how proper consideration of the *structures* in a pattern language (the types of relationships obtaining between patterns) can provide an effective basis for carrying out educational (re)design work. They identify a number of connecting rules that can be used to combine, or decide between, patterns. For example, some patterns *complete* or "embellish" other (higher level) patterns. In other cases, patterns can be seen as *complementary* (use two or more) or as *alternatives* (use just one). Again, some patterns are *specialisations* of more general design ideas, existing at the same level of aggregation. To this we would add the reciprocal of "complete"—to point out that some patterns function as the *context* for lower level patterns (which, in turn, complete them). Hernández-Leo et al. (2010) identify a range of 18 patterns for CSCL scripting, including patterns which help implement relatively well-known CSCL designs such as JIGSAW.

Goodyear et al. (2006) show how collections of design patterns can become core parts of a shared knowledge base for a community of practice (e.g. teacher-designers involved in networked learning). The argument depends upon a sense of patterns as offering what the authors call an "actionable locus"—a place where evidence from the analysis of research data, theorising, previous praxis and practical strategies come together.

To date, there has been rather little research evaluating the usefulness of design patterns for CSCL, beyond reflective case studies from the pattern-writers' own teaching. This could take one or both of the two possible foci—(1) the effectiveness and efficiency of the design process and (2) impacts on learning (Rusman, van Bruggen, Corvers, Sloep, & Koper, 2009). Given the rapid expansion of interest in the use of educational design patterns more generally, the need for research of this kind is becoming urgent.

Conclusions and Further Research

In this chapter we have provided an overview of recent research in CSCL, paying particular attention to instructional, group process and design issues. Reviewing research in recent years, we see a strong interest in the design and use of collaboration scripts. There have also been some impressive efforts in improving the methodology of CSCL research, including through the use of new analytic and visualisation techniques. A rebalancing of emphasis from research that focuses on patterns of co-variation to research that tracks the sequence of critical events is particularly welcome, especially given the opportunities it opens up for explaining the processes behind observable patterns of variation and difference.

We have also identified a number of promising areas for future research. Some of these are being created by the richer flows of process data being generated by increasingly ubiquitous personal learning technology. Others are the result of a widening interest in the spaces in which learning takes place—with distinct moves away from formal education and the classroom (virtual or otherwise).

The development of a range of applications, often subsumed under the broad heading of Web 2.0, opens up a new research area for CSCL. The new technologies suggest that CSCL may need to operate at a different scale using large open networks in which participation is the structural imperative and ties between participants can vary in strength and nature. The study of the various media involved in Web 2.0 and the specific detail of how they might support CSCL is still in its infancy. CSCL will also need to understand the potential for collaboration in a technical landscape that invites users to blur the boundaries between a range of new and emerging applications on devices that are mobile and connected to fast networks. The study of large open networks is an emerging field for research both in terms of new ways to collect and visualise data but also in relation to the basic philosophy and understanding of what computer-support and collaborative learning might mean in this new context.

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Inquiry Learning

36

Ard W. Lazonder

Abstract

The basic tenet of inquiry learning is that students arrive at an understanding of the subject matter by engaging in self-directed investigations. The foundations of this mode of learning are derived from three related fields of study. Psychological research on *scientific reasoning* revolves around the cognitive processes involved in inducing knowledge from empirical data, and intends to give an account of the problems students encounter in performing these processes. These learning difficulties (should) serve as a starting point for educational research into the effectiveness of *support* or *scaffolding* that can be used to overcome known skill deficiencies. Research and development of *software tools and environments* addresses the ways in which this support can best be offered to the learner so as to enhance learning processes and outcomes. This chapter outlines recent trends and issues in these three research areas, and attempts to synthesize key findings in order to identify the latest advancements in inquiry-based learning.

Keywords

Inquiry learning • Scientific reasoning • Scaffolding • Learning environment

Introduction

"I hear and I forget. I see and I remember. I do and I understand." This ancient Confucius quotation reflects the basic premise of many contemporary approaches to education. These approaches encapsulate inquiry learning, a method of science education that advocates active engagement in authentic science activities in order to concurrently develop a sound understanding of domain concepts and scientific reasoning skills. In many science classrooms, however, the educational advantages of "learning science by doing science" are challenged by various practical constraints. Chinn and Malhotra (2002b), for instance, attested that many inquiry tasks given to students in schools do not reflect the core attributes of authentic scientific inquiry. Even though these tasks might enable students to learn about the topics they are investigating, the skills involved in task performance replicate neither the cognitive processes employed in authentic scientific inquiry nor the epistemology that guides authentic scientific reasoning. If anything, school inquiry tasks promote the development of a restricted set of mostly practical inquiry skills, and a limited view on the nature of science.

A straightforward solution to this problem would be to persuade science teachers to use more authentic inquiry tasks that, due to their complex underlying models, call upon a wider range of scientific reasoning skills. Such tasks have been designed in various long-term research projects that revolve around the development of technology-enhanced inquiry learning environments. Some of these environments have actually found their ways into the schools; well-known examples include BGuILE (Reiser et al., 2001), GenScope (Horwitz, Neumann, & Schwartz, 1996), and WISE (Linn, 1995).

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However, the comprehensive and open-ended nature of authentic inquiry tasks poses additional challenges for students—who already experience quite a few difficulties when trying to accomplish less ambitious inquiry tasks. De Jong and Van Joolingen (1998) provided an overview of the intrinsic problems students may encounter in performing the latter type of tasks. Among the most pertinent problems are students' failures to infer hypotheses from data, design conclusive experiments, systematically collect data, and attend to anomalous data. Krajcik et al. (1998) further showed that the same difficulties arise during inquiry learning in project-based science classrooms, and Mulder, Lazonder, and De Jong (2010) recently confirmed that these problems have "survived the decade" and also apply to twenty-first century students.

These studies imply that more authentic inquiry tasks can only be used for educational purposes if students are adequately supported during their investigations. Accumulating evidence confirms that the effectiveness of inquiry learning relies on the presence of learner support. A recent meta-analysis revealed that unguided discovery learning is less effective than direct instruction. With support, however, learning outcomes are favorable for discovery learning when compared with other forms of instruction (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011). Likewise, a synthesis of research in K-12 science classrooms showed that students' conceptual understanding increased more when they were actively engaged in the learning process through scientific investigation than when they were taught by more passive or receptive strategies (Minner, Levy, & Century, 2010).

Recent experimentally controlled comparisons of instructional approaches confirm these meta-analytical findings. Eysink et al. (2009) demonstrated that well-guided inquiry learning is more effective than hypermedia learning and observational learning, and only slightly less effective than self-explanation-based learning. Of particular interest is the superiority of guided inquiry learning over observational learning, an approach closely related to studying worked examples. This difference might be due to the fact that participants in the latter condition observed an expert and mentally rehearsed task performance without any hands-on practice. While Klahr and Nigam (2004) showed that merely watching a teacher demonstration is more effective than unguided discovery learning, the findings of Eysink et al. once again demonstrate the importance of learner support and practice opportunities.

Even though the importance of support for inquiry learning seems beyond questioning, scholars diverge on what would be the right amount of support and when it should be offered. Some educational psychologists have (sometimes fiercely) contended that students should possess *all* relevant knowledge and skills before starting their own investigation (Kirschner, Sweller, & Clark, 2006), whereas others have convincingly argued that it can be just as effective to offer this information during the students' inquiry on a just-in-time or on-demand basis (Hmelo-Silver, Golan Dunca, & Chinn, 2007). The latter type of assistance is often referred to as scaffolding (e.g., Reiser, 2004), and can be provided by a teacher, a more knowledgeable peer, or tools within the learning environment.

The main focus of this chapter is on scaffolding by and within software tools. As software scaffolds aim to compensate for students' knowledge and skill deficiencies, their designs should be rooted in a rational analysis of the scientific reasoning required by the inquiry task at hand, as well as an empirical assessment of the students' difficulties in engaging in these processes. Such evidence-based design of software scaffolds requires a synergistic research strategy that starts from psychological research into what characterizes scientific reasoning in children, teenagers, and adults. Insights derived from these studies could help identify potential learning obstacles that should be resolved through scaffolding. Once designed, these scaffolds should be evaluated in educational studies under controlled circumstances. The results of these studies, in turn, should inform the development of well-scaffolded inquiry learning environments that should be tested on effectiveness in educational practice.

This chapter is organized according to the key components of this evidence-based design approach. The next three sections synthesize the main accomplishments in psychological research on scientific reasoning, educational research on scaffolding, and software development of inquiry learning environments. The final section discusses to what extent research findings have managed to cross disciplinary boundaries.

Psychological Research on Scientific Reasoning

Klahr's (Klahr, 2000; Klahr & Dunbar, 1988) Scientific Discovery as Dual Search (SDDS) model identifies "hypothesis generation," "experimentation," and "evidence evaluation" as the core components of scientific inquiry. Zimmerman (2007) conducted a comprehensive review of research on the performance and development of these scientific reasoning skills. One consistent finding is that "children are far more competent than first suspected, and likewise, adults are less so" (p. 213). This result implies that inquiry learning can be used across all levels of education, and that additional support is always needed regardless of the students' age. Useful guidance on the design of this support can be gleaned from the substantial body of research synthesized by Zimmerman. The sections below summarize the main results from her review, and highlight recent works not included in this research integration.

Hypothesis Generation

Hypotheses convey a student's conceptions of the phenomena he/she is investigating. Hypotheses can either be generated from prior knowledge or induced from experimental data, and college students are generally capable of doing both (Lazonder, Wilhelm, & Hagemans, 2008). Most participants in this study engaged in theory-driven experimentation, and the specificity of their hypotheses mirrored their initial familiarity with the task domain. Yet the latter result seems to be of minor importance because the number of hypotheses (and not their domain-specificity) appears to be the strongest predictor of performance success (Lazonder, Wilhelm, & Van Lieburg, 2009). Generating and testing hypotheses per se thus is an important determinant of successful inquiry learning.

Other studies have shown that adults and teenagers typically generate few hypotheses to guide their investigations in unfamiliar domains. Gijlers and De Jong (2005) recorded the dialogues of 15 high-school dyads during a simulation-based inquiry task. Analysis of the students' utterances showed that 70 % of their discourse was related to task orientation whereas less than 2 % of the utterances involved hypothesis generation. Njoo and De Jong (1991) observed equally low proportions of hypothesizing in university students. These findings imply that students find it difficult to induce hypotheses from experimental results. This was substantiated by Mulder et al. (2010), who found that domain novices stated as many and equally specific hypotheses as domain experts. However, analysis of the students' think alouds revealed that the novices based their hypotheses on mere guesswork rather than the results of the experiments conducted with the simulation.

Children often hold strong prior beliefs about the topics they are investigating. Pupils in the age of 12–14 are able to state and investigate their own hypotheses; younger children often conduct experiments without explicit hypotheses (Penner & Klahr, 1996; Tomkins & Tunnicliffe, 2001). Cross-sectional research has shown that children, as opposed to adults, tend to generate plausible hypotheses from prior knowledge, and often center their investigation on a single hypothesis (Klahr, Fay, & Dunbar, 1993). During an inquiry, children are unable to induce implausible (but correct) hypotheses from data—a skill that is known to be problematic to older students too, in particular when data are anomalous. As a result, both children and adults are susceptible to confirmation bias (Tschirgi, 1980) and prefer to state and verify "safe" or familiar hypotheses. Falsifying alternative hypotheses that contradict the student's initial beliefs occur significantly less often, but are the driving force behind the discovery of new ideas (Dunbar, 1993). It thus seems that students of all ages use an investigation to demonstrate their knowledge of a domain rather than rigorously test thought-provoking hypotheses in search for new understanding.

Together these studies paint a fairly consistent picture of students' capabilities and difficulties in hypothesis generation. Students around the age of 12 and up are able to generate hypotheses from prior knowledge. Both adults and children tend to begin their inquiry by focusing on hypotheses consistent with prior beliefs, but diverge in their attempts to generate subsequent hypotheses. Children tend to keep generating plausible hypotheses (if at all), whereas older students more often generate implausible hypotheses. Inducing new or alternative hypotheses from data is difficult across age groups, and challenges the effectiveness of inquiry learning as instructional method to develop new knowledge.

These challenges can in principle be met through scaffolding, and the research reviewed here provides some implications for the design of this support. One is that students should have at least a rudimentary understanding of the topic they are investigating, for this will enable them to generate an initial hypothesis. Content support should be given in cases where the students' prior knowledge is insufficient. In addition, process support during an inquiry is needed to prompt students to generate subsequent hypotheses. These instructions should assist students in generating implausible or alternative hypotheses, and include directions to induce these hypotheses from experimental outcomes.

Experimentation

The design and conduct of experiments is a relatively well-studied scientific reasoning skill. The lion's share of attention in this research has been devoted to the design of unconfounded experiments through the control-of-variables strategy (CVS). This strategy implies that only the variable of interest should be manipulated while holding constant all other variables. Building on the pioneering work of Piaget (e.g., Inhelder & Piaget, 1958), Tschirgi (1980) showed that both adults and children rely on CVS when trying to uncover the reason for a previously obtained negative result. In case of a positive outcome, the less robust strategy of holding just the variable of interest constant prevailed in both age groups. These findings suggest that CVS is mainly used to falsify implausible hypotheses. Bearing in mind the conclusions from the previous section, this might explain why many students tend to exhibit ineffective experimentation behavior.

Zimmerman (2007) concluded that 6-year-olds can differentiate between conclusive and inconclusive experiments, and Schauble, Glaser, Duschl, Schulze, and John (1995) found that 12-year-olds have a rather complete understanding of what constitutes a well-designed experiment. The knowledge underlying CVS thus seems to be in place at a relatively young age. However, the skills to apply this knowledge in designing an exhaustive set of valid comparisons to test a hypothesis develop slowly without instruction or practice. Veenman, Wilhelm, and Beishuizen (2004) confirmed that proficiency in the execution of CVS shows a developmental trend from childhood (grades 4 and 6) to adolescence (grade 8) to adulthood. These cross-sectional differences are independent of task domain, as is the intra-individual development of the CVS through repeated practice (Kuhn, Schauble, & Garcia-Mila, 1992). Students' initial understanding of a task domain does not affect the use of CVS either, and their final understanding is associated with the use of this strategy in an unfamiliar domain only (Wilhelm & Beishuizen, 2003).

This snapshot of the research provides implications for how students can be scaffolded in designing unconfounded experiments. As even young children possess considerable knowledge of what is a "good" experiment, support should mainly be geared toward the application of that knowledge during the students' own investigations. A brief instruction or demonstration of the CVS seems sufficient to achieve this goal; prompts or feedback might be given during the investigation to remind students of the use of this strategy. Alternatively, offering ample opportunities for practice can also promote students' proficiency in CVS, but yields little immediate improvement. A combination of both options is probably the best way to bring about a steady increase in students' ability to construct valid experiments.

These implications nevertheless reflect a somewhat limited view of experimentation. Kuhn has repeatedly criticized the research on experimentation skills for focusing too narrowly on the execution of the CVS (e.g., Kuhn, Black, Keselman, & Kaplan, 2000; Kuhn & Dean, 2005; Kuhn, Iordanou, Pease, & Wirkala, 2008). While acknowledging the importance of setting up confounded experiments, she also encourages researchers and educators to attend to aspects beyond the control of variables. These include students' metastrategic understanding that determines whether CVS is applied spontaneously in their own investigations, and the skills to interpret the results produced therein. The former aspect is addressed in the section on educational studies; the latter pertains to the evidence evaluation skills that are reviewed next.

Evidence Evaluation

Evidence evaluation involves inducing regularities from data obtained through experimentation in order to generate, test, or refine a hypothesis. Kuhn, Amsel, and O'Loughlin (1988) found that this skill develops slowly and hardly ever reaches maturity. They identified the coordination of theory and evidence as the major stumbling block, and report several strategies people use to wrongly keep the two in alignment. Well-known examples include ignoring or distorting anomalous data, and adjusting one's hypothesis to match inconsistent evidence. This repertoire of strategies was extended by Chinn and Brewer (1993), who proposed seven ways to respond to anomalous data. Their taxonomy has been validated and further extended through empirical studies with undergraduate students (Chinn & Brewer, 1998; Lin, 2007).

It thus seems that people of all ages are rather reluctant to change their beliefs when confronted with anomalous data. To illustrate, undergraduates consider contradictory findings less relevant or plausible than confirmatory evidence. Consistent evidence, in addition, was found to strengthen students' prior belief, whereas inconsistent evidence did not weaken it (Koslowski, Marasia, Chelenza, & Dublin, 2008). In the absence of prior knowledge or beliefs, children tend to create new, sometimes highly implausible, theories to make sense of data (Amsel & Brock, 1996). This data is interpreted on the basis of domain-general features such as the number of observations in a data set, and the variability of scores between data sets. Masnick and Morris (2008) showed that children (grades 3 and 6) and adults attend to both characteristics when interpreting data. The use of these characteristics was found to improve with age.

However, data should first be collected before it can be interpreted. Obtaining reliable data requires skilled observation which, in turn, requires the coordination of domain-specific knowledge and domain-general sensory perception skills (Eberbach & Crowley, 2009). As children generally lack both, they often fail to systematically attend to cues that point at the underlying properties of a phenomenon. Older learners too are inclined to focus on surface features of novel phenomena and situations (Chi, Feltovich, & Glaser, 1981). Domain knowledge thus aids the ability to observe scientifically, and this influence becomes stronger when sensory stimuli are ambiguous (Penner & Klahr, 1996). Yet people do not simply see what they expect to see. Chinn and Malhotra (2002a) had fourth-graders watch a heavy and a light rock dropped simultaneously. Children who believed that the rocks would hit the ground at the same time tended to make the correct observation whereas children with incorrect beliefs were not biased to make observations that fit their predictions.

To conclude, evidence evaluation may be the most critical and difficult skill to develop. Across settings and ages, the observation and interpretation of data require additional support and guidance. Providing content support by offering background information or predefined hypotheses could be a powerful means to help domain novices to make more accurate observations. When students already have some understanding of the topic they are investigating, possible incorrect beliefs might impede observation and interpretation. Process support could help overcome this problem by instructing or prompting domain-general strategies and techniques to handle data. Examples include strategies to attend to visual *and* auditory clues during observation, bracket prior beliefs during interpretation, and differentiate true effects from measurement error. This type of scaffolding, if accompanied with ample hands-on experience, could promote students' understanding of and engagement in scientific practices during evidence evaluation.

Educational Studies on Scaffolding

Having established students' need for support, this section addresses the effectiveness of various forms of scaffolding to support scientific reasoning and facilitate the acquisition of domain knowledge.

Scaffolds for Hypothesis Generation

Scientific reasoning research suggests that content support might assist students in generating an initial hypothesis. Following in the footsteps of Klahr et al. (1993), several studies provided students with a predefined hypothesis to jumpstart their investigation. Results are inconclusive as to whether this type of support promotes subsequent hypothesis generation and learning (Burns & Vollmeyer, 2002; Schunn & Klahr, 1993; Vollmeyer & Burns, 1996). Njoo and De Jong (1993a, 1993b) supplanted the generation of initial *and subsequent* hypotheses by a worksheet. Students who received this aid outperformed those who did not on the posttest. However, these differences cannot be attributed solely to the predefined hypotheses because the worksheets (which were unavailable in the control condition) structured the entire inquiry learning process.

Offering content explanations about the nature of relationships between variables yields similar benefits (Lazonder, Hagemans, & De Jong, 2010). Students who could consult this information before and during their investigation had more domain-specific hypotheses and learned more than students who only had access to this information before their inquiry. Both groups outperformed students from an unsupported control group. In case of collaborative inquiry learning, one's peer(s) can serve as additional source of hypotheses. Gijlers and De Jong (2009) made group members' conceptions overt through a shared proposition table, and found that this scaffold caused students to consider more hypotheses and learn more compared to students who received a hypothesis scratchpad or no support at all.

While content support for generating an initial hypothesis has been extensively studied, process support for inducing subsequent hypotheses from data is not (cf. Zimmerman, 2007). Instead, studies on process support have merely examined the effects of prompts to remind students to generate hypotheses. Njoo and De Jong (1993a, Study 1) gave students a nonspecific hint to generate and test a hypothesis before each round of experiments. These open suggestions proved ineffective: students with and without hints stated no hypotheses at all. More restrictive directions are not very effective either. Quinn and Alessi (1994) obliged students to write down either the most plausible hypothesis or a list of all plausible hypotheses. When task complexity was low, students in the latter condition stated and tested more hypotheses and performed better; with increased task complexity; however, these effects disappeared. Likewise, Van Joolingen and De Jong (1993) required half of their students to list all hypotheses prior to experimentation while the other half could hypothesize at will during their inquiry. This restriction resulted in more hypotheses and a better assessment of their truth value, but comparable posttest scores.

In sum, these studies show that content support can promote hypothesis generation and learning in teenagers and adults; its effect on children has not yet been assessed. While the optimal nature and timing of this support remain undetermined, evidence suggests that extensiveness and effectiveness go hand in hand. Process support has proved largely ineffectual, which might be due to the fact that the investigated scaffolds do not address the students' principal support needs.

Scaffolds for Experimentation

Educational research on experimentation has produced more consistent findings. Klahr and coworkers have repeatedly shown that direct CVS-instruction (either with or without practice opportunities) leads to more proficient use of this strategy than unguided practice (see, for an overview, Klahr & Li, 2005). Dean and Kuhn (2007) found that the immediate effects of direct instruction fade away after 3 months of practice, whereas Strand-Cary and Klahr (2008) report sustained benefits of direct instruction even after 3 years and without any efforts to consolidate and maintain acquired skills. Lorch et al. (2010) recently established that direct instruction and unguided practice make distinguishable contributions to students' understanding of CVS. Their combination has a synergistic effect on the acquisition and consolidation of this strategy.

Kuhn and Dean (2005) demonstrated that simply prompting children to select one variable as the focus of investigation leads to more goal-oriented experimentation plans and valid inferences. While these prompts have been criticized for being essentially equivalent to CVS instruction (Klahr, 2005), Kuhn and Dean postulated that their prompts enhanced children's metastrategic understanding that, in turn, may eventually cause them to design controlled comparisons. Even though direct evidence to support this claim was not collected, other studies have shown that interventions aimed at fostering metastrategic knowledge can promote unconfounded experimentation (e.g., Keselman, 2003; Zohar & Peled, 2008).

It thus seems that the research on experimentation scaffolds has consistently addressed the implications from scientific reasoning research. The general conclusion from these studies is that direct CVS-instruction, hands-on experience, and metastrategic training all yield immediate and sustained effects on students' experimentation skills. The effectiveness of these interventions seems to depend upon their potential to make the rationale and constituents of the CVS strategy explicit to students (cf. Ross, 1988). It should be noted, however, that the cited studies involved elementary school children who were scaffolded by their teacher. Future research should examine whether obtained findings generalize to both older age groups and software scaffolds. Work in this direction has been started already by Klahr and colleagues, who have converted their teacher-led CVS instruction into an intelligent tutoring system (see http://www.psy.cmu.edu/~tedtutor/index.html). Evaluation of this tutor is in progress.

Scaffolds for Evidence Evaluation

The importance and complexity of evidence evaluation stand in marked contrast with the attention it has received in educational research. A notable exception is the work of Chinn and Malhotra (2002a), who investigated the influence of content and process support on children's responses to data. Process support was found to be generally ineffective. In one experiment, an introductory guided walkthrough of all experiments in teacher-led discussions failed to promote conceptual change. In a follow-up experiment, prompt questions that aimed to encourage unbiased observation and interpretation enhanced neither the use of these skills nor learning outcomes. Content support on the other hand improved performance on an immediate and delayed posttest. Path analyses suggested that content explanations improved the quality of the children's prediction which, in turn, increased the chance of making correct observations, interpretations, and generalizations.

A more technologically advanced form of process support was developed by Veermans, Van Joolingen, and De Jong (2000, 2006). They designed a computer-based method for generating adaptive feedback that supports the process of interpreting obtained data in light of the students' hypothesis. This method was embedded in a simulation-based learning environment and compared with a version of the environment that provided generic feedback on the students' hypotheses, independent of their experimentation behavior. The results of both studies showed that providing adaptive feedback on the correctness of hypotheses is little effective, even if the strategies underlying the feedback are explicated.

These results paint a rather pessimistic picture of the effectiveness of process support. Providing content support appears to be more a fruitful option to enhance students' abilities to observe and interpret evidence. Yet offering content explanations is seemingly at odds with the basic premise of inquiry learning (Lazonder et al., 2009), and limited in its potential to strengthen students' ability to evaluate evidence (Chinn & Malhotra, 2002a). Future research should therefore explore new ways to scaffold this important scientific reasoning skill.

Software Development of Inquiry Learning Environments

Scaffolds that have proven effective under controlled experimental conditions qualify to be incorporated in technology-enhanced inquiry environments. This section reviews three software R&D projects for evidence that the results of educational studies on scaffolding inform the design of inquiry learning environments. As a full review of these environments is well beyond the scope of this chapter, the review addresses tools within the learning environment that aim to assist students in the three core scientific reasoning processes.

Evolution Readiness

Launched by the Concord Consortium in 2008, this project aims to introduce the topic of evolution in the elementary grades. The project is creating a Web-based learning environment comprising ten activities that are being tested in fourth-grade classes (Horwitz, O'Dwyer, & Rosca, 2010). Activities involve simulation-based investigations that are larded with teachers' introductions, class discussions, and reading/writing assignments.

The learning environment incorporates software scaffolds to support children's scientific reasoning. *Hypothesis generation* is supported by careful task structuring and content support. In the "virtual ecosystem" activity, for example, children investigate how the survival of a single animal depends upon population size. Following an introductory experiment with a single rabbit in a field of edible plants, children are asked to predict whether it will be easier or more difficult for the rabbit to survive when other rabbits enter the field. They have to select a prediction from a predefined list ("easier," "harder," "no difference") and justify their choice. As each activity addresses a single, predefined hypothesis, there is no need for process support to assist children in inferring new hypotheses from data.

Predictions are then tested through experiments with a simulation. *Experimentation* is supported by just-in-time instructions that explicate the steps in setting up a controlled comparison (see Fig. 36.1). As these instructions are used consistently within and across activities, the Evolution

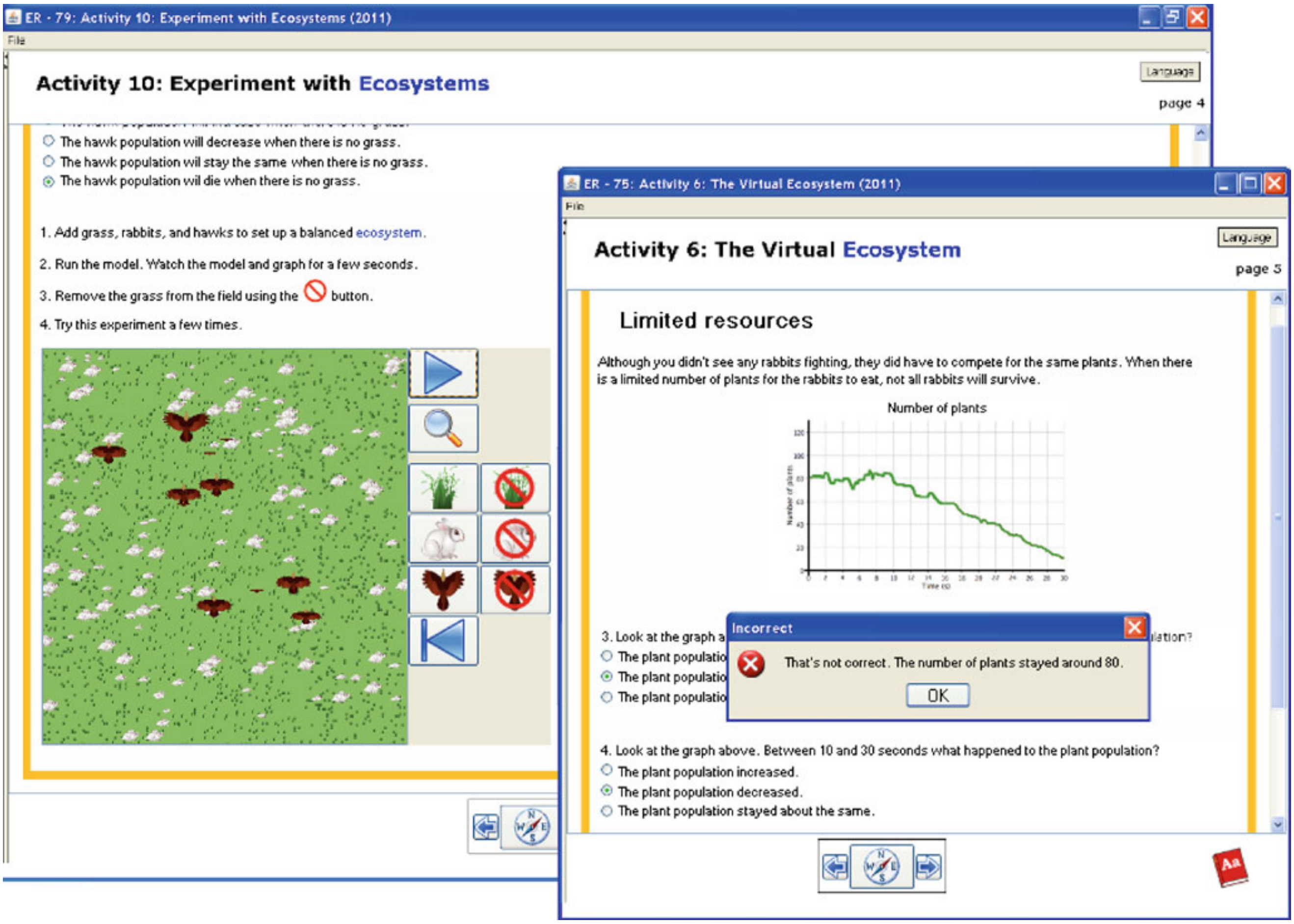

Fig. 36.1 Scaffolds for experimentation (*left image*) and evidence evaluation (*right image*) in the Evolution Readiness environment (*source*: http://er.concord.org)

Readiness curriculum enables children to develop experimentation skills through repeated, guided practice.

Evidence evaluation is supported by various process scaffolds. Some activities contain pop-up messages that supplant observation and interpretation at the end of each experiment. Instead of performing these processes themselves, children are offered a full explanation of what the simulation output means (e.g., "Uh oh, 4 of your plants are wilted") and how they should continue their investigation ("Try to find the right environment for them using the Carry button"). Other activities support interpretation by multiple choice questions with immediate feedback; an example is shown in Fig. 36.1. In both cases, the scaffolds ensure that children get to the "correct" answer by following a predefined sequence of activities.

ASPIRE

The Astrophysics Science Project Integrating Research & Education (ASPIRE) has produced over 20 online science lessons and labs for middle school students. These materials have been developed by science teachers in collaboration with software designers and content experts. A typical example is the "Gas particles in motion" Lab that enables students to investigate the behavior of gases due to changes in variables such as volume and temperature. Scaffolding for all three scientific reasoning processes is embedded within the environment.

Content support for *hypothesis generation* is threefold. First, students' prior knowledge is activated by means of a fun exercise (stick a toilet plunger to the wall); the experiences gained are used as springboard to introduce important domain concepts and relations (e.g., changes in the volume of a gas will affect the pressure of that gas). These content explanations, in addition, prompt students to predict what happens to the pressure of a gas when the volume is increased. Unlike in the Evolution Readiness environment, there is no list of predefined hypotheses, so students have to use the information that is offered in the environment to make their own predictions. This seems feasible given the students' age and the well-defined nature of the task.

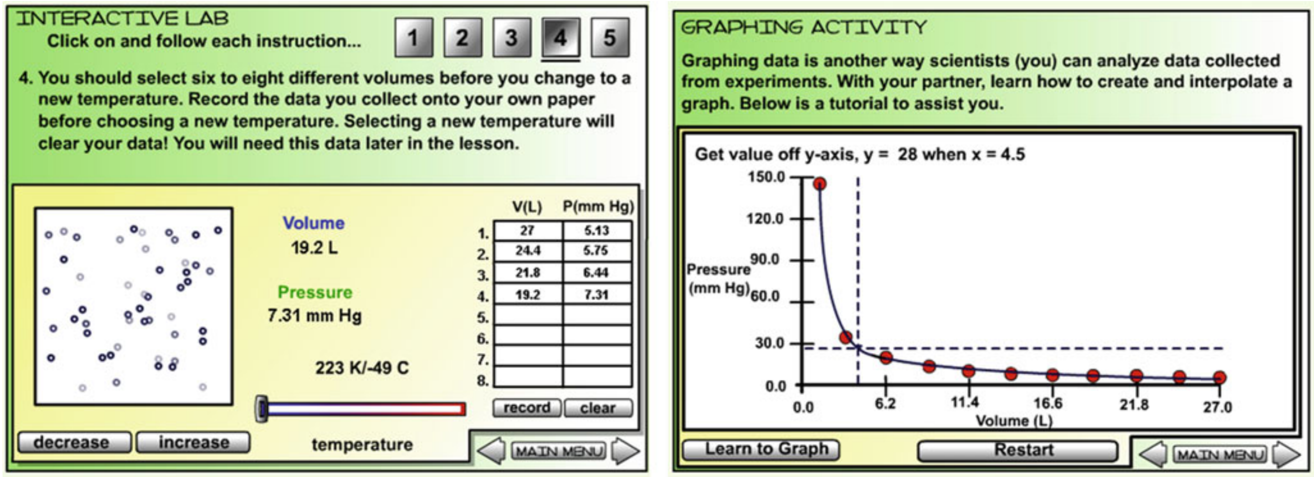

Fig. 36.2 Scaffolds for experimentation (*left image*) and evidence evaluation (*right image*) in ASPIRE Lab (*source*: http://aspire.cosmic-ray.org)

Process support for *experimentation* takes the form of step-by-step instructions that appear upon clicking the buttons 1–5 (see Fig. 36.2). This approach is essentially equivalent to that of the Evolution Readiness environment. Systematic experimentation is further warranted in that the independent variable "volume" can only be increased (or decreased) in increments of 2.6 by clicking the corresponding buttons. The variable "temperature"—that does not influence the nature of the relationship—can be set to any value by using the slider. Simulation output is added to the data table by clicking the "record" button.

Interpretation of this data is pivotal to several *evidence evaluation* scaffolds. These include templates with guiding questions and sentence starters to help students infer the inverse relationship between volume and pressure from their data. After this rough interpretation, students complete two tutorials to learn how to create and interpolate a graph (see Fig. 36.2), and apply these instructions to their own data so as to reveal the curvilinear nature of the inverse relationship. To scrutinize this relationship, students receive step-by-step instructions to analyze the mathematical patterns in their data.

Science Created by You

The science created by you (SCY) project is creating authentic learning experiences ("missions") that revolve around contemporary socio-scientific issues. Students perform these missions within the SCY-Lab learning environment (De Jong et al., 2010). Content is currently available for four interdisciplinary topics: CO_2-emission, ECO systems, healthy food, and DNA. Scaffolding in SCY-Lab will be exemplified on the basis of the CO_2-mission: a 20-h unit in which high-school students design and investigate a climate-friendly house.

Hypothesis generation is implicitly supported by the suggested learning route, and explicitly by process and content scaffolds. Prior to their investigation, students engage in preparatory activities to establish an initial knowledge base. As in authentic scientific inquiry, they list and prioritize all factors that might influence domestic CO_2-emission, and study background information about the most pertinent factors. Once students have developed a basic understanding of what causes domestic CO_2-emission, they decide which topics merit further investigation. They then translate these issues into research questions, and state hypotheses on the basis of acquired domain knowledge. Hypotheses are written down in a text file; general guidelines for hypothesis generation are available in an associated help file. Text file input is analyzed by a software agent to assess whether students' hypotheses are syntactically correct and coherent with their research questions. Where appropriate, the agent generates feedback messages to help students improve their hypotheses before they start experimenting.

Experimentation is supported by the experiment planning tool displayed in Fig. 36.3. This scaffold organizes the process of designing unconfounded experiments via a template that prompts students to specify all elements of a scientific experiment. A checklist to evaluate the experimental setup appears in a help file that is incorporated in the tool. During experimentation, a software agent monitors and analyzes the students' use of the CVS while interacting with the simulation (Weinbrenner, Engler, Wichmann, & Hoppe, 2010). Analysis results are currently represented in dynamic line charts; attempts to create a more intuitive representation, possibly with additional hints, are in progress.

Scaffolds for *evidence evaluation* offer process support for data interpretation. This support consists of general guidelines that are delivered through help files. Guidelines include suggestions to record and organize numerical data

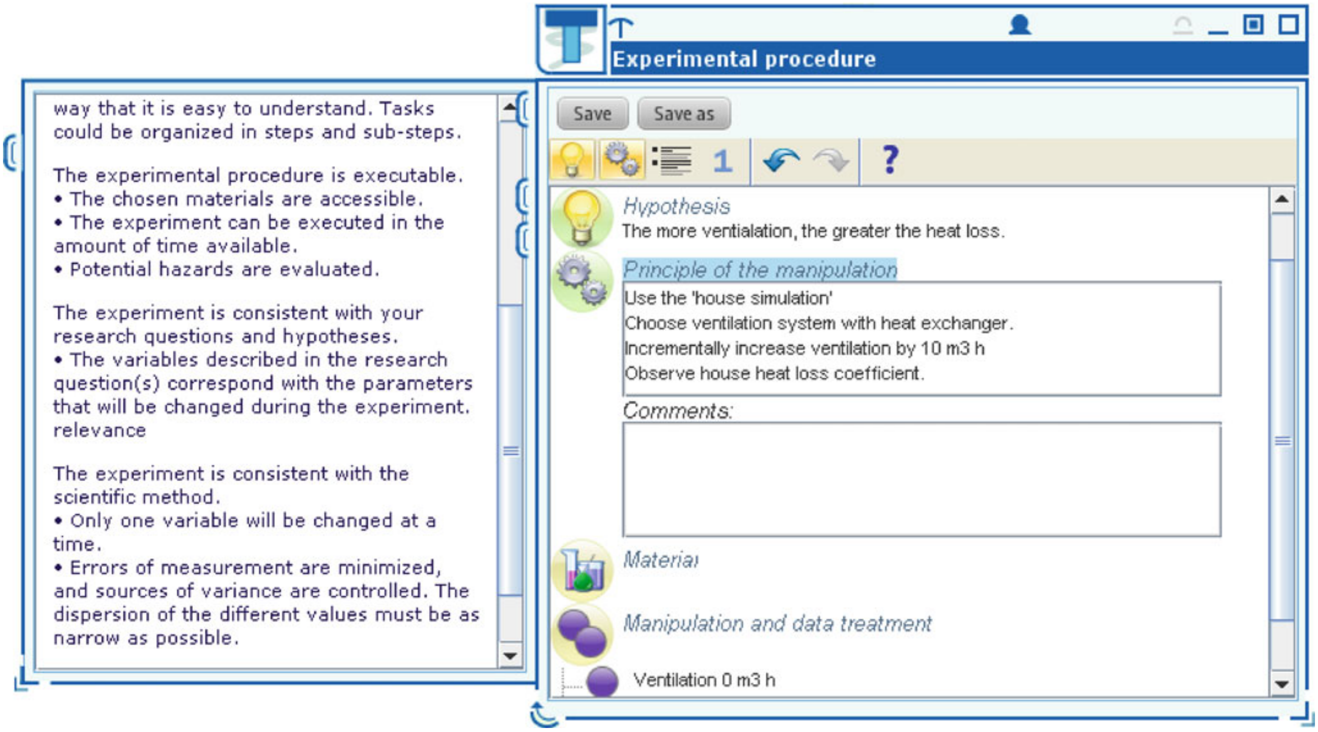

Fig. 36.3 SCY-Lab's experimental planning tool with associated help file

(e.g., store raw data in tables, plot important data in graphs, calculate means and standard deviations), and compare experimental outcomes with hypotheses. This guidance is deliberately minimal for two reasons. One is the high-school students' comparatively high level of proficiency in scientific inquiry. Another reason is that SCY missions are open-ended projects in which hypotheses and experiments may differ among students. Ongoing evaluation studies will bear out whether such minimal guidance is sufficient to support evidence evaluation.

Conclusions

This chapter illustrated how psychological and educational research can foster the design of inquiry learning environments. Even though the works reviewed here do not allow for any definitive conclusion, they do contain some typical instances of this evidence-based design approach. One key example involves hypothesis generation. Across learning environments, content support for creating an initial hypothesis was designed in an evidence-based and age-appropriate way. Young children, who often experiment without explicit hypotheses, receive predefined hypotheses in the Evolution Readiness environment. ASPIRE Labs require teenagers to generate a hypothesis from readily available content explanations, whereas the young adults in SCY Lab have to infer multiple hypotheses on the basis of their own preparatory activities.

Experimentation scaffolds were equally well attuned to the scientific reasoning abilities of the different age groups. Consistent with educational research, all three environments provide ample opportunities for guided practice. The complexity of the students' experiments increases with age: young children are explicitly instructed to manipulate one dichotomous variable whereas high-school students in SCY Lab receive a few general directions to set up a series of experiments with several continuous variables. The software agent in SCY embodies a promising and innovative approach to offer adaptive feedback through software tools.

Evidence evaluation, in contrast, is characterized by a less consistent flow from psychological research through educational research to software development. This scientific reasoning skill has received little attention in educational studies, and the studies that do exist failed to demonstrate the effectiveness of process support. The learning environments, however, incorporate a broad repertoire of process scaffolds that seem effective at face value. The next logical step would therefore be to assess the merits of these scaffolds under controlled and ecologically valid circumstances.

Notwithstanding these highlights, it is inherently difficult—if not impossible—to draw firm conclusions from this research synthesis because the selection of its resources is both personal and incomplete. This pertains first and foremost to the learning environments. Due to space limitations, one environment per age group could be addressed, and the present choice is biased in that only reasonably well-scaffolded environments were considered for inclusion. Other inquiry learning environments could incorporate fewer, more, or different scaffolds for scientific reasoning. Readers who wish to develop a more representative view of scaffolding in inquiry learning environments could consider the overviews by Quintana et al. (2004) and De Jong (2006b, 2010).

Another limitation of the present review is its somewhat narrow focus on scientific reasoning. While hypothesizing, experimenting, and evaluating evidence undoubtedly are pivotal to scientific inquiry, they can only be performed well when embedded in a broader set of scientific practices. These include orientation to the problem at hand, modeling of the variables and relations in the simulation, reporting the results of an inquiry, and reflection on the (learning) process and its outcomes. In addition, self-regulatory skills are needed for students to plan, monitor, and evaluate their investigations (e.g., De Jong, 2006a; White, 1993). All of these skills can cause learning obstacles too, and research has shown that these problems can be alleviated by software scaffolds. The results of these studies have been published elsewhere (e.g., Bernacki, Aguilar, & Byrnes, 2011; Kali & Linn, 2008), and have actually informed the design of inquiry learning environments (e.g., Manlove, Lazonder, & De Jong, 2009).

Educational studies that assessed the joint effect of multiple scaffolds were not dealt with either. Examples of such integrated support include model progression with assignments (Swaak, Van Joolingen, & De Jong, 1998), assignments with content explanations (Hulshof & De Jong, 2006), and content explanations with graphical/textual feedback (Rieber, Tzeng, & Tribble, 2004). Others have gone beyond combining two scaffolds and provided students with support tools for all three scientific reasoning processes and their regulation (e.g., Chang, Chen, Lin, & Sung, 2008; Fund, 2007; Reid, Zhang, & Chen, 2003; Zhang, Chen, Sun, & Reid, 2004). Studies like these stand midway between a controlled comparison and a practical evaluation, and lack the experimental rigor necessary to draw valid conclusions on the effectiveness of a single scaffold to enhance a single scientific reasoning skill.

On the other hand, practical evaluations can lead to new ideas to scaffold inquiry learning which can then be tested under controlled conditions by educationalists and psychologists. This reversed evidence-based design approach could shed light on some of the unresolved issues that were identified in this review. Why, for instance, was process support generally ineffective, or at least less effective than content support? And how can evidence evaluation best be supported? Another interesting avenue for future research would be to examine the effectiveness of software agents in general, and for young learners in particular. Do learners across age groups accept and learn from this type of support? Answers to questions like these are needed to advance our understanding and appreciation of inquiry learning as a method for science education.

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Model-Based Learning and Performance

37

Norbert M. Seel

Abstract

Model-based learning is both a new and old paradigm of psychology and education. In pedagogy we can find this idea since decades (and until today various conceptions of model-based learning have been developed in the fields of mathematics, physics or geography education aiming at guided discovery and exploratory learning. Traditionally, there are two major approaches of theory and research on model-based learning: A functional-pragmatic approach and a constructivist approach, which is closely related with the theory of mental models. This chapter focuses on both approaches with a particular emphasis on measuring the effects of model-based learning on different performance criteria, such as understanding and problem solving, analogical reasoning, and situation-dependent decision making.

The chapter starts with a description of the theoretical foundation of model-based learning with a particular emphasis on the learning-dependent progression of mental models and its systematic assessment by means of particular diagnostic methodologies. The epistemology and psychology of mental models as the fundamental basis of model-based learning are described whereby models will be separated from cognitive schemas, discussed as the "building blocks" of the psychological understanding of cognition. The impact of mental models on comprehension and problem solving as well as on analogical reasoning and decision making is discussed. Comprehension and reasoning in specific situations necessarily involve the use of mental models of different qualities. Besides the mental model approach, model-building activities have been emphasized in various areas of instructional research aiming at the improvement of learning and problem solving in subject matter domains, such as physics or mathematics. In contrast to the mental model approach, these instructional approaches of model-based learning correspond with functionalist-pragmatic conceptions of model-building activities within the realm of mathematics and physics education. Both approaches of model-based learning have had initiated numerous empirical studies which are summarized and discussed.

Keywords

Mental models • Analogical reasoning • Problem-solving • Knowledge diagnosis • Model-based teaching • Situation awareness • Decision making

Introduction

Model-based learning is both a new and old paradigm of psychology and education. In education this idea has been around for decades (cf. Chapanis, 1961), and a variety of

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conceptions of model-based learning aimed at guided discovery and exploratory learning have been developed in the fields of mathematics, physics, and geography education (cf. Hodgson, 1995; Lesh & Doerr, 2000; Penner, 2001). These conceptions correspond to a large extent to functional and pragmatic approaches of model-based learning, whereas the construct of mental models as it emerged in cognitive science in the 1980s corresponds to a constructivist view on model-based learning (Johnson-Laird, 1983; Seel, 1991).

Although the two movements differ with regard to their epistemological and theoretical foundations, they share a strong instructional impetus insofar as the suggestion has been made that models are constructed from the significant properties of external situations, such as school settings, and the subject's interactions with well-designed learning environments (cf. Lehrer & Schauble, 2010; Norman, 1983). Indeed, learning environments can be designed in such a way that students may be involved in a process of discovery and exploratory learning in which they extract facts from information sources, look for similarities and differences between these facts, and thus develop new concepts (cf. Carlson, 1991). In this context, instruction is oriented toward facilitating model-based learning and providing the students with opportunities to create their own models for solving tasks and problems. Advocates of this approach argue that learning occurs as a multistep process of model building and revision (Lehrer, 2009; Penner, 2001). Similarly, proponents of the mental model approach argue that learning occurs when people actively construct meaningful mental representations, such as schemas and coherent mental models that communicate subjective experiences, ideas, thoughts, and feelings (cf. Seel, 1991). Although these conceptions obviously overlap to a great extent with regard to the impact of instruction on model-based learning and performance, they approach this topic from different theoretical perspectives and research interests, as described in the following sections.

Major Lines of Research on Model-Based Learning

The intentional construction of models has played an important role in mathematics (Schichl, 2004), the philosophy of science (Bailer-Jones, 2009), and psychometrics (Borsboom, 2005) for a long time. However, in this chapter the focus is on model-based learning and performance in various subject matter domains, such as physics and mathematics, where models serve explanatory functions. These conceptions can be classified as functional-pragmatic approaches that go "beyond constructivism" (Lesh & Doerr, 2003). In addition, the chapter also describes the impact of the mental model approach on learning and reasoning. Clearly, this approach goes "beyond pragmatism" and aims at creating epistemological plausibility with regard to the "cognized world" as well as reasoning (Seel, 1991).

Pragmatic Approaches of Model-Based Learning

Pragmatic and functional approaches of model-based learning and performance have played an important role within the realm of instructional psychology since the 1980s, but their origins can be dated back further. The concept of models already played a central role in information science in the 1950s and 1960s, where one can find the idea that the learning consists of the procedures people use to construct *internal models* of their environments (e.g., Steinbuch, 1961). At the same time, Chapanis (1961) classified models into two broad categories: *reproduction models*, such as architects' models that operate with physical objects and diagrams, and *symbolic models* aiming at the representation of knowledge about the world. The various approaches of the 1960s culminated in the advent of a "general model theory" applied to issues of representation and scientific understanding (Stachowiak, 1973; Wartofsky, 1979).

From a pragmatic point of view, talking about *models* always implies asking for the *original* to be modeled. Globes are models of the earth. Naturally, a globe is not a reduced earth but rather it is designed to give answers to questions about the locations of different places or the distances between places. With regard to the chemical composition of the earth, a globe is not relevant. This example illustrates a basic property of models: Every model is constructed in accordance with specific intentions in order to simplify its original in several respects. By virtue of its nature as an idealized reduction to relevant characteristics of its original, *a model may be understood as a concrete, comprehensible, and feasible representation of nonobvious or abstract objects* of consideration. The representation of the objects' attributes and components comes second to the representation of structural relationships. Evidently, the functions of a model—and in consequence, also the requirements for its structural features—are defined on the basis of the intentions of the model-constructing person. Therefore, in physics as in other disciplines the term *model* is principally used in accordance with functional intentionality:

- Models may serve as means of *simplifying* an investigation to particular and relevant phenomena in a domain.
- Models may serve to help the user *envision* that which is being modeled and make the invisible visible.
- Models are constructed as analogies that identify relationships within an unknown domain to be explained (e.g., quantum mechanisms) with the help of the relationships within a known domain. (e.g., Rutherford's atomic model).

Such models are heuristic hypotheses about structural similarities of different domains. Usually, they are called *analogy models*.

These characteristics of models are also emphasized in various areas of instructional psychology with the aim of improving learning and problem solving in subject matter domains such as physics or mathematics. Stewart, Hafner, Johnson, and Finkel (1992), for example, have summarized the central idea of these instructional approaches by stating that "a science education should do more than instruct students with respect to the conclusions reached by scientists; it should also encourage students to develop insights about science as an intellectual activity" (p. 318). Accordingly, advocates of this approach argue that "given that we wish to involve students in the practices of scientists, we focus primarily on model building" (Penner, Lehrer, & Schauble, 1998, p. 430). In science, an important goal of instruction is to help students develop powerful models for making sense of their daily experiences involving light, gravity, electricity, and magnetism. These models respond to the partial and incomplete models that students are likely to build with regard to phenomena of everyday physics (Clement, 1979, 2000). In order for these preconceptions or misconceptions to be changed, model-based learning in the classroom must correspond to the conceptual models and the constructs of the respective scientific discipline in the curriculum (Etkina, Warren, & Gentile, 2005).

A similar argumentation can be found with regard to the learning of mathematics in the classroom. Mathematizing is considered as a form of modeling and requires the use of specialized formal languages, symbols, graphs, pictures, concrete materials, and other notation systems to develop mathematical descriptions and explanations that often make great demands on students' representation capabilities. Therefore, Hodgson (1995), Lesh and Doerr (2000), and other authors argue that helping students to develop powerful mathematical models should be among the most important goals of math instruction, helping them to understand not only mathematics but also how it can be applied to phenomena of the real world that involve mathematical entities such as directed quantities (negatives), multivalued quantities (vectors), ratios of quantities, changing or accumulating quantities, or locations in space (coordinates). Actually, the "big idea" of those who advocate model-based learning in the math and science classroom is to provide students "with the skills they will need to accomplish this in the real world. This is the objective of mathematical modeling" (Hodgson, 1995, p. 353).

Comparable argumentations concerning the importance of model-based learning, and especially the use of mathematical models, can also be found in the areas of geography (e.g., Guermond, 2008), biology (e.g., Laubichler & Müller, 2007), and chemistry (Heyworth & Briggs, 2007).

Constructivist Approaches of Model-Based Learning

In the 1980s, the theory of mental models emerged and introduced a constructivist approach to modeling into cognitive science and related fields of interest (Gentner & Stevens, 1983; Johnson-Laird, 1983). The theory of mental models is based on the assumption that cognition takes place in the use of mental representations in which individuals organize symbols of experience or thought in such a way that they effect a systematic representation of this experience or thought, as a means of understanding it or explaining it to others (Seel, 1991).

In a historical review, Johnson-Laird (2004) traced the theory of mental models back to Peirce's (1883) early semiotics as well as to Wittgenstein (1922), and the Gestalt psychologists, such as Wolfgang Köhler (1947), who argued that vision creates an isomorphism between the force fields of the brain and the cognized world. Similarly, information theorists of the 1950s (e.g., Steinbuch, 1961) argued that learning consists in constructing *internal models* that are conceived as a cognitive isomorphism of structured domains or elements of the environment. This isomorphism is considered to be a threshold value, which can be approached by the internal models of a subject but not reached.

In accordance with Peirce's semiotics and the distinction between index, icon, and symbol, cognitive psychology differentiates at the very least between images (picture-like) and propositions (language-like) as forms of mental representation. Johnson-Laird (1983) added mental models as a particular form of representation that mediates between images and propositions. Markman (1998) has illustrated this idea with the following example: "Imagine a situation in which a boy stands at the top of a hill, makes a snowball, and rolls it down the snow-covered side of the hill. A person may never have witnessed an event like this, but one can construct the event and talk about it. One can imagine that the snowball rolls down the hill and gets larger and larger as it rolls, because snow sticks to it. A mental image of this event occurring might be formed … but this situation goes beyond a mere mental image; it requires reasoning about the physics of the situation to determine how the image changes over time" (Markman, 1998, p. 248).

In addition to the argumentation that mental models are a particular form of mental representation, Johnson-Laird (1983, 2004) also referred to the work of Craik (1943), who argued that an individual who intends to give a rational explanation for something must develop practicable methods in order to generate adequate explanations from the available knowledge of the world and his or her limited information processing capacity (Khemlani & Johnson-Laird, 2011). Thus, in order to create plausibility the individual constructs an internal model that both integrates the relevant semantic knowledge and meets the requirements of the situation to be mastered. Accordingly, this model "works" when it fits the subject's knowledge as well as the explanatory need with regard to the concrete situation to be mastered cognitively. More generally, Craik pointed out:

> If the organism carries a 'small-scale model' of external reality and of its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and the future, and in every way to react in a much fuller, safer, and competent manner to the emergencies which face it (Craik, 1943, p. 61).

By means of an internal or mental model, an individual is able to simulate real actions in the imagination. This means that a "mental simulation runs" envisioning in the imagination the events that would take place in the world if a particular action were to be performed. Thus, mental models allow one to perform actions entirely internally and to judge the consequences of actions, interpret them, and draw appropriate conclusions. Accordingly, model-based reasoning occurs when an individual interacts with the objects involved in a situation in order to mentally manipulate them so that the cognitive operations simulate specific transformations of these objects which may occur in real-life situations. This means that these *simulation models* operate like thought experiments to produce qualitative inferences with respect to the situation to be mastered. Although there were some authors before the advent of the mental model approach (such as Hacker, 1977; Veldhuyzen & Stassen, 1977) who emphasized the importance of internal models in operating with complex technical or physical systems, the idea of conducting simulations with mental models is probably the most important characteristic of the mental model theory. It constitutes the fundamental basis for qualitative reasoning as well (Forbus & Gentner, 1997; Greeno, 1989). Mental models "run in the mind's eye" to produce qualitative inferences with respect to the situation to be mastered cognitively.

The essence of the mental model theory can be described in the words of Johnson-Laird, who proclaimed that "mental models play a central and unifying role in representing objects, states of affairs, sequences of events, the way the world is.… They enable individuals to make inferences and predictions, to understand phenomena, to decide what action to take and to control its execution, and, above all, to experience events by proxy" (Johnson-Laird, 1983, p. 397). However, the question remains of how mental models are constructed.

Another question that repeatedly appears in the literature concerns the distinctiveness of mental models in relation to schemas. Ever since the concept of mental models was introduced into cognitive science it has been criticized by proponents of schema theories, who consider mental models to be mere instantiations of local schemas rather than a discrete theoretical construct (e.g., Brewer, 1987; Rips, 1987). In contrast, the schema concept is not popular in the field of cognitive science. For example, Anderson (1983) and Johnson-Laird (1983) did not operate with the schema concept, and other researchers, such as Brown (1979) and Prinz (1983), have rejected "schemas" as an unnecessary and insufficiently defined construct of cognitive psychology. This is not the place to expound on the arguments of this controversial debate about schemas and mental models and their cognitive functions. Basically, cognitive scientists agree on the point that schemas and mental models serve different cognitive functions: Schemas represent the generic and abstract knowledge acquired on the basis of manifold individual experiences with objects, persons, situations, and behaviors (Mandler, 1984). As soon as a schema is fully developed it can be applied immediately to assimilate information about new experiences. But how do people operate cognitively in the case of novel problems for which no schema can be retrieved from memory? The answer for those who advocate modeling activities is that people construct a mental model of the situation or problem to be mastered. In accordance with this argumentation, the next section of this chapter describes a theoretical model that integrates schemas and mental models into a more comprehensive architecture of cognition with the aim of explaining their mutually compensating cognitive functions.

A Cognitive Architecture of Model-Based Learning and Reasoning

According to Rumelhart, Smolensky, McClelland, and Hinton (1986), people have three essential abilities for processing information and acting successfully in various environments. First of all, people are very good at *pattern matching*. They are obviously able to quickly "settle" on an interpretation of an input pattern. This ability is central to perceiving, remembering, and comprehending. It is probably *the* essential component of most cognitive behavior—and it is based on the activation and instantiation of schemas. Secondly, people are very good at *modeling* their worlds due to their ability to anticipate new states of affairs resulting from actions in the world or from an event they might observe. Both pattern matching and modeling are grounded on building up expectations by "internalizing" experiences and are crucial for making inferences (Seel, 1991). Thirdly, people are good at *manipulating* their environments. This can be considered as a version of man-the-tool-user, which is perhaps the crucial skill for building a culture. Especially important here is the ability to manipulate the environment and to create artifacts as external representations which can be manipulated in simple ways to get answers to very difficult and abstract problems.

As people gain experience with the world created by their actions they internalize their experiences with external representations to develop mental models.

Schemas and Models: Two Sides of the Same Coin?

In order to explain the aforementioned basic capabilities, Rumelhart et al. (1986) divide the cognitive system into two modules or sets of units. One module—called an *interpretation network*—is concerned with producing appropriate responses to any input from the external world, while the other module is concerned with constructing a *model of the world* and producing an interpretation of "what would happen if we did that" with a particular external representation. The modeling part of the cognitive architecture is concerned with generating expectations about possible changes to the world as a result of imagining an external representation and operating on it. The interpretation network receives input from the world and reaches a relaxed mental state by producing relevant cognitive responses, whereas the "model of the world" predicts how the input would change in accordance with these responses.

From a psychological point of view, it can be argued that the interpretation network operates with *schemas*, which help the learner to assimilate new information into cognitive structures and constitute the fundamental basis for the *construction of mental models* of the world as well. In cognitive psychology as well as in PDP models, schemas are characterized asslot-filler structures used to organize concepts, relations between them, and operations with them semantically. However, PDP models do not consider schemas as stored structures of the semantic memory that can be activated when necessary but rather as representations of complex constraint satisfaction networks that trigger the interpretation of input information. Schemas emerge at the moment they are needed to interpret new information. Each schema results from the interaction between a large number of simpler units, which all work together to come to an interpretation of input information. Schemas are implicit in people's knowledge and are triggered by the events that they have to interpret. Clearly, this conception contradicts the conventional belief that schemas are stored in memory. From the point of view of the PDP approach, *nothing stored actually corresponds directly to a schema*; rather, "what is stored is a set of connection strengths which, when activated, have implicitly in them the ability to generate states that correspond to instantiated schemata" (Rumelhart et al., 1986, p. 21). Schemas are active processes but not products. They can be understood as recognition devices which aim at the evaluation of their goodness-of-fit to the data being processed.

Basically, Rumelhart et al. (1986) see the emergence of "models of the world" or *mental models* in the same way. A mental model also consists of a network which does not take its input from the external world but rather from the interpretation network, with the aim of specifying the actions that can be carried out in pure imagination. Its product consists of an interpretation of what can happen when actions are performed. Accordingly, the function of the mental model is to simulate actions in the mind, to assess their consequences, to interpret them, and to use these interpretations for making inferences. While the interpretation network takes its inputs from the world, the model-based network takes its inputs from actions of the interpretation network and predicts what changes they will bring about. Therefore, the model-based network can also be considered as an "action network" and constitutes the space for mental simulations. The two networks are related closely to one another and constitute the fundamental basis for mental operations (Seel, 1991).

Schemas and Mental Models as Modes of Assimilation and Accommodation

According to Seel (1991), the cognitive architecture proposed by Rumelhart et al. (1986) corresponds to Piaget's (e.g., 1976) idea that cognition is regulated by the interaction between assimilation and accommodation, which aims at adjusting the mind to meet the necessities of the external world. Assimilation can be considered as the fundamental basis of the interpretation network and is dependent on the activation of cognitive schemas, which allow new information to be integrated into existing cognitive structures. In cognitive psychology, schemas are understood as slot-filler structures that serve central cognitive functions, such as integrating information into cognitive structures, regulating attention, making inferences in the process of acquiring knowledge, and reconstructing it from memory. As soon as learners have consolidated schemas to a sufficient extent through learning and development, they provide them with the cognitive framework for "matching" information from stimuli with content from knowledge memory, thus allowing them to select the information that is consistent with a schema. Anderson (1984, p. 5) captures the essence of these functions of schemas when he remarks: "*Without a schema to which an event can be assimilated*, *learning is slow and uncertain*." Schemas represent the *generic* knowledge a person has acquired in the course of numerous individual experiences with objects, people, situations, and actions. As soon as a schema can be activated, it is automatically "played" and regulates the assimilation of new information in a "top-down" procedure. This allows information to be processed very quickly, a function which is vital for humans as it enables them to adapt to their environment more quickly.

Assimilation is a basic form of cognitive processing, but certainly not the only one. Another basic form consists in

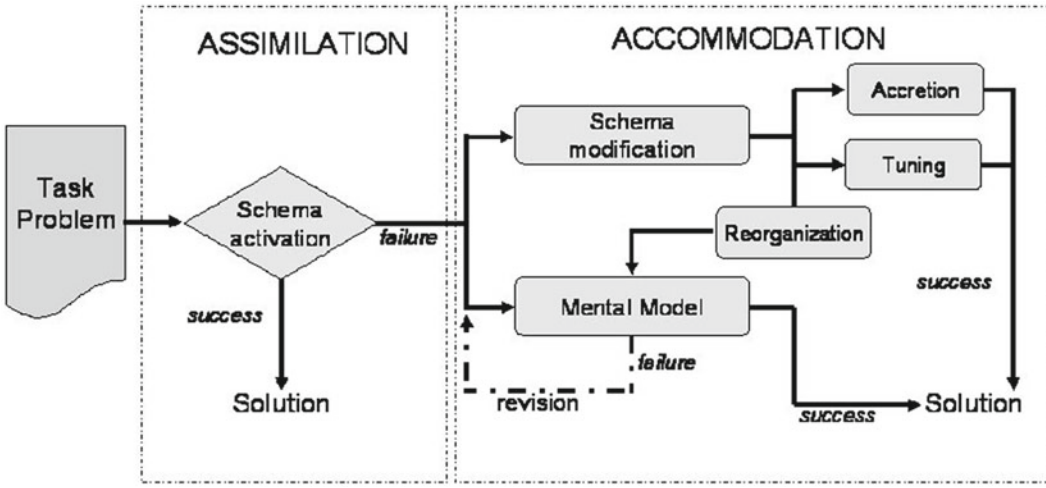

Fig. 37.1 Cognitive functions of assimilation and accommodation

accommodation aiming at restructuring knowledge. Accommodation aims, first of all, at a modification of a schema by means of accretion, tuning, or the reorganization of its structures and content (Norman & Rumelhart, 1978). This kind of accommodation presupposes an adjustment of existing schemas to new but familiar input information. However, if this adjustment of a schema is not possible, i.e., if the accretion, tuning, and/or reorganization of a schema fails—or if there is no schema to be activated at all—the learner either can abandon the cognitive processing or invest mental effort to develop a mental model as a more elaborated form of accommodation. Accordingly, mental models must be seen as products of accommodation (as discussed in Piaget's epistemology) that aim at adjustments of cognitive structures to the environment whenever the subject is not able to activate and modify an appropriate schema (Seel, 1991, 2006). In contrast to schemas, mental models operate from the "bottom up" under the continuous control of consciousness. As long as the information being processed can be assimilated promptly into cognitive structures and as long as schemas can be modified by means of accretion, tuning, and reorganization, there is no need to construct a mental model. This theoretical conception can be illustrated as in Fig. 37.1.

Mental models constitute the fundamental basis for developing "models of the world," discussed here in accordance with Rumelhart et al. (1986), and they may serve as *models for reasoning* as well as *models for understanding* (Mayer, 1989). In both cases, mental models are constructed to meet the specific requirements of situations and tasks the subject is faced with for which the activation and/or modification of a schema fails. While a schema is a slot-filler structure, a mental model contains a set of assumptions that must be justified by observations. This justification of assumptions is closely connected with a *reduction to absurdity* (Seel, 1991), which is a process of testing continuously whether a model can be replaced with a better model. As long as this is not possible, the model is considered suitable.

Models for understanding have their starting point in the tentative integration of relevant simple structures or even single bits of domain-specific knowledge step by step into the coherent design of a working model in order to meet the requirements of the task to be accomplished. Johnson-Laird (1983) considers this process of a stepwise enrichment of models as a "fleshing out" that also refers to the learning-dependent progression of mental models. Mental models for understanding represent the structure of world knowledge because they are generated to structure it and not to reproduce or copy a given external structure. Models for understanding correspond to pragmatic conceptions of modeling. They can be externalized by means of particular symbol systems and generate subjective plausibility with regard to complex phenomena to be understood and explained. However, in contrast to the pragmatic approach of modeling, proponents of the mental model theory agree on the point that mental models are cognitive artifacts which correspond only more or less to the external world since people can also construct pure thought models which bear no direct correspondence to the external world but rather only to world knowledge. This corresponds to the idea of coherence epistemology (Seel, 1991). In general, models for understanding have the following characteristics: (a) They are incomplete and constantly evolving; (b) they are usually not an accurate representation of a phenomenon but typically may contain errors and contradictions; (c) they are parsimonious and provide simplified explanations of complex phenomena; and (d) they often contain measures of uncertainty about their validity that allow them to be used even if incorrect.

Modeling and Reciprocal Emotions

Since its introduction into cognitive science, mental model theory has clearly placed emphasis on cognitive aspects of modeling. However, the integration of schemas and mental models into a cognitive architecture that adapts Piaget's epistemology also allows for the inclusion of emotional aspects of schema activation and model-based learning (Ifenthaler & Seel, 2011).

Emotions are mental responses that arise spontaneously. According to Goetz, Preckel, Pekrun, and Hall (2007), emotions can be divided into *stateemotions* (e.g., "I am anxious while taking this math exam") and *traitemotions* that occur consistently in various situations (e.g., "I am generally anxious"). Kuhl (1983) has introduced a model of emotional emergence in which cognition, emotions and operations reciprocally affect each other. Accordingly, cognitive processes and the reciprocal interactions with emotional states are the basis for goal-directed actions, which are particularly important for mental models.

Naturally, the construction of a mental model and schema modification both presuppose an *assimilation resistance* that provokes not only a cognitive dissonance but also emotional responses that interact reciprocally with cognitive processes. Kuhl(1983) has introduced a model of emotional emergence in which cognition, emotions, and operations reciprocally affect each other. In this model, cognitive processes and the reciprocal interactions with emotional states are the fundamental basis for goal-directed actions (Gross, 1998)—which are particularly important for mental models. Whenever assimilation in a schema fails and corrective attempts are not immediately successful, this schema enters a state of *disequilibrium*, which in turn evokes arousal (Eckblad, 1981; Piaget, 1945). This *assimilation resistance* may have various causes due to the complex, novel, and incongruous objects to be processed, but it always results in varying degrees of disequilibrium and arousal of the cognitive system. The amount of arousal may vary from one point in time to another and from person to person, but according to Berlyne (1971) it always stimulates epistemic curiosity and active stimulus seeking. The role of arousal may be formulated as follows: (1) Arousal is assumed to increase with the degree of incongruity in schemas. (2) High levels of incongruity are innately aversive and associated with negative feelings. (3) It is assumed that the stronger a schema is, the larger will be the effect of incongruity in that schema and the more arousal will be generated. (4) Incongruity occupies processing capacity and stimulates bottom-up processing of information. (5) Arousal and incongruity are to be regarded foremost as two facets of a unitary process, the activation of a schema.

In accordance with this argumentation, Eckblad (1981) has proposed a cognitive theory of affect that integrates assimilation resistance and emotional responses (see Fig. 37.2).

Eckblad's theory contends that affects are mediated by cognitive schemas which match input information. Performance is intimately linked to the moving edges of assimilated variation and assimilated complexity along two

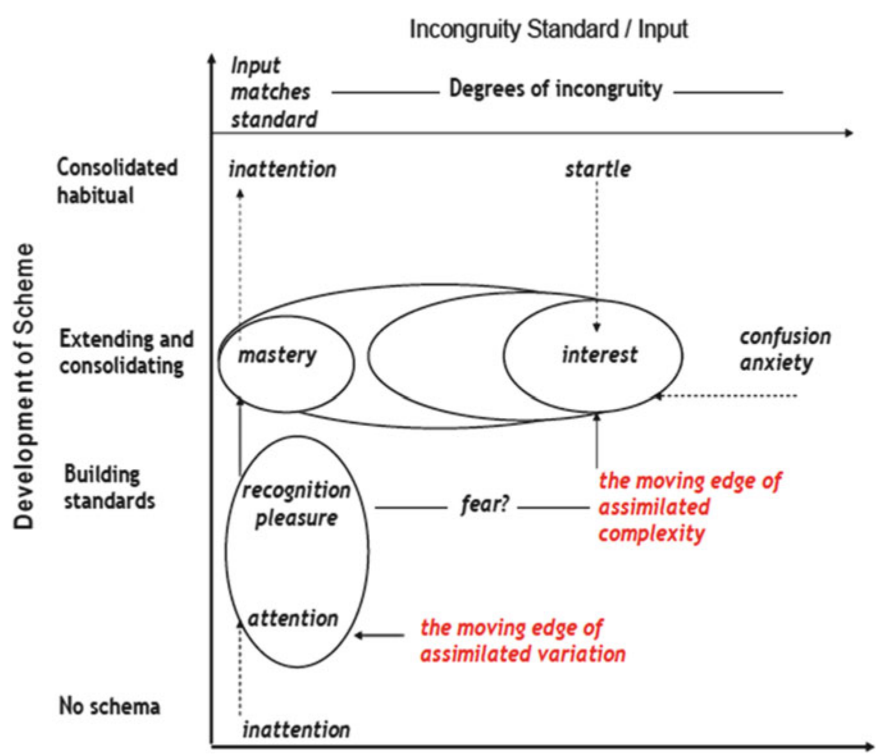

Fig. 37.2 Eckblad's (1981) cognitive theory of affect (Eckblad, 1981, p. 39)

dimensions, namely the development of schemas and the degree of experienced incongruity. With regard to the first dimension, inattention results if there is no schema available or if a schema corresponds to a consolidated habit. Between these poles, the development of schemas is associated with building standards as well as with extending and consolidating the standards (discussed in terms of slot-filler structures). Depending on the degree of assimilated variation of the input to be processed, attention moves to recognition and then to mastery. According to Eckblad, recognition is connected with pleasure. Varying degrees of incongruity between the input and schemas may result in different emotions as the schemas develop. While incongruity in the phase of building standards may result in fear, it may evoke interest in the phase of consolidation. However, when incongruity becomes stronger during the consolidation phase, the interests move to confusion and anxiety.

From Eckblad's theory one can conclude that assimilation in general goes along with pleasure and interest, whereas assimilation resistance and the need for accommodation goes along with confusion and anxiety. Accordingly, it can be argued that the successful activation of schemas is accompanied by positive emotions whereas the construction of a mental model starts with negative emotions. Positive emotions may increase the learner's optimism and confidence and thus facilitate the application of available schemas. Indeed, recent experimental research has consistently shown that *positive state emotions* are more likely associated with the productive use of schemas as generic knowledge structures and related with top-down processing. In contrast, *negative state emotions* are more likely associated with bottom-up processing and a more systematic gathering of information, as well as with paying more attention to the details of the tasks to be mastered (e.g., Fiedler, 2001; Schwarz, 2000). According to the schema- and model-based approach as discussed in this article, positive emotions seem to promote the activation of schemas whereas negative emotions seem to promote the construction of mental models. According to the *mood repair hypothesis* (Krohne, Pieper, Knoll, & Breimer, 2002), people with negative emotions spend more time collecting information in a systematic manner in order to cope effectively with situational demands, which are considered to be a cause for negative emotions. Similarly, Fiedler's (2001) *affect-cognition theory* postulates that positive and negative emotions have a strong impact on the modality of information processing and motivation: "While negative mood supports the conservative function of sticking to the … facts and avoiding mistakes, positive mood supports the creative function of active generation, or enriching the stimulus input with inferences based on prior knowledge" (Fiedler, 2001, p. 3). Interestingly, Fiedler also refers to the Piagetian terms *accommodation* and *assimilation*. In his view, negative emotions facilitate accommodation and can be related with model-based learning, whereas positive emotions support assimilation and can be related with schema-based learning.

Fields of Application of Model-Based Learning and Performance

Although the idea of model-based learning and performance has a long past, it has a short history. Schichl (2004) and Johnson-Laird (2004) have traced the roots of modeling back to the cultures of the Ancient Near East (Babylon, Egypt) and Ancient Greek philosophy. These authors delineate the two major lines of argumentation. Schichl focuses on the use of mathematical models to represent the real world through mathematical objects (or a formalized mathematical language), whereas Johnson-Laird emphasizes the concept of internal models as a particular format of mental representation. Clearly, there has been a continuous tradition of modeling in physics, biology, chemistry, geography, economy, architecture, and other disciplines throughout the centuries. However, modeling seems to have been taken for granted in these sciences and did not become a matter of educational concern until the 1950s and later. Since this time, modeling has been increasingly recognized as a powerful tool for promoting students' understanding of a wide range of mathematical and scientific constructs. Today, teaching students to develop powerful models is regarded as among the most significant goals of mathematics and science education (Clement, 2008; Lesh & Sriraman, 2005).

The theory of mental models struck a chord in the 1980s independently of this movement and became one of the most prospering fields of research in cognitive science. Due to the particular emphasis on language and reasoning in Johnson-Laird's (1983) seminal textbook, the theory of mental models and related research focused on text and discourse processing (Rickheit & Habel, 1999) and deductive reasoning (Evans & Over, 1996) for over two decades. Furthermore, the theory of mental models became prominent in the areas of human–computer interaction, system dynamics and simulation, spatial cognition, developmental and cultural psychology, and educational psychology.

Generally, both approaches to model-based learning and performances center on several basic functions of models, such as explaining complex phenomena of the physical and social world, making predictions and decisions, and communicating knowledge. Accordingly, we can distinguish the following fields of application of model-based learning (Seel, 2003).

- Models for understanding complex phenomena
- Models for reasoning
- Models for making predictions and decisions
- Models for communicating knowledge

Models for Understanding Complex Phenomena

How does the immune system respond to constantly changing bacterial and viral invaders? How do birds achieve their flocking formations? Can a butterfly influence the weather? Why do traffic jams form and how can traffic flow be improved? How do galaxies form? These questions asked by Jacobson (2000) focus on phenomena that may be regarded as complex systems. Jacobson (2000) and other authors, such as Seel (2006) or Clement and Rea-Ramirez (2008), have pointed out that unusual or complex phenomena like the structure of the lungs or cells, molecular structures and reaction mechanisms in chemistry, or causes of current flow in electricity are notoriously difficult to learn and can only be made sense of through the construction and application of a (mental) model. Thus, a mental model can be seen as an ad hoc construction a person uses to explain something and to create subjective plausibility with regard to complex world phenomena.

According to Schichl (2004), most of the theories developed in physics have started with models for understanding: Newton's mechanics, thermodynamics, Einstein's theory of relativity, quantum mechanics, the Standard Model of particle physics, and many more. However, models for understanding also play an important role in biology (e.g., predator–prey models or epidemiological models), geography (e.g., avalanche models), and economics (e.g., inflation models). Indeed, it seems that most people can cope effectively with a complex phenomenon or system by constructing and maintaining a mental model that provides them with enough understanding of the system to control it. In this sense, the notion of mental models is not only interrelated with the explanation of complex phenomena but also with complex problem solving, which usually provides a unique challenge for learning and instruction (cf. Seel, 2006).

Models for Reasoning

From the very beginning, one of the major fields for the application of mental models has been logic, i.e., deductive and inductive reasoning. Coming from a syntactical approach, Johnson-Laird (1983) emphasized the specific role of mental models especially for deductive reasoning. Although this approach did not remain uncriticized and was contrasted with schema-based approaches of deductive reasoning, the application of mental models can be considered as one of the most complete theories of human reasoning, as Evans and Over (1996) and Wilhelm (2004) have stated. Schema-based reasoning and the application of pragmatic judgment schemas are considered as the fundamental basis of *semantic or pragmatic approaches* that constitute mental logic theories. Proponents of mental logic theories (e.g., Braine, 1990; Cheng & Holyoak, 1985; Evans, 1982) argue that individuals apply schemas of inference when they reason. Errors in reasoning occur when pragmatic reasoning schemas are not retrievable or cannot be applied successfully.

The theory of mental models, on the other hand, argues that reasoning is primarily a matter of constructing mental models of the premises (for instance, of a syllogism) that enable mental "leaps" in the establishment of truth values and operate only with the premises which are consistent with the conclusion. Thus, mental models make it possible for people with minimal information to reach correct conclusions since they test the truth value of only premises which are subjectively plausible and do not contradict the conclusion when combined with one another. Comparing the schema-based and model-based approach of reasoning, Wilhelm (2004) concludes that the mental model theory covers a broader range of phenomena than mental logic theories do. According to the *mental model theory* of logical thinking, humans are capable of making deductive inferences of a certain degree of complexity without having knowledge of or applying the rules of logical reasoning. The theory of mental models states that a person who goes about solving a syllogism first "translates" the propositions included in the premises into an internal analogous representation on the basis of his or her semantic knowledge, then tests whether various possibilities of interpreting the premises are consistent with a conclusion, and finally modifies, if necessary, the model he or she constructed at the outset until the premises and the conclusion are "suited" to each other.

As with deductive reasoning, some authors (e.g., Holyoak & Thagard, 1995; Johnson-Laird, 1994; Seel, 1991) also emphasize the importance of mental models for inductive reasoning. Induction enables cognitive systems, on the basis of only a few examples, to progress from given evidence to more general propositions. According to Holland, Holyoak, Nisbett, and Thagard (1986), creating analogies (or analogy models) is an especially effective inductive mechanism. In order to understand or explain an unknown phenomenon (target domain) a person refers to available knowledge about similar phenomena (base domain) and creates an analogy model for both. On the basis of the structural similarities between the models of the base and target domain, the person reaches a conclusion by analogy, integrates both models into a unified solution model under the assumption that they are similar, and tests whether it is possible to create an alternative solution model which then could replace the former model. Holyoak and Thagard (1995) have exemplified this mechanism of inductive reasoning as follows: Our general knowledge about water enables us to create a mental model of how water moves. In the same way, our knowledge about sounds enables us to create a mental model of how sound is transmitted through the air. Each of these mental models links a representation with a phenomenon in the physical world. Now, when we create an analogy between waves in the water and the spreading of sound through the air, we build an *isomorphism* (i.e., a structurally compatible map) *between two mental models*. This means that we assume we can use our model of water to progressively modify and improve our model of sound. In the end, we must validate this explanation by testing whether the analogy between the two analogy models has helped us to achieve a better understanding of the transmission of sound in the physical world. Thus, analogy models may be understood as heuristic hypotheses of a structural similarity between different domains. Another way of making inferences through inductive reasoning is by constructing and applying what Gigerenzer, Hoffrage, and Kleinbölting (1991) refer to as a *probabilistic mental model*. This type of mental model is not the product of long contemplation, but rather of the spontaneous creation of plausibility. Probabilistic mental models generate inductive inferences by associating the specific structure of a problem with a probable structure of the natural surroundings one is familiar with. Although the theory of probabilistic mental models has had an important influence on research on probability judgment (e.g., Betsch & Fiedler, 1999) it has also been criticized as psychologically implausible (Dougherty, Franco-Watkins, & Thomas, 2008).

Models for Making Predictions and Decisions

One of the most intriguing features of mental models is that they can be used for mental simulations. In addition to the practice of making inferences, there are two major fields of mental simulations: (1) making predictions about the future development of a phenomenon and (2) making decisions.

The predictive power of mental models has been investigated since the 1980s (e.g., Kurland & Pea, 1985) and is currently one of the most promising fields of research in various fields of interest, such as dynamic systems forecasting (Wang, 2007), the forecasting of the effects of global climate changes (Stott et al., 2006), and the prediction of water availablity and water quality by means of watershed modeling (Chaplot, Saleh, & Jaynes, 2005). It is noteworthy that the current research on model-based predictions goes beyond the mental model approach, operating instead with mathematical models and algorithms (e.g., Hu, Si, & Yang, 2010).

Another important application of model-based simulations is *decision making*, especially under risk. This is closely related with the field of naturalistic decision making in everyday situations. Decision making under risk (e.g., in fire fighting, military, rescue) is in general characterized by dynamically changing conditions, the challenge to respond immediately to these changes, ill-defined tasks, time pressure, and far-reaching personal consequences in the case of mistakes. Several analytical methods of decision making, such as the Expected Utility Theory or the Prospect Theory (Kahneman & Tversky, 1979), have traditionally been referred to in the literature, but Klein and Calderwood (1991), Stewart, Chater, Stott, and Reimers (2003), and others argue that analytical methods of decision making under risk eventually fail because they take too much time and lack the flexibility to allow the decision maker to respond to rapidly changing conditions of situations. In accordance with the idea of schema theory, it can be argued that the activation of a schema brings about enormous time advantages for the mastery of challenging situations if they are similar and belong to the same category (Falzer, 2004; Marshall, 1995). However, in the case of novel phenomena and problems, the available schemas are usually inappropriate and must be replaced by mental models. Indeed, the theoretical approach of mental models emphasizes cognitive processes of generating plausibility and of probabilistic reasoning (Gigerenzer et al., 1991) that are involved in decision making under risk. Therefore, natural decision making on the basis of mental models can be considered as an effective alternative to schema-based decision making.

This kind of natural decision making is at the core of Klein's (1989) *Recognition Primed Decision* (RPD) model, which contains aspects of problem solving and decision making for natural decisions. The fundamental basis of this model consists in an action of the decision maker that is based on the identification of a situation as known or prototypical. The decision maker apprehends a situation in terms of familiarity with former experiences. The evaluation of familiarity with a set of known cases results in the recognition of accessible objectives, relevant evidence, expectations, and plausible behaviors. The decision maker creates a possible option and evaluates it by means of a mental simulation in order to check whether there are any pitfalls which could prevent it from being realized. If it is possible to avoid these pitfalls the option will be strengthened. Otherwise, it will be rejected. If there are no barriers or pitfalls the option will be realized. This argumentation corresponds to the theory of mental models (Kieras, 1985)—especially with regard to its emphasis on mental simulations of options for action. In addition, the RPD model includes the concept of *situation awareness*, which has been popular in the areas of military and rescue since the 1980s (e.g., Craig, 2001; Klein, Calderwood, & Clinton-Cirocco, 1986; Sparkes & Huf, 2003). Situation awareness "is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and projection of their status in the near future" (Endsley, 1995). Due to obvious similarities in argumentation, situation awareness and mental models have been integrated into the theoretical concept of the *situation model* (Endsley, 2000), which is a mental

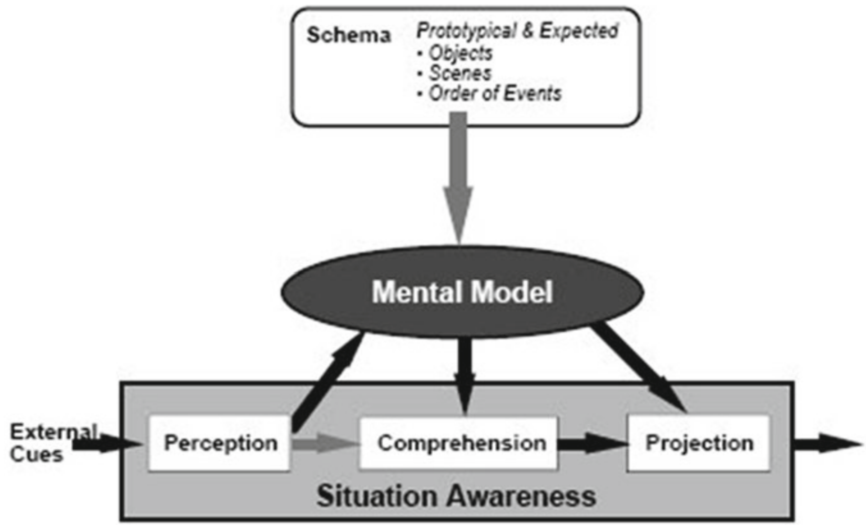

Fig. 37.3 Situation models as a combination of mental models and situation awareness (Endsley, 2000, p. 2)

model enriched by situation awareness. This is illustrated in Fig. 37.3.

Basically, the concept of situation models corresponds to a large extent to the theory of mental models, which are situation-dependent ad hoc constructions of the mind that can be used to create subjective plausibility with regard to problems to be solved by means of probabilistic reasoning.

Models for Communicating Knowledge

An important aspect of models is that they can be used to communicate knowledge. In math education, for example, modeling activities may help students to externalize their understanding of situations by helping them to develop models to conceptualize mathematical ideas and processes (Lesh & Doerr, 2000). In terms of Rumelhart et al. (1986) models for communicating are the same as *external representations* (of mental models). External representations play an important role in human learning in general. Hiebert and Carpenter (1992) have pointed out that there are close relationships between external and internal representations of knowledge. More specifically, the form of external representation with which students interact affects how their knowledge is represented internally, and in turn, the form of an external representation is dependent on the internal representation of knowledge and its structures.

Norman's (1983) comments on mental modeling have led theorists to make a distinction between mental models and conceptual models. A *conceptual model* is an external representation (of a mental model) created by teachers or scientists in order to facilitate the comprehension of something to be learned or to communicate the scientific knowledge shared by a community. These external representations can be mathematical formulations, analogies, graphs, or physical objects. An example of an object could be a water pump, which is sometimes used to model a battery in an electric circuit. Conceptual models express and communicate the shared knowledge of a discipline. Nevertheless, like all models they are simplified and idealized representations of real objects, phenomena, or situations.

The idea that conceptual models represent the shared knowledge of a scientific community externally has occasionally been modified to form the concept of so-called *shared mental models*, which are created in teams (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). Shared mental models are designed to enable teammates to perform their tasks better by combining their shared knowledge, skills, attitudes, and facilities (Cannon-Bowers, Salas, & Converse, 1993; Druskat & Pescosolido, 2002). Although it seems plausible to assume a close relationship between a shared mental model and successful team performance, it remains unclear how a shared mental model can be generated from multiple external representations of the teammates' individual mental models (Mohammed, Klimoski, & Rentsch, 2000). Furthermore, there has not been much consideration of the factors of shared mental models that can show a causal relationship between them and team performance.

As the case may be, the communication of professional knowledge is generally considered to be a key activity for today's specialized workforce, where knowledge communication problems between experts and nonexpert decision makers (Eppler, 2007) often occur. In order to master these problems, some authors suggest the application of *mental models interviewing* for more effective communication, aiming at the detection and mutual understanding of the mental models of specialists and nonspecialists (Cone & Winters, 2011). Accordingly, mental models interviewing is concerned with the generation of shared mental models between specialists in a particular subject (e.g., teachers) and individuals who are not specialists in that subject (e.g., students). The technique of mental models interviewing has been successfully applied in the area of risk communication (Morgan, Fischhoff, Bostrom, & Atman, 2002). However, not only can communication between experts and nonexperts be difficult but also that between people with comparable knowledge and levels of expertise. Haig, Sutton and Whittington (2006) have proposed the application of a technique called SBAR (Situation, Background, Assessment, and Recommendation) which aims at generating shared mental models for improving communication between clinicians. These approaches all agree on the point that the key to success in communication is learning all one can about others' models and thinking just by listening to them. Accordingly, the intended externalizations of mental models are based on verbal or written communications that can be more or less structured, for example by semi-structured interviews. This emphasis on language-based forms of externalizations in mental models corresponds to Seel's (1991) view that language may be considered the most important "medium" for expressing thoughts, ideas, and feelings. However, language-based external representations can be enriched with illustrations and graphs visualizing a phenomenon. Indeed, *visualization* is the graphical display of information that provides the individual a visual means of information processing—often in combination with texts aiming at successful dual-code processing (Mandl & Levin, 1989; Schnotz, 2002). Due to the basic assumption of cognitive psychologists that representations of knowledge are connected to form (graph-like) networks of knowledge (Hiebert & Carpenter, 1992), external representations of mental models often appear as causal diagrams, concept maps, or semantic networks. Jonassen (2000) calls these forms of external representation *mindtools* and describes them assemantic organization tools which help learners to analyze and organize what they know or what they are learning. Mindtools are computer applications that assist learners in representing what they know and how they think. Certainly, semantic organization tools are helpful devices for externalizing mental models, but maybe more relevant are dynamic modeling tools (such as Stella or Model-It) that help learners to represent the dynamic relationships among ideas (Jonassen & Cho, 2008). In principle, two broad categories of dynamic modeling mindtools can be distinguished: (a) tools which help with the exploration of a model and (b) tools which can be used for the construction of models (Clariana & Strobel, 2008). Both categories have been disseminated widely in education and instruction.

Empirical Research on Model-Based Learning and Performance

Since the emergence of the mental model approach in the 1980s, an abundance of research articles and book chapters (possibly more than 2,000) emphasizing model-based learning and performance has been published. In addition to the pragmatic approach of modeling, the constructivist approach of mental models has also proved to be one of the most productive fields of basic and applied research in cognitive science and education. From the 1980s until the present, research on model-based learning has focused particularly on the functions of mental models in narrative comprehension (Bower & Morrow, 1990), language and text processing (e.g., Garnham, 2001), text and picture processing as well as learning from multiple representations (Schnotz & Bannert, 2003). Another area of extensive research on mental models is human–computer interaction and system dynamics (Groesser, 2012). In view of the multitude of research on model-based learning it is nearly impossible to describe all of the lines of research and their results in detail here. Therefore, I'll focus in the next sections on what we have learned from past research and what we still have to learn from future research.

Lessons Learned from Research on Model-Based Learning

With regard to the aforementioned fields of application of model-based learning and performance one can state that each field has been studied extensively in the past. However, whereas pragmatic approaches have focused primarily but not exclusively on models for understanding and the use of external representations, the mental model approach has focused additionally on deductive reasoning in particular and the predictive power of mental simulations in general. Clearly, the mental model approach has attracted many more scientists from various disciplines than the more pragmatic approach with its emphasis on subject-matter oriented model-based learning. Nevertheless, both approaches have contributed significant findings on the impact of models on understanding and problem solving, but they differ with regard to their theoretical foundations and preferred research methodologies.

Some Methodological Considerations

The pragmatic line of research is characterized by the reference to the traditional use of models in subject-matter domains such as mathematics, physics, chemistry, and others (e.g., Lesh & Doerr, 2003; McClary & Talanquer, 2011; Pearson et al., 2006). Typically, this line of research situates model-based learning in the classroom and aims at systematically observing the emergence of students' qualitative models of phenomena to be explained. In sum, this research provides really impressive examples of modeling activities in the classroom (e.g., Penner, Giles, Lehrer, & Schauble, 1997;

Lehrer, Kim, & Schauble, 2007; Lehrer & Pritchard, 2002), and it shows that even young students invent models of their own, which, however, often prove to be partial, incomplete, and false (Clement, 2000; English & Watters, 2005). Changing these students' ways of thinking about mathematical and scientific concepts demands strong instructional efforts to challenge and test these qualitative models. Research on subject-matter oriented model-based learning is regularly, but not exclusively, related to a clear preference of qualitative research methods, such as collecting verbal data from think-aloud protocols, observational data, and videotape analyses (e.g., Lehrer et al., 2007). In addition, some researchers feel obliged to do design-based research and consider model-building in the classroom as a testing ground for design experiments (e.g., Cobb et al., 2003; Lehrer & Pritchard, 2002; Schorr & Koellner-Clarke, 2003). This is not the place to describe the methodology of design experiments in detail. What can be said is that it provides strong ecological and external validity but poor internal validity (Seel, 2009; Shavelson, Phillips, Towne, & Feuer, 2003) and that it is not suitable for causal inferences concerning treatments or instructional interventions. Finally, it is noteworthy that proponents of the model-building approach in subject-matter domains often avoid the theoretical term of mental models (Lehrer & Schauble, 2003), and sometimes they even attack the underlying constructivist paradigm (e.g., English, 1997). However, there are examples that show how meaningful and fruitful it can be to adapt the concept of mental models to reach a theoretically sound foundation of model-building activities in the classroom (e.g., Clement, 2008).

Unlike pragmatic approaches of model building, the approach of mental models seems to be more dedicated to experimental (and quasi-experimental) research and to the application of quantitative methods of data collection. Of course, there are also numerous examples of operating with qualitative methods (e.g., Clement & Steinberg, 2002), but most mental model research, especially in the area of deductive reasoning, is of a quantitative nature and aims at testing hypotheses derived from the theory of mental models. This also holds true for mental model research within the realm of educational research, where model-based learning is involved primarily with understanding and problem solving (Seel, 2006). As with the pragmatic line of research, the instructionally motivated research on mental models conducted in the past 30 years has resulted in a comprehensive and unique view on model-building activities under the condition of instruction.

Lessons Learned from Research on Models for Understanding and Problem Solving

In the article "Models for understanding," Mayer (1989) hypothesized that students given model instruction might be more likely to build mental models of the systems they are studying and to use these models to generate creative solutions to transfer problems. Similarly, Johnson-Laird (1989) argued that "what is at issue is … whether there is any pedagogical advantage in providing people with models of tasks they are trying to learn" (p. 485).

Hundreds of studies indicate that it is effective and efficient to provide students with model-relevant information before or during learning in order to help them to construct adequate models for understanding (Mayer, 1989; Seel & Dinter, 1995). Clearly, mental models are not fixed structures that can be retrieved from memory but are constructed when needed to master the specific demands of a new learning situation. Students dynamically modify and restructure their initial mental models when they evaluate externally provided information as being more plausible and convincing than their prior knowledge. This can be interpreted as an indicator of the learners' semantic sensitivity with regard to relevant information from the environment (Seel, 2012). Thus, the learning environment serves as an information resource from which the learners extract the information they need to construct an explanatory model. Model-based learning evidently depends on the learner's retrievable domain-specific knowledge structures, the nature of the material to be learned, and the modality in which the content to be learned is presented by media (Seel, 1986). Actually, it is often easier, especially for a novice learner, to assimilate an explanation provided through a conceptual model than to develop a model of one's own. The provided conceptual model can easily be incorporated into cognitive structures, and related information can be progressively integrated into the adapted model. In contrast, self-organized *discovery learning* aimed at helping students to invent their own models is practicable only if the learner possesses adequate meta cognitive skills to guide the model-building process. As a matter of fact, this approach can be a rather challenging affair which even an expert might sweat over sometimes (Kirschner, Sweller, & Clark, 2006). For most novice students, self-organized discovery learning is often closely associated with learning by trial and error and increases the probability of producing false models (Briggs, 1990; Seel & Dinter, 1995). A substantial conceptual change does not occur, and relatively stable intermediate states of understanding often precede the intended conceptual mastery.

From an instructional point of view, providing students with relevant information in order to help them to construct adequate models might be an efficient method, but most probably it is not appropriate for problem solving or for investigating individual processes of model building and revision. Although research within the realm of the pragmatic approach of model building provides some excellent examples of discovery-based modeling in the math and science classroom (e.g., Doerr, 2006; English & Watters, 2005; Lehrer et al., 2007; Lesh, 2006; Penner et al., 1997), this line of instructional research on model building is still in its infancy. Accordingly, the question of how discovery-based model building can be facilitated by means of particular instructional support has not yet been investigated sufficiently either.

Lessons Learned from Research on the Learning-Dependent Progression of Models

Model-based learning focuses on the construction of mental models of the phenomena under study. In accordance with the aforementioned cognitive architecture of model-based learning, it can be argued that when a mental model is used successfully, it is reinforced and may eventually become a precompiled, stable conceptual model, or even, after many repetitions, a schema (Halford, Bain, Maybery, & Andrews, 1998). If the model is not satisfactory, it will be revised or rejected in the further progression of learning. Changing mental models constructed by students to make them more complete, complex, and dynamic is one of the primary goals of instructional interventions. Or as Johnson-Laird (1989) says: "What is at issue is how such models develop as an individual progresses from novice to expert" (p. 485).

Ifenthaler and Seel (2005) identified the learning-dependent progression of mental models as a specific kind of transition that mediates between preconceptions or misconceptions, which describe the initial states of the learning process, and causal explanations, which are considered as the desired end states of learning. Alternatively, it can be argued that model building consists in progressing through a series of tentative models that will be tested and revised until a model issufficiently stableto function—at least temporarily—as a "conceptual model" (Schaffernicht, 2006). According to this conception, the process of modeling begins when assimilation resistance occurs and ends with a conceptual model or even with a schema. If learning was what caused the model to change, then the differences between the various versions of the model in progress are considered to be the result of the learning (Schaffernicht & Groesser, 2011).

In addition to early studies that focused on the development of children's and students' mental models (e.g., Clement & Steinberg, 2002; Halford, 1993; Kurland & Pea, 1985; Oliver & Hannafin, 2001; Vosniadou & Brewer, 1992), the investigation of the learning-dependent progression of mental models has also been at the core of my own research for the past twenty years (e.g., Darabi, Nelson, & Seel, 2009; Ifenthaler & Seel, 2005, 2011). According to Seel and Ifenthaler (2012), the learning-dependent progression of a mental model is a dynamic process with changes at discrete points in time. Learning can be represented as a sequence of events where each event occurs at an instant in time and marks a change of state in the cognitive or behavioral system. The process of learning can be expressed in the form $y(k) = fy(k-1), \ldots, y(k-ny), \ u(k-d), \ldots, u(k-\mathrm{d}-nu), e(k-1), \ldots, e(k-ne)) + e(k)$, where $y(k)$ is the system output, $u(k)$ the input, $e(k)$ is a zero-mean disturbance term, d is the relative degree, and $f()$ is some nonlinear function. This model allows the process of learning to be seen as a stochastic process that moves in a sequence of phases through a set of states. Although the probability of entering a certain state in a certain phase is not necessarily independent of previous phases, it depends at most on the state occupied in the previous phase. This is known as the *Markov property*. Accordingly, the change of mental models is conceived as a discrete learning process with the Markov property. The whole process involves the following steps: construction of an initial working model which relies upon the individual's generic semantic knowledge, interpretation of the model in terms of plausibility, revision of the initial model, generation of a second model which is again tested with regard to plausibility, followed by a revision of the model that leads to the next test and revision, and so on. Based on this continuous sequence of constructing, testing, and revising models, the learning process will finally reach a state of equilibrium at which the mental model merges into a stable model or even a schema (Halford et al., 1998; Seel, 1991). From that point on, there should only be a slight variation in performance.

The results of the various studies show a relatively consistent and coherent picture. There is no evidence for a transition of a mental model to a schema in any of them, even if there were ten or more tasks to be accomplished and corresponding points of measurement during the learning process (Ifenthaler & Seel, 2011). Although a tendency towards a stabilization of mental models was observable insofar as they were not constructed independently of each other at various points of measurement, their structures were regularly different. Obviously, it was cognitively less demanding for the students to construct a new model at each point of measurement than to remember and stabilize previously constructed models. Across the various studies, mental models proved not only to be highly situation- and task-dependent but also relatively independent of each other, and they showed only a minor tendency to become stabilized as general models. From this observation one can conclude that mental models are, to a large extent, singular formats of representation and usually do not form schemas, although they have a tendency to stabilize increasingly during extended learning. However, more research is necessary to find out how many tasks or situations are necessary for the emergence of a stable conceptual model or even a schema.

Assessment of Model Building and Mental Models

The research on mental models in the 1980s and 1990s highlighted several complexities and consistencies. One consistency was concerned with the development of a new methodology for assessing the construction and learning-dependent progression of mental models. The principles of this methodology include embedding the diagnosis of mental models in a complex problem situation, collecting data in a longitudinal design, providing valid and reliable quantitative data, and enabling a methodologically straightforward analysis and interpretation of the data collected (Seel, 1999).

From its very beginnings, research on model building was concerned with the problem of an appropriate assessment of models and their learning-dependent change. Language is of great importance for human communication about thoughts, and various methods of overt verbalizations have thus always played a central role in the diagnosis of mental models. Many studies have used think-aloud protocols, verbal explanations, speculations, and justification as means to assess knowledge and cognitive artifacts like mental models (Halford, 1993). Some authors (e.g., Garrod & Anderson, 1987; Sasse, 1991) have emphasized the method of *constructive dialogue* between individuals communicating their mental models at comparable levels of expertise (Cone & Winters, 2011). However, methods of verbalization have been criticized by several authors due to their psychometric weaknesses. As a consequence, researchers have applied traditional tests for assessing model-based performances, questionnaires and rating scales, the time needed for learning or the accomplishment of model building, drawings, and other measurements (e.g., eye fixations during task accomplishment) (Seel, 1999). However, these methods for organizing, representing, and mapping mental models were designed, first of all, to assess stable states of mental models and to localize their errors rather than to measure changes in them. It was therefore necessary to develop new methodologies for measuring change in mental models (Doyle, Radzicki, & Trees, 2008; Ifenthaler, Masduki, & Seel, 2011).

Over the past fifteen years, there has been some discussion of several possible methods for the diagnosis of mental models, most of them technology-based, that can be characterized as graphical and language-based approaches. Graphical approaches include the structure formation technique (Scheele & Groeben, 1984), causal diagrams (Al-Diban, 2008), pathfinder networks (Schvaneveldt, 1990), and mindtools (Jonassen & Cho, 2008). Language-based approaches include verbal data from thinking-aloud protocols, "mental model interviewing" (Cone & Winters, 2011), cognitive task analyses (Kirwan & Ainsworth, 1992), and several computer linguistic techniques (Seel, Ifenthaler & Pirnay-Dummer, 2009). In view of the rapid progress in the area of knowledge diagnosis, one can conclude that the problem of the diagnosis of mental models and their change has been solved (Ifenthaler, Pirnay-Dummer, & Seel, 2010). Indeed, one can choose from among a variety of assessment methods which meet psychometric standards. Interestingly, there are also some technology-based approaches which integrate various assessment practices and tools into a comprehensive methodology, such as HIMATT (Pirnay-Dummer, Ifenthaler & Spector, 2010). They can be applied to measure changes in the structure of external representations of mental models as well as similarities between models.

Fields of Interest for Future Research

Model-based learning and performance is probably one of the best and most extensively investigated fields across several disciplines, especially due to the efforts in the area of mental model research. Nevertheless, there are still some issues that demand more research.

One area of future research is the use of models for reasoning, even though an abundance of studies have investigated the role of mental models in deductive reasoning. According to the theory of mental models, individuals are capable of making deductive inferences of a certain degree of complexity without having knowledge of or applying the rules of logical reasoning. Rather, most people make inferences on the basis of mental models (Johnson-Laird, 1983). Although this theoretical approach has been contrasted with schema-based approaches of deductive reasoning, the theory of mental models can be considered as the most influential and pervasive theory in the area of logical thinking. As with deductive reasoning, numerous authors also emphasize the importance of mental model theory for inductive reasoning (Johnson-Laird, 1983; Seel, 1991) as well as for abductive reasoning (Magnani, 2009). Up to now, however, only little empirical research has been conducted on the function of mental models for inductive and abductive reasoning. In accordance with the concept of the learning-dependent progression of mental models, solving inductive or abductive reasoning tasks can be understood as a process of sequential interpretation and integration of task-relevant information and hypotheses for solutions into a mental model of the situation. This "situation model" serves as the context for interpreting new observations, generating new hypotheses, and drawing inductive or abductive inferences. This prediction was confirmed in a series of experiments by Johnson and Krems (2001) and Ifenthaler and Seel (Ifenthaler et al., 2011; Ifenthaler & Seel, 2011). Nevertheless, in comparison with the abundance of empirical research on model-based deductive reasoning, the research on model-based inductive and abductive reasoning is still in its infancy. This also holds true with regard to model-based reasoning by means of analogy models, as several authors (e.g., Lehrer & Schauble, 2006) have shown for subject matter learning in the classroom.

A second field of future research on model-based learning and performance is related to *model-based decision making*. There are two major fields of application: (1) the role of mental models for decision-making within the realm of management and organization and (2) the role of mental models for decision making under risk, necessary in the fields of fire fighting, military, and rescue. The importance of mental models for organizational issues was stressed by Senge (1990) and has been adopted in studies on so-called team mental models (e.g., Christensen & Olson, 2002; Mohammed et al., 2000; Steiger & Steiger, 2009) but more systematic research on this issue is still needed. Basically, this also holds true for decision-making under risk by means of situation models, defined as a combination of mental models and situation awareness.

A third promising field of future research on model-based learning and performance is the area of *system dynamics research*. Dynamic modeling presupposes functional intentionality in the construction and use of mental models for simulating transformations of states of a system. These simulation models allow a learner to explore a dynamic system in a controlled way to understand how the system's components interact and how alternate decisions can affect desired outcomes. Mental models provide a rationale for operating effectively with the complexity of dynamic systems. Accordingly, one can find more and more studies in the area of system dynamics research that work on the basis of mental model theory (Groesser, 2012; Schaffernicht & Groesser, 2011). However, dynamic modeling provides a new perspective called learning by system modeling and an extension to approaches of simulations: When students are involved in learning by modeling, they build their own models and engage at a much deeper conceptual level of understanding of the content, processes, and problem solving of the domain. There are also indications that operating with models of dynamic systems and simulations can be considered as an important future field of instructional research on understanding and problem solving in complex domains (Blumschein, Hung, Jonassen, & Strobel, 2009).

Finally, a new field of research on model-based learning focuses on reciprocal emotions in the process of model building. As mentioned above, model-based learning has attracted many scientists from different disciplines and the idea of mental models has been examined in various fields, such as management, marketing, information systems, consumer behavior, psychology, education, and neuroscience. However, most scientists have limited their focus to cognitive processes, neglecting the interactions of these processes with emotions and feelings. Only very little research has explicitly taken into account both cognitive and emotional aspects of mental models. However, there is some empirical evidence that there are reciprocal interactions between emotions and model building and related cognitive processes (Ifenthaler & Seel, 2012), but this line of research on mental models and model-based learning is only beginning to be explored.

Conclusion

In comparison with other fields of research, model-based learning and performance can be seen as one of the most prospering areas of research across several disciplines, such as cognitive science and education. In view of many hundreds of studies it is nearly impossible to give justice to the variety of research issues and results. Therefore, this chapter's focus was on what we have learned from previous research and what not.

Traditional views on model building activities in the classroom have been contrasted with the mental model theory that emerged in the 1980s as a central theoretical construct to capture situated cognition and pragmatic reasoning. Actually, the metacognitive psychologists who consider mental models to be the best organized representations among declarative learning results (Glaser, 1990). More specifically, it has been argued that comprehension and reasoning in specific situations (e.g., in schools and real-life situations) necessarily involve the use of mental models of different qualities (Greeno, 1989). Most people can cope effectively with a complex phenomenon or system by constructing and maintaining a mental model that provides them with enough understanding of phenomenon or the system to control it. In this sense, the notion of mental models is interrelated with the investigation of problem solving in complex systems, which provides a unique challenge for research in the field of learning and instruction. In consequence, mental models in particular and model building activities in general are closely related with the discussion on higher-order instructional objectives concerning problem-solving and discovery learning in the classroom. Several scholars, such as Lesh and Doerr (2003) encourage the pursuit of higher-order objectives and argue that helping students to develop their own "explanatory models" should be among the most important goals of math and science education. A recommendation often made in recent learning theory and research is to involve students, either individually or in groups, in actively working on challenging problems. If it is true that knowledge about complex systems poses a special learning challenge for students, it seems likely that students should experience difficulties when given problem-solving tasks involving phenomena in complex systems.

When we take the major fields of research on model-based learning and performance into closer consideration, we find a tension between strong theoretical assumptions that lead to precise conclusions and weak assumptions that lead to less precise conclusions. Strong assumptions are helpful when the assumptions apply, but they often do not apply, which then invalidates the conclusions prescribed by the theory. Weak assumptions are less helpful in creating specific instructional systems and learning activities, but they are more generally applicable and less likely to be invalidated. Finding the right balance is the challenge for professional practitioners. They can learn a lot from experimental research on mental models as it is based on strong theoretical assumptions.

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Game-Based Learning

38

Sigmund Tobias, J. Dexter Fletcher, and Alexander P. Wind

Abstract

This chapter reviews a rapidly growing body of empirical evidence on the effectiveness of using video and computer games to provide instruction. Evidence of their effectiveness is drawn from existing results and data. The topics covered here are transfer from computer games to external tasks, enhancing cognitive processes, guidance and animated agents, playing time and integration with curricular objectives, effects on game players, attitudes toward games, cost-effectiveness, and, finally, the use of games for evaluation. Areas where the evidence base is particularly weak are identified in the discussion section. Findings and recommendations for the design of games used in instruction are summarized in a table. The chapter concludes with a call for development of tools and technology for integrating the motivating aspects of games with good instructional design. People do learn from games. Missing are generally effective design processes that ensure that learners will acquire the specific knowledge and skills the games are intended to impart.

Keywords

Video games • Computer games • Serious games • Transfer of learning • Cognitive processes • Evaluation

Introduction

The popularity of computer games[1] has been evident for some time. McGonigal (2011) estimated that more than 180 million people in the United States report playing these games for more than 13 h per week. The Entertainment Software Association (ESA, 2009) reported that computer game sales in America grew 22.9 % in 2008 to $11.7 billion—more than quadrupling industry sales since 1996. The mean age of gamers was found to be 35, and 40 % were female. Relatively new is the increasing program time allocated to computer games at professional and scientific meetings and the development of programs of study dealing with computer games at academic institutions around the world (Tobias & Fletcher, 2011a). Few instructional methods engage similar levels of interest among learners or induce them to persist on tasks for as long as games do. Because of the evident motivational qualities of games, educators and trainers alike seek to use them for instruction.

This chapter examines existing research evidence in a number of areas covering the use of computer games for instruction. Topics where the evidence base is weak, such

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[1] These may also be called video games or video and computer games. All refer to games with an interactive user interface and visual feedback. We use "computer games" in this chapter—or just "games" to keep it short—unless we are quoting from someone who uses "video game."

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as the effect of learner characteristics, are identified in the discussion section.

The studies included here were all conducted after the publication of the games research review by Randel, Morris, Wetzle, and Whitehead (1992). There has been a sharp increase in the number of studies dealing with computer games, since we started to monitor this literature (Fletcher & Tobias, 2006). It is, therefore, impossible to list every study in the area, even in a review of research running to 95 printed pages (Tobias, Fletcher, Dai, & Wind, 2011). We have tried to abstract the most representative research studies and those we considered most important for review.

Review of Empirical Evidence

Our perspective is empirical. It concerns studies that compare computer games to other instructional delivery systems. Of course there are other approaches (Barab, Gresalfi, & Ingramp-Noble, 2010; Gee, 2003, 2011; Squire, 2005, 2006) influenced by linguistics which could be called experiential, or perhaps constructivist. Learning from computer games—as in all learning—is mediated by engaging appropriate cognitive processes, irrespective of whether knowledge is acquired by playing games, by participating in game-related communities, or by using worked examples in the games. As suggested elsewhere (Tobias, 2009) we believe that an empirical approach helps identify the cognitive processes controlling learning.

Areas reviewed here are transfer from computer games to external tasks, enhancing cognitive processes, playing time and integration with curricular objectives, effects on participants, cost-effectiveness, guidance and animated agents, the use of games for evaluation, and, finally, recommendations for game design. Details (e.g., Ns, treatments, results) of primary studies are summarized in Table 38.1; a more complete table describing primary studies may be found elsewhere (Tobias et al., 2011).

Transfer from Games to External Tasks

A critical question about using games for instruction is whether cognitive or psychomotor capabilities or attitudes acquired during game play generalize to nongame contexts, such as school, work, or everyday life, i.e., do they transfer? Of course, if there is no transfer, games would be of little use for instruction. Contrasting findings of two studies from the 1990s illustrate the transfer issue clearly.

Gopher, Weil, and Bareket (1994) used the *Space Fortress II* computer game, modified by Donchin (1989) from the original (Mane & Donchin, 1989), to simulate a complex and dynamic aircraft flight environment. Game groups performed significantly better than the control group in piloting real aircraft. The superiority of the game groups was attributed to similarities in cognitive load and attention demands of the game with actual flight conditions.

In contrast, Hart and Battiste (1992) found no transfer effects for an off-the-shelf computer game (*Apache Strike Force*). The diverging results are probably attributable to the modifications of *Space Fortress* to simulate the cognitive demands of aircraft cockpits, whereas no similar attempts were made to *Apache Strike Force*. Tobias and Fletcher (2007) and Tobias et al. (2011) concluded that near or far transfer (e.g., Barnet & Ceci, 2002) from computer games may be expected when similar cognitive processes are engaged by the game and external task. When there is little overlap, transfer seems unlikely.

More recent transfer results have also been reported. Brown et al. (1997) found that young diabetic patients playing a computer game dealing with diabetes content gained more on various diabetes self-care behaviors than a comparison group playing a game without this content. Kato, Cole, Bradlyn, and Pollock (2008) found improved behaviors, knowledge, and efficacy attributable to a game among young cancer patients. Greitemeyer and Oswald (2010) demonstrated that playing a pro-social computer game, compared to one that was neutral, increased helping behaviors. Similar transfer findings have been reported elsewhere (Cannon-Bowers, Bowers, & Procci, 2011; Mayer, 2011; Sitzmann & Ely, 2009; Tobias et al., 2011).

Summary and Discussion

A number of studies have found that near and far transfer from computer games to external tasks occurs if they engage comparable cognitive processes. These findings further indicate that if transfer to external tasks is the objective, cognitive task analyses (Crandall, Klein, & Hoffman, 2006; Schraagen, Chipman, & Shalin, 2000) of both the game and the task need to be conducted to assess overlap in the processes engaged by both. If transfer from games to external tasks is desired, overlap must exist in the cognitive processes engaged by both, a finding consistent with research on transfer generally (Mestre, 2005). If such overlap is minimal, transfer is unlikely. Of course, transfer cannot be assumed on the basis of the task analyses alone, but must be determined independently by research.

While some findings suggest that computer games hold promise for transfer, current evidence for transfer is much weaker than the enthusiasm for using computer games in instruction. Substantial further research is needed, and specific suggestions were made (Tobias & Fletcher, 2011b; Tobias et al., 2011) to confirm these tentative conclusions, extend the supporting evidence, and specify game features likely to increase transfer.

Table 38.1 Research on games and learning

Reference SS characteristics	*n* per group	Treatment and duration	Metrics	Results
Adams (1998)		60 % of geography, planning, or urban study majors liked *SimCity* without reservations, 89 % of other majors like it without reservation. SS with prior topic knowledge more likely to recognize the program to be unrealistic and evaluated it more critically than less knowledgeable SS.		
Introductory urban geography class of 46 (11♀)	No groups	SS instructed to use *SimCity* software to complete 3 tasks	SS turned in an essay on game enjoyment, task, learning, and ideologies	0 % of ♀ and 60 % of ♂ SS had prior experience with game, 89 % non-majors and 60 % majors liked program
Anderson et al. (2010)		Meta-analytic procedures were used to test the effects of violent video games on aggressive behavior, aggressive cognition, aggressive affect, physiological arousal, empathy/desensitization, and pro-social behavior. Meta-analyses yielded significant effects for all six outcomes Variables suggesting that exposure to violent video games is a causal risk factor for increased aggressive behavior, aggressive cognition, and aggressive affect and for decreased empathy and pro-social behavior		
138 papers $K=136$, $N=130{,}296$ drawn from Western and Japanese sources		Studies were identified and coded	Effect size ($r+$), research design, SS' ages, culture (West or Japan)	Exposure to violent games led to higher aggressive behavior ($r+=0.21$) and aggressive cognition ($r+=0.217$). Too few experimental/long studies for effect on pro-social behavior, empathy/desensitization, or arousal
Bailey et al. (2010)		Participants with high and low video game experience performed the Stroop task while brain activities were recorded. Results suggest that video game experience has a negative influence on proactive, but not reactive, cognitive control		
51 ♂ college students 18–33 years old	26 low gamers (1.76 h play/week), 25 high (43.4 h play/week)	SS selected based on prior questionnaire, Study given again, SS given computerized Stroop task	Usage questionnaire, EEG activity (68 sensors), eye movement tracking, Stroop performance, and speed	No difference between groups time or accuracy on Stroop. No difference for reactive control. High gamers showed significant change on proactive reaction, low gamers no significant change
Baylor (2002)		Agents affected SS' self-reports, but not performance		
135 preservice teachers enrolled in Intro Educational Technology Course	2×2 design ± instructivist agent, ± constructivist agent	SS developed an instructional plan within computer-based environment	Meta-cognitive awareness and attitude	Presence of constructivist agent SS reported a change in planning, decreased reflection, and increased use of constructivist ideas. Presence of instructivist agent SS was more negative to instructional planning
Betz (1995–1996)		Simulation group, plus coordinated readings, had more knowledge, understanding, & application of concepts learned than reading group alone		
Freshmen engineering tech. SS enrolled in Materials & Methods of Construction	Not indicated	SS in game group played *SimCity 2000* game and did reading, SS in control only read	20 multiple choice and true false item exam and follow-up survey	Only 24 SS took exam, but experimental group outperformed control. Experimental group enjoyed computer simulation more than reading
Brown et al. (1997)		Improved diabetes self-care skills, communicating with parents, & decreased urgent care visits after playing game with diabetic content compared to controls playing an entertaining game		
59 diabetes patients, ages 8–16	Experimental: Educational game treatment group ($n=31$), entertainment game control group ($n=28$)	Experimental: A game with diabetes content. Control: Entertainment game with no diabetes information. 6 months	Self-care behaviors	Game groups superior in diabetes-related self-efficiency ($p<0.07$); communication with parents about diabetes ($p<0.025$); self-care behaviors ($p<0.003$); fewer unscheduled doctor visits ($p<0.08$)
Coller and Shernoff (2009)		Engagement of SS playing game to teach mechanical engineering assessed by self-report. SS who played game as part of homework showed more engagement than in other engineering courses		

(continued)

Table 38.1 (continued)

Reference				
SS characteristics	n per group	Treatment and duration	Metrics	Results
51 university students in dynamic systems and controls course		SS wore watches for three 1-week periods over semester which reminded to take self-inventory 20 times/week	Recorded what doing and perception of activity	SS used game related to the course. They were more involved and felt better using game than studying for other no-game courses
Costabile et al. (2003)		Lecture group outperformed game group. In later study after the game group was informed that teachers would monitor game performance carefully, no differences between lecture and game groups		
Experiment 1: 54 primary SS scoring below 7/10 on baseline logic test. Experiment 2: 40 primary SS	Experiment 1: The control group teacher assisted (TA), experimental group *Logiocando*. Experiment 2: Control and experimental ea $n=20$	Experiment 1: Control got two lectures from teacher; experimental used *Logiocando* tutoring software. Experiment 2: Same but more motivation training	Experiment 1 and 2: Pre- and posttests on set operations and diagrams	Experiment 1: All SS improved pre–post ($p<0.001$). Group effect was significant ($p<0.01$) favoring lecture. Experiment 2: All subjects improved pre–post ($p<0.001$). Group effect not significant
Din and Calao (2001)		SS improved spelling and reading, but not math, scores on standardized test compared to controls		
From 2 kindergarten classes, 5–6-year-olds, Black low SES families, most w 1 parent	$n=24$ in experimental class, $n=23$ in the control class	SS in the experimental received educational game consoles and used in class for 11 weeks	WRAT-R3 test of spelling, math and reading	Both groups improved pre to post. Experimental showed significantly greater imp. on spelling ($p<0.05$) and reading ($p<0.001$), but not math
Ferguson (2007)		Meta-analysis of 17 (1995–2007) studies found an average correlation of .14 between video game playing and aggressive behavior; 0.04 when corrected for publication bias		
Articles published between 1995 and 2007 with specific keywords	17 studies total sample size of 3,602	Meta-analysis	Pooled r	Effect of video game exposure on aggression $r^2=0.14$, publication bias is very prevalent, effect of violent game exposure on visuospatial cognition $r+=0.49$
Ferguson and Rueda (2010)		SS given a frustration task then played no game, a nonviolent game, a violent game with good versus evil theme, or a violent game in which they played as a "bad guy." Results do not support a link between violent video games and aggressive behavior, but do suggest that violent games reduce depression and hostile feelings in players through mood management		
103 undergrads (62♂) (98 Hispanic)	Antisocial violent game $n=26$, pro-social violent $n=26$, nonviolent game $n=25$, no game $n=26$	SS played violent, nonviolent, or no game then given computer frustration task	Video game use, aggression measure, post-game affects	No significant difference between groups on aggression, hostile feelings, depression
Ferguson et al. (2008)		Study 1 found that neither randomized exposure to violent video games nor prior real-life exposure to violence had any effect on aggressive behavior in the lab. Study 2 indicated that trait aggression, family violence, and male gender were predictive of violent crime but exposure to video game was not		
Study 1: 101 undergrads (46 ♂) Study 2: 428 undergrads (173 ♂)	Study 1: 1 group played violent games, 1 group played nonviolent, 1 group given choice of either. Study 2: no groups	Study 1: SS played games condition specific Study 2: SS given questionnaire	Study 1: Trait aggression video game habits. Study 2: demographics, trait aggression, video game habits, crime history	Study 1: No group differed on lab aggression $p>0.05$, no effects of past game exposure on lab aggression $p>0.05$. Study 2: Game violence is related to trait aggression $r=0.21$, not aggression or violent crime
Fontana and Beckerman (2004)		Students playing a violence prevention video game increased knowledge of conflict and anger management strategies		
204 second graders in 14 classes	90 in experimental, 114 in control	Experimental had access to interactive antiviolence video game and instruction, control engaged in no formal violence prevention program	Pre- and posttest on concepts of violence prevention and conflict resolution	Experimental group increased scores, control decreased, significant difference $p<0.05$

Gentile (2009)		A national survey of 1,178 US youths found that among those aged 8-18 pathological play patterns by 8.5 % who exhibited at least 6 of 11 symptoms listed in DSM. Pathological gamers played mean of 24.6 h/week, compared to a mean of 11.8 for non-pathological players		
1,178 nationally representative (US) sample 8–18-year-olds	NA	SS invited via e-mail and given 20-min survey online	SS asked about video game habits and pathological gaming based on DSM-IV path-gambling criteria	Data were weighted. 88 % of US youths play some video games. ♂ played more often and for longer ea session. As many as 19.8 % of the sample exhibited pathological gaming
Gopher et al. (1994)		After playing game dealing with flight (modified for similarity to cockpit processing demands), two experimental groups scored higher than controls in flying aircraft		
$n = 59$ Israeli Air Force Cadets	16 full-time training, 17 in emphasis-only, 25 in control	Experiment: Ten 1-h sessions playing flight game modified to resemble cockpit processing demands; Control: No game experience	Flight instructor ratings from 8 training flights of 45–60 min	Game groups received higher instructor ratings than controls ($p < 0.05$)
Green and Bavelier (2003)		In 4 experiments SS playing action game had superior performance on indices of visual attention compared to controls		
Male game players aged 18–23 played action games for 4 h/week	Varied	SS' game experience was ascer-tained, then tested	Performance on tests of visual attention and spatial distribution	Game players and those trained in games did significantly better on measures of visual attention than control
Greitemeyer and Oswald (2010)		In 4 experiments. playing pro-social video game increased pro-social behaviors		
German University students aged 18–56	Randomly assigned to conditions	Experiment 1: SS played pro-social, neutral, or aggressive games. Experiments 2–4: SS played pro-social or neutral	Pro-social behavior (actual and reported)	Showed that playing video games with pro-social content is positively related to increases in different kinds of pro-social behavior
Gremmen and Potters (1997)		Lectures supplemented with a game were more effective for teaching economics principles than lectures alone		
Three economics classes, 47 students total	Ea. class split into half	All SES played economics game, *SIER*, once, experimental played more and control received lectures only	Tests of SS' knowledge of international economics model	Both groups improved, but experimental improved more (p at least < 0.1 for each test)
Harris and Williams (1985)		For SS playing mean of 240.8 min per week, English grades correlated −0.28 with game playing time and −0.20 with money spent on video games		
152 high school SS (80 ♂)	No groups	SS filled out questionnaire during class	1 page questionnaire with demographic and video game usage inquiries	All but 3 had played games, 23 did not currently play. SS played average 241 min/week. English grades correlated −.28 with time and −.20 with money spent on video games
Hart and Battiste (1992)		No transfer effects after playing game dealing with flight		
Student aviators who were about to enter flight school	2 × 3 design (33 warrant officer candidates, 37 officers) × (14 Space Fortress, 14 Apache Strike, 14 control)	SS in control did nothing, SS in experimental played either *Space Fortress* or *Apache Strike* in 10 daily 1-h sessions	*Space Fortress* yielded 15 measures of success, *Apache* yielded measures of success. Performance of all SS on Common Core flight training were assessed by SS and instructors	Performance on games improved from first to last session for both experimental groups ($p < 0.0001$). Fewer in the Space Fortress failed at least 1 check ride than others. They did better on some components than other groups
Karle et al. (2010)		Video game players demonstrated a task-switching benefit compared to non-players. However, this benefit disappeared when proactive interference between tasks was increased, with substantial stimulus and response overlap in task set rules		

(continued)

Table 38.1 (continued)

Reference				
SS characteristics	*n* per group	Treatment and duration	Metrics	Results
Experiment 1: 56 undergrads all ♂ Experiment 2: 40 undergrads all ♂	Experiment 1: 30 action game players, 26 non-VG players. Experiment 2: 20 action game players, 20 non-VG players	Experiment 1: SS given computerized perception test. Experiment 2: SS given computerized task-switching test	Experiment 1: Perception test performance. Experiment 2: Task-switching performance	Experiment 1: Players showed significantly decreased reaction times on more complicated trials. Experiment 2: Players showed significantly decreased reaction times ($p < 0.05$), no significant difference in accuracy
Kato et al. (2008)		*Re*-Mission, a cancer education game, or a commercial adventure game, taught adolescents and young adult cancer patients adherence to cancer-related prescribed behaviors. Adherence to medication was greater in the intervention group. Self-efficacy and knowledge also increased in the intervention group compared with the control group, but did not affect self-report measures of adherence, stress, control, or quality of life		
Patients who were aged 13–29 years w/ malignancy diagnosis undergoing treatment	Intervention *Re-Mission* game $n = 197$, control commercial game $n = 178$	All SS received computer asked to play game (either *Re-Mission*, a cancer education game, or a commercial adventure game) 1 h/week over 3-month period	Game usage was recorded, self-reported treatment adherence, antibiotic adherence, cancer knowledge, quality of life instrument	22 % of control and 33 of experimental played game at least 1 h/week. No significant difference between groups on treatment adherence. Experimental took 62 % of prescribed meds versus 53 % control. Intervention showed greater increase in cancer knowledge ($p = .035$) and no significant difference between groups on quality of life
Ke (2008)		A math computer game improved attitudes to math learning but not math performance and metacognitive awareness		
487 SS from 18 fifth-grade classes in 4 rural PA districts, 49 % ♀, 38 % low SES, 23 % below basic math ability, 34 % proficient, and 23 % advanced	Computer games $n = 177$ (individualistic $n = 57$, competitive $n = 51$, cooperative $n = 69$) Pen-and-paper drills $n = 181$ (individualistic $n = 58$, competitive $n = 63$, cooperative $n = 60$)	SS played *ASTRA EAGLE* edu games or pen and paper equivalents	Math skills, attitude test, and metacognitive scale	Experimental SS significant main effect for learning, and classroom goal structures
Laffey et al. (2003)		Children using math games gained more on math posttest than controls; "at-risk" children gained more than others		
187 pre-K-first grade low SES SS	22 at-risk with interactive computer tech (ICT), 19 at-risk with no ICT, 10 no-risk with ICT, 10 no-risk with no ICT	SS of high/low problem behavior had 16 sessions with interactive computer technology	Tests of mathematics behavior measures	Kids in ICT group had significantly more gain in math, $p < 0.00$, no difference between at-risk and no risk in ICT group. No significant Δ in behavior
Leutner (1993)		SS without instructional support learned to play the game, but learned little about domain-specific concepts. SS given advice learned more domain-specific concepts, but learned to play the game only to a limited degree		
Study 1: 64 German seventh graders. Study 2: 38 University students. Study 3: 80 seventh and eighth graders	Study 1: 16/condition. Study 2: 19/group. Study 3: 20/group	Study 1: 2×2 design with ± pretutorial information and ± adaptive advice. Study 2: 2 groups ± adaptive advice. Study 3: 2×2 with ± background information ± adaptive advice	Study 1: Test of domain geology and game knowledge. Study 2: Functional knowledge, residual game, and domain knowledge. Study 3: Same	Study 1: Pretutorial—adaptive advice group did best on domain knowledge. Study 2: Presence of adaptive advice was significantly associated with increased scores. Study 3: Main effect of background information ($p = 0.012$)
Moreno et al. (2001)		Animated agent facilitated transfer, recall, and interest ratings but not retention. Retention and transfer to problem solving improved with speech not text		
Study 1: Undergrads from psych pool. Study 2: 7th graders in urban middle school	Study 1: n = 24 in no-pedagogical agent group, 20 in pedagogical agent group. Study 2: 24 in no-pedagogical agent group, 24 in the pedagogical agent	Computer tutorial either had a pedagogical agent or not. Study 1 took ~1 hr. Study 2 took ~90 min	Retention and transfer tests	Study 1: No significant group difference on retention. Agent significantly better on transfer than no agent ($p < 0.005$). Study 2: No significant difference on retention between groups. Agent significantly better on transfer than no agent ($p < 0.005$)

Rodrigo et al. (2008)		Compared intelligent tutoring system in mathematics and entertaining general problem-solving game and found observational ratings of frustration and boredom to be higher for the game and SS spent more time on task conversations in the game		
TIM study: 176 students in 6 Philippines high schools aged 12–19 (76♀)	36 students played The Incredible Machine game, 140 used *Aplusix* math tutoring software	SS in game condition played for 10 min in groups of 9, SS in tutoring used software for 45 min in groups of 10	Observed affect and behavior during session	SS in both groups mostly in flow state, but significantly more so in game ($p=0.1$), frustration more common in game ($p=0.001$), boredom more common with tutoring ($p=0.0001$)
Roe and Muijs (1998)		Frequent European gamers also frequent television viewers, users of VCRs, film viewers, listeners to music and radio; they read less than others, spent less time with friends, scored lower on all indices of achievement, and had lower self-concepts and self-esteem		
Stratified random sample of 1,001 Flemish fourth graders from 51 schools	No groups	2 waves of questionnaires and concurrent parent questionnaire	Computer usage, self-concept, parent variables	9.2 % heavy computer game users. These were more likely to have working-class parents with lower education, watched more TV, and saw more movies
Ronen and Eliahu (1999)		Students liked using simulation for homework and found it more interesting and effective than other homework activities		
71 ninth graders (30♂) who completed computer literacy course	No groups	SS learned about electricity with open-environment software and workbook	Questionnaire, interviews, and grades	SS liked simulation (especially frequent users and higher scorers), most SS relied on simulation for feedback over other sources ($p<0.001$)
Rosser et al. (2007)		Physicians' skill on 3 video games correlated with laparoscopic skill and suturing ability; past game experience predicted laparoscopic proficiency; players with no prior video game experience took more time to complete laparoscopic surgery drills and made more errors on them than those who played more than 3 h a week		
33 surgeons—21 residents, 12 attending	No groups	SS completed questionnaire on past videogame usage. Then they completed Top Gun virtual endoscopic training over 1.5 days. Finally SS played 3 commercial video games	Video game usage was self-reported, Top Gun success measures were time to completion and errors, video game scores were a composite of 3 game scores	Surgeons who never played video games took more time to complete and committed more errors in Top Gun drills than those who played >3 h a week (both $p=0.03$)
Sims and Mayer (2002)		Skilled players outperformed less skilled on mental rotation tasks with stimuli similar to shapes used in game		
Study 1: Undergrads from psych pool. Study 2: Female grad students w/o *Tetris* experience	Study 1: 53 in low-skill group. Study 2: 8 experienced group, 8 no experience	Study 1: SS divided based on *Tetris* ability 2 sessions of ~40 and 60 min. Study 2: SS in experimental group played *Tetris* for fourteen 1-h sessions, non-experimental group played nothing	Both studies, performance on mental rotation tasks	Study 1: SS in high-skill group quicker on rotation tasks. Significant difference on rotation of *Tetris* shapes ($p<0.01$). Study 2: No significant difference on pre- to posttest or between groups
Spicer and Stratford (2001)		SS using a virtual hypermedia-based field trip emphasizing televised images, with some opportunity for interaction, were unanimous that it was not a substitute for real field course. Result contrasted with findings that attitudes to virtual trip were positive and that student test scores re learning from trip did not differ from actual field trip		
Second-year students in zoology	No groups	SS participated in a "Virtual Field Trip"	Likert-type and open-ended rating of program	SS indicated "field notebook" feature as best feature (73 % of SS), and text to voice-over ratio as worst (37 %), SS liked the activity, but did not view it as replacement for real field trips
Sung et al. (2008)		Preschoolers playing a game designed to improve classification skills had improved skills in making distinctions between thematic and taxonomic relationships and hierarchical taxonomic concepts in comparison to other groups		
60 Taipei preschoolers aged 3.5–5.5	20/condition (10 each/age group)	SS took pretest, participated in 1 of the 2 games or a non-software activity, and then took posttest	SS took geometric tile test, thematic/taxonomic concept test, and hierarchical taxonomic concept test	SS in the sort software program outgained other 2 on pre- to posttest

(continued)

Table 38.1 (continued)

Reference				
SS characteristics	*n* per group	Treatment and duration	Metrics	Results
Tompson and Dass (2000)		Undergraduate business majors in a simulation strategic management course had greater increase in self-efficacy than controls studying the same material using case studies		
252 fourth-year undergrads in strategic management course	Experimental group $n = 126$, control $n = 126$	Experimental enrolled in courses which used computer simulation, whereas control taught primarily w/ case studies	Pre- and post-measures of course content knowledge and self-efficacy	Simulation accounted for significantly more gains in self-efficacy pre to post ($p < 0.01$)
Virvou and Katsionis (2008)		Educational games were more likable than non-game software. Novice players wasted most time suggesting a useful role for training and guidance in games		
Vos et al. (2011)		Compared students creating their own memory game versus those who played a premade memory game. Creating group showed greater motivation and deep strategy use		
113 fifth graders and 122 sixth-grade students from 9 Dutch classes	5 classes ($n = 128$) in construction condition, 4 classes ($n = 107$) in play condition	SS told about Dutch proverb. SS in construction condition instructed to create own drag-and-drop game about proverbs, SS in play played an existing drag-and-drop game on proverbs	Pre- and posttests on student use of deep strategy use and intrinsic motivation	Students in the construction condition showed greater motivation on all subscales, perceived competence ($p = 0.004$), interest ($p < 0.001$), and effort ($p < 0.001$). SS in construction condition showed more deep strategy use ($p < 0.001$)
50 children, 11–12 years old	15 novice, 20 intermediate, and 15 expert game players	SS played virtual and then non-virtual game. Later were given virtual game and then commercial game to take home	Computer monitoring, self-report use	Novice players did not use all game features. SS preferred virtual game to non-virtual. Advanced users preferred commercial game, no difference in preference for novices

Enhancing Cognitive Processes

Enhancing cognitive processes is an important outcome. Some research has found evidence for improvement in such processes from computer game playing. These findings may transcend issues of near or far transfer since, as indicated above, overlap in the cognitive processes engaged by games and external tasks is the basis for both types of transfer.

Green and Bavelier (2003) conducted five experiments comparing the visual abilities of those who played action games to non-players. They found improvements in different indices of visual attention for the players. Anderson and Bavelier (2011) reviewed a program of research and found that fast action games improved processes dealing with perception, attention, and cognition. They suggest that the results from many of their experiments may be attributable to increases in speed of processing, sensitivity to inputs in the environment, or flexibility in allocating cognitive and perceptual resources. They expected that such improvements would enhance performance in tasks like reading fine print or driving. Karle, Watter, and Shedden (2010) found that computer game players had significantly shorter reaction times on complicated perceptual tasks. However, they observed no group differences in time or accuracy in the ability to switch from one task to another.

Bailey, West, and Anderson (2010) compared the performance of groups playing an average of 43.4 h per week to those playing only 1.76 h per week on the Stroop (1935), considered to be a measure of selective attention, interference, cognitive flexibility, and/or processing speed. There was no difference between the players on test accuracy, but EEG activity indicated greater proactive reaction to changes for the high playing group suggesting enhanced cognitive processing activity. Sung, Chang, and Lee (2008) evaluated a multimedia computer game involving sorting designed to improve children's classification skills. Tests examined the children's ability to grasp simple and complex taxonomic concepts. They found improved classification skills for the group playing the classification skills game compared to participants in a non-software activity or others playing a game not designed to improve classification schemes.

Sims and Mayer (2002) found that undergraduates who were already skilled *Tetris* players outperformed less skilled players only on mental rotation tasks that presented stimuli similar to shapes used in the game. In a second experiment, female graduate students who played Tetris for fourteen 1-h sessions showed no improvement on mental rotation tasks. These results suggest that improvements in cognitive processes may be very specific to processes and stimuli used in the game, i.e., they lead to near but not far transfer.

Rosser et al. (2007) reported that game-playing surgeons made fewer errors and worked more rapidly during laparoscopic surgery (where a tiny camera and instruments are controlled by joysticks outside the body) than non-players, presumably because they engaged similar cognitive and psychomotor processes. Further evidence of improvements in processes underlying game performance was reviewed by Tobias et al. (2011).

Summary and Discussion

The findings suggest that computer games may lead to improvements in some cognitive and psychomotor processes. Results from Bavelier's research program (Anderson & Bavelier, 2011) and other studies suggest that the ability to flexibly alternate between tasks could lead to improvements in the skills of pilots, as also suggested by the Gopher et al. (1994) results. While the research in Bavelier's laboratory, and by others, is carefully designed and executed, the findings should be replicated and extended. These results offer the intriguing possibility of investigating the use of computer games to train cognitive processes in specific populations of interest (Tobias & Fletcher, 2011b). For example, while performance decrements due to aging are unlikely to be reversed by training, perhaps the pace of the decline in older groups could be reduced by games. Also, could games be used to improve the cognitive processes contributing to the difficulties of individuals with dyslexia or attention deficit disorders? The implications of Bavelier's results for effects on players' aggression are discussed later in this chapter.

Guidance and Animated Agents

Computer games often provide assistance or guidance to help players navigate in the game. Virvou and Katsionis (2008) found that such guidance was needed by novices to help them use the game effectively. Similarly, Leutner (1993) compared system-initiated advice and student-requested background information. Students who requested background information learned to play the game, but acquired minimal domain-specific concepts. The opposite occurred with system-initiated advice, i.e., students acquired more domain-specific concepts, but only learned to play the game to a limited degree.

Guidance is often delivered by animated agents, usually cartoon-like characters resembling human or animal figures, to help players use the game. Research findings regarding the use of animated agents have been equivocal (Dehn & van Mulken, 2000; Tobias et al., 2011). For example, Moreno, Mayer, Spires, and Lester (2001; see also Mayer, 2011) used a guided discovery learning environment and found that having animated instructional agents facilitated transfer and interest ratings but not retention. Baylor (2002) used two types of agents and found that they affected students' self-reports of different processes, but had little effect on performance in an instructional planning task.

Summary and Discussion

Moreno (2005) reviewed research on animated agents and concluded that since no studies found that agents interfered with learning or transfer, there seems to be little reason, other than development costs, to avoid them. The issue of providing guidance is more complex. Research reviews (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003; Wittwer & Renkl, 2008) found that help offered in computer displays, not necessarily game based, is infrequently used and does not facilitate learning. Furthermore, Wise and O'Neil (2009) found that the term "guidance" is ambiguous, and used to cover explanations, feedback, help, modeling, scaffolding, and procedural direction, among other instructional alternatives. Perhaps the guidance issue should be reframed in terms of instructional support (Tobias, 1982, 2009), i.e., any type of assistance that helps students learn. The ambiguity of findings regarding help or guidance may be clarified by developing a hierarchy of different forms of instructional support and studying the types of support that facilitate game learning.

Playing Time and Relationship to Course of Study

Time on task in technology-based instruction is readily measured and may be used for assessment or to guide individualization. Although studies have shown that time in simulations and computer games may not always track student learning because of student excursions to explore and answer their "what-if" questions (Hoover & Fletcher, 2011), it has been found to be far more closely related to learning and transfer than seat time in classroom learning (e.g., Bickley, 1980; Orlansky & String, 1977; Suppes, Fletcher, & Zanotti, 1975, 1976). Research on time devoted to game playing and the relationship of games to curriculum are discussed below.

Time

Harris and Williams (1985) found that students, including some non-game players, were playing an average of 241 min per week. Students' English grades were negatively correlated with both time and money spent on games. Betz (1995–1996) reported that participants spent more time on a simulation than on a comparison reading task. Similarly, Laffey, Espinosa, Moore, and Lodree (2003) reported that students in game conditions received more instruction than did non-gaming controls.

Integration with Courses of Study

Coller and Shernoff (2009) found that students who played a computer game designed to teach mechanical engineering as part of their homework evaluated it more positively and were more engaged in the course than in other engineering courses. Din and Calao (2001) reported that learning increased when the games played were integrated into the curriculum. Similarly, Henderson, Klemes, and Eshet (2000) stressed the importance of curriculum integration, and Gremmen and Potters (1997) found that lectures supplemented by a computer game were more effective for teaching economics principles than lectures alone. Costabile, De Angeli, Roselli, Lanzilotti, and Plantamura (2003) found that learning from a game increased when students were informed that teachers would monitor their performance in an instructional game. Jackson and McNamara (2011) found that adding game elements improved student engagement and enjoyment in an intelligent tutoring system.

Finally, Sitzmann and Ely (2009) reported that students learned more from computer games supplemented by other instruction than from games alone. Their analysis of 55 studies (Sitzmann, 2011; Sitzmann & Ely, 2009) found that learners using computer-based simulation games outscored control groups on self-efficacy, declarative and procedural knowledge, and retention. Learning was found to increase if games conveyed content actively rather than passively and learners could access the game as often as desired. More learning occurred in the comparison instructional method if it engaged learners actively. Surprisingly, games receiving higher ratings for fun were no more likely to yield gains in motivation and affect than those receiving lower ratings.

Summary and Discussion

With regard to time, the evidence indicates that students spend more time on computer games and simulations than on comparison instructional methods. These findings raise the possibility (Tobias et al., 2011) that any gains from games may be attributable to the greater amounts of time spent playing them rather than any affordances of games. It is well known (Fisher & Berliner, 1985; Suppes et al., 1975, 1976) that the amount of time students are engaged with instructional material is positively related to learning. Research is needed in which time on task is systematically varied to determine whether learning from games is attributable to increased engaged time, or to other factors. If learning gains can be attributed to time spent playing, research might compare games to other ways of increasing students' time on task to assess their cost-effectiveness.

Playing computer games unrelated to curricula may be fun, but it is not likely to enhance progress toward targeted learning objectives unless the game is integrated with other instructional material (Tobias et al., 2011). Games can be integrated by including features requiring students to retrieve additional information from resources external to the game, such as printed matter, laboratory exercises, and Internet inline links ("hot links"). Reentry into games could be made contingent on students' mastering the data from external sources. These are relatively simple ways of integrating learning from computer games into courses of study. Game designers will doubtless develop other, more imaginative techniques of integration.

Effects of Games on Players

The amount of time people spend playing computer games may well affect their behavior and performance away from the games they play. We discuss research on the effects of game playing in two areas: school learning and aggression.

School Learning

Roe and Muijs (1998) found that students who were frequent game players were often also frequent television viewers, users of VCRs, film viewers, or listeners to music and radio. They read less than others, spent less time with friends, had lower self-concepts and self-esteem, and scored lower on all indices of school learning and achievement. Harris and Williams (1985) found that students' English grades were negatively correlated with both time and money spent on games. Gentile's integrative article (2011) reported similar effects.

Aggression

Gentile's (2005) review of the effects of games on aggression found that despite major design flaws in some research "given the preponderance of evidence from all types of studies (experimental, cross-sectional, longitudinal, and meta-analytic), it seems reasonable to conclude that violent games do indeed have an effect on aggression" (p. 17). Similar conclusions were reached by Gentile, Lynch, Linder, and Walsh (2004).

Using the *Diagnostic and Statistical Manual of Mental Disorders* (American Psychiatric Association, 2000), Gentile (2009) found that among youths aged 8–18, "8.5 % of video-game players exhibited pathological patterns of play as defined by exhibiting at least 6 out of 11 symptoms of damage to family, social, school, or psychological functioning" (p. 600). Players exhibiting these pathological patterns played a mean of 24.6 h per week, compared to a mean of 11.8 for those who did not. In view of these findings extensive game playing is of concern and should be studied more intensively.

Anderson et al. (2003) reviewed research on violent television and films, computer games, and music. They found "unequivocal evidence that media violence increases the likelihood of aggressive and violent behavior" (p. 81). Their summary dealing with games alone concluded that "The experimental studies demonstrate that in the short term, violent video games cause increases in aggressive thoughts, affect, and behavior; increases in physiological arousal; and decreases in helpful behavior. The cross-sectional studies link repeated exposure to violent video games with aggressive and violent behavior in the real world. The longitudinal studies further suggest long-term effects of repeated exposure to violent video games on aggression and violence" (p. 93).

Contrary to these results, Ferguson (2007) conducted a meta-analysis of 17 studies and found an average correlation of 0.14 between game playing and aggressive behavior; corrected for publication bias the correlation dropped to 0.04. A later study (Ferguson et al., 2008) had 101 undergraduate students play games that were violent, nonviolent, or gave them a choice of the two. The results indicated that neither random exposure nor previous real-life exposure to violent computer games had any effect on aggressive behavior in the laboratory using a task that involved punishing a fictional opponent. In a second study they found that trait aggression, family violence, and male gender, but not exposure to computer games, were predictive of violent crime. Ferguson and Rueda (2010) found no difference in aggression, hostile feelings, or depression following play of a violent, nonviolent, or no game at all.

Finally, Anderson and Bavelier's (2011) results present a paradox. The improvements they found in cognitive processes resulting from playing first-person shooter games raised the possibility that games that improve cognitive capabilities may also increase aggressive or hostile behavior. Whether it was the aggressive or the hostile content or the rapid reaction times that facilitated the learning noted by Anderson and Bavelier remains to be determined. Research is needed to examine if games requiring very fast reactions but lacking aggressive components lead to cognitive enhancement without increasing aggressive and/or hostile behavior.

Summary and Discussion

The negative relationships between school learning and computer game playing is a statistical finding. Whether game playing actually causes a reduction in school performance or is simply a correlate remains to be determined. Some results, e.g., Sitzmann and Ely (2009), suggest that there might even be a positive effect of playing some games on school learning. The body of research and findings on this issue, as on others related to game playing, is still young and emerging.

Given the contrary reports now available it seems possible that computer game playing may increase tendencies toward hostile and/or aggressive behavior in some individuals, but the evidence is not conclusive. Still, it would be paradoxical to assume that students can learn different knowledge, skills, and attitudes from games but *not* aggressive reactions (Tobias et al., 2011). The findings described above (see also Anderson et al., 2010) echo findings by Bandura and Walters reported in 1963 (before the use of computers) that participation in aggressive games increased aggression in non-game contexts. Even Ferguson (2007) argued about the effect size of aggressive games, rather than whether they did occur. Future research needs to clarify these effects.

An interesting alternative to games that may be increasing players' aggressiveness is to provide games with pro-social content. Greitemeyer and Oswald (2010), as summarized above, found that games with such content increased similar actions in daily life. Also, Fontana and Beckerman (2004) found that a game used to teach conflict resolution techniques increased the use of these techniques. These findings suggest research to investigate whether increases in aggressive behavior observed among some game players can be reduced by assigning them to games with pro-social content.

Attitudes Toward Games

Ronen and Eliahu (1999) reported that students they surveyed preferred using a program especially designed for developing and presenting simulation-based activities on electric circuits for homework and found it both more interesting and effective than other homework activities. On the other hand, Spicer and Stratford (2001) reported that students employing a simulation dealing with a virtual hypermedia-based field trip that emphasized televised images, with some opportunity for interaction, "were unanimous in their view that it was not a substitute for a real field course" (p. 351). This result contrasted with their findings that attitudes to the virtual trip were positive and that student learning from the trip, determined by test scores, did not differ from an actual field trip.

Adams (1998) reported that "only 60 % of geography, planning, or urban studies majors reported liking *SimCity* without reservations, while 89 % of other majors '… professed to like the program without reservation" (p. 52). Students with prior knowledge of the topic were more likely to recognize that the program was unrealistic and evaluated it more critically than less knowledgeable students. Ke (2008) found that a mathematics game, compared to learning math with pen-and-paper drills, improved attitudes to math learning but not math performance or metacognitive awareness.

Similarly Ronen and Eliahu (2000) reported that the same simulation used in their prior study described above (Ronen & Eliahu, 1999) contributed to students' confidence and enhanced their motivation to stay on task. They noted that the simulation helped 70 % of the students with the task. Neither students with insufficient understanding of the domain nor those with substantial understanding profited from the simulation.

Rodrigo et al. (2008) found that observers' ratings of frustration and boredom for students were higher for a computer game than for an intelligent tutoring system. However, the tutoring system and the game did not deal with the same subject area, were used by students in different years, and were not used for the same amounts of time. Finally, the results for several other variables were not significant when evaluated by the multiple t tests reported. A multivariate analysis of variance may have altered the pattern of the results.

Agency, or control, over game play may determine the level of involvement and motivation in using a game for learning (Sitzmann & Ely, 2009), as also demonstrated by Klimmt, Hartmann, and Frey (2007). Vos, van der Meijden, and Denessenm (2011) found that students who constructed games showed greater motivation, perceived confidence, interest, effort, and deep strategy use than those who played a previously constructed game.

Summary and Discussion

Even though computer games are clearly popular, results of attitudes to game studies are mixed. There seems to be a hint of interaction between attitudes and prior domain knowledge (Dai & Wind, 2011; Tobias & Fletcher, 2011b). Therefore, studying both variables simultaneously may help determine the features of games and simulations that are most important in improving attitudes and facilitating learning from games for students with differing levels of domain familiarity.

Collecting attitudinal data on educational games may be especially important since researchers (Games & Squire, 2011) and game designers (Prensky, 2011) indicate that games specifically designed for educational purposes are not as much fun to play compared to those designed only for fun. Educational games are certainly not as widely distributed, or as successful financially as those developed for amusement.

Cost-Effectiveness Analysis

The problem for decision makers in education and training is not simply to improve current practice with new and more effective approaches. They must also balance such improvements against what must be given up, i.e., costs to implement and employ them. Without knowledge of costs, decision makers' risk is greater and their decisions more precarious. Without this knowledge, they may well opt for the status quo, no matter how promising a new direction might be.

The cost-effectiveness argument for using games in learning appears to be fourfold (Fletcher, 2011):

(a) People will voluntarily persist in playing games longer than they will engage in non-game learning.

(b) If the game is instructionally relevant, this engagement increases time on (learning) tasks.

(c) Increased time on learning tasks will yield increased learning.

(d) Therefore, people may learn more from games than from some other instructional environments without increasing costs.

There is support for this argument. For instance, if, as Gentile (2009) reported, young people aged 8–18 are averaging 13.2 h per week playing computer games, not because they have to, but because they want to, then they might persevere equally persistently in playing games with embedded learning material.

Cost analyses use a variety of techniques. Two of the most common are Return on Investment (ROI) and Cost-Effectiveness Analysis (CEA).

Return on Investment

The basic formula for calculating ROI is as straightforward as its name suggests. As discussed by Phillips (2003) and others, it is

$$\text{ROI} = \frac{\text{Value of the result} - \text{Cost of the investment}}{\text{Cost of the investment}}$$

ROI shows the net value returned per unit of cost invested. It is usually calculated for some period of time, such as a year. The time period chosen depends on those seeking information and performing the analysis. There are, of course, spikes, dips, and diminishing returns to be considered with differently timed units of investment. ROI requires "Value" and "Cost" to be commensurable—expressed in the same unit of measure, which is usually and most frequently monetary.

The issues that arise with the investment side of ROI usually concern what cost elements should be included, how to define them, and what values should be assigned to parameters such as discount, interest, depreciation, inflation, and amortization rates. Levin and McEwan (2001), Phillips (2003), Rossi, Lipsey, and Freeman (2003), and Fletcher (2010) among others have discussed the use and application of these matters in general. They should be considered in the specific case of game-based learning.

Cost-Effectiveness

Unlike ROI, CEA does not require commensurability. Effectiveness can be expressed in whatever terms that are most useful to analysts and decision makers. However, and also unlike ROI, CEA is a relative term; it must be expressed in reference to other alternatives—such as use of games versus conventional classroom instruction.

Cost-effectiveness is usually calculated as a ratio providing the amount of effectiveness delivered per unit cost. It is common practice in determining cost-effectiveness to hold costs constant and observe variations in effectiveness (e.g., amount learned) or to hold effectiveness constant and observe variations in costs (e.g., time to criterion). For example, Fletcher, Hawley, and Piele (1990) examined the costs to increase scores one standard deviation on a standard mathematics test under five alternatives: increasing length of school day, reducing class size, using hired tutors, using peer tutors, and using computer-based instruction. Ross, Barkaoui, and Scott (2007) provide a review of 31 carefully selected studies with examples of CEA in education.

Summary and Discussion

Cost analyses are as subject to controversy as are any other analyses or assessments. Differences in data, data definitions, analysis techniques, models, and assumptions are all subject to question. It is unlikely that any cost analysis will satisfy all decision makers. The problem has been mitigated elsewhere by the acceptance of specifications and standards. Analysts have suggested a variety of models with practicable, well-defined cost elements for education (Fletcher, 2010; Levin, 1983; Levin & McEwan, 2001), industrial training (Kearsley, 1982; Phillips, 2003), and military training (Fletcher & Chatham, 2010; Knapp & Orlansky, 1983), but these are rarely noted, heeded, or used. They could be reconciled and abstracted into a unified, generally applicable model, but at present they remain separated by different approaches, cost elements, and definitions.

The best that can be done today in cost analysis for game-based learning, as in any other analysis, is to be compulsively explicit so that decision makers can determine how well the specific objectives and methodology of any particular cost analysis apply to and inform the decisions they must make. In short, these analyses can never be perfect, but they can, and should, be as explicit as possible. Decisions about implementing and using game-based learning need to be explicitly informed by empirically derived cost data, which, as indicated above, is often scarce, or absent.

Using Games for Evaluation

It has been suggested that computer games may become an important new capability in evaluation (Everson, 2011; Gee & Shaffer, 2010). Shute (2011) proposes a "stealth" evaluation paradigm to assess learning from games unobtrusively enabling data collection without interrupting game play. Stealth evaluation would reduce the division between game play, instruction, and evaluation. If research supports such use of games some interesting research possibilities arise. It would be useful to study whether enjoyment in game playing reduces test anxiety, which is generally associated with being evaluated (Tobias, 1992), compared to other forms of evaluation. If such reductions occur, research could then examine whether games may be more useful, or accurate, assessment tools especially for individuals high in test anxiety.

Summary and Discussion

At present there are few examples and less data on the application and value of computer games used for evaluation. For instance, there has been very little, if any, research on the psychometric properties of games. How many games must be played for how long to ensure reliability, validity, and precision in assessing not just game proficiency but also progress toward achieving specified instructional goals? Some of the techniques developed for assessing learning in intelligent tutoring systems and in simulation-based learning may well be applicable, but few games now employ them in a systematic manner. In any case, it is difficult to imagine any successful instructional program without some systemic assessment of learning. Research and development must be completed to develop techniques and procedures for game-based learning assessment if we are to be serious about the use of games in instruction.

Discussion

The research reviewed above indicates that games hold promise as instructional delivery systems, a conclusion also reached by Honey and Hilton (2011) in a special committee report of the National Academies charged with studying the effectiveness of using games in science instruction. As noted above, there is research support for that conclusion, but the evidence is much thinner than the enthusiasm for using game-suggests, leading to two implications.

First, further research and theoretical development are urgently needed in a variety of areas. We have made some suggestions above, and summarize others below. However, space constraints make it impossible to discuss the many questions that should be investigated. We have done so elsewhere (Tobias & Fletcher, 2011b; Tobias et al., 2011), as have others. Second, the study and development of computer games in instruction need a generally agreed-upon taxonomy of games used in this manner.

Taxonomy of Games

The literature is filled with such terms as "serious games," "educational games," "fast action games," "first person shooters," etc. While these terms are convenient shorthand descriptions of game genres, they are insufficiently precise to differentiate the characteristics of games from each other. There is a need for a generally accepted taxonomy of games. That is especially important because different types of games may have different learning outcomes.

A taxonomy will make it possible to relate types of games to the learning results that may be expected from them. Such specificity helps game developers and researchers organize the knowledge base about game-based learning, identify needed research more effectively, and provide research-based prescriptions for using different types of games. Gentile (2011) proposed five dimensions of game play, four of which may be applied in developing a game taxonomy. They are content of play, game context, game structure, and mechanics of game play.

An additional layer in a game taxonomy should cover student characteristics. There is evidence (e.g., Dai & Wind, 2011; Tobias et al., 2011) that outcomes vary for different types of individuals. For example, Kamill and Taitague (2011) found that a vocabulary game facilitated vocabulary acquisition for some students who were *not* native speakers of English, but had little effect on native English speakers. Similarly, Fraas (1982) reported that students with lower prior knowledge of economics, or lower scholastic aptitude, profited more from games than others with higher knowledge or aptitude. As suggested elsewhere (Gustafsson & Undheim, 1996; Tobias, 2009) interactions with prior knowledge are often reported in the literature dealing with instruction generally and may be one of the most frequently replicated effects in research on adapting instruction to student characteristics. Emerging techniques for modeling prior knowledge with links to ontological descriptions of subject matter seems a particularly promising approach in this area (e.g., Grubiši , in preparation).

Interactions between prior knowledge and instructional support (Tobias, 1973, 1976, 1989, 2009) predict that students with limited prior knowledge need substantial support to learn, whereas those with extensive prior knowledge could succeed with little support. As Dai and Wind (2011) suggest, games may be especially useful for students who do not succeed with traditional instructional methods, a conclusion also reached in the National Research Committee report (Honey & Hilton, 2011). Because they can adjust more readily to learners, games may not require as much prior knowledge as school-based instruction. Furthermore, the strong motivation to play games may be an antidote for students with low motivation for school and/or learning, leading them to work longer and more intensely than they do in traditional instructional settings. These factors all suggest that a taxonomy of games should include information about the types of students for whom particular types of games may be especially beneficial.

Recommendations for Game Design

A number of research-based recommendations for the design of games were made by Tobias and Fletcher (2007), and extended elsewhere (Tobias et al., 2011). We have summarized these and updated them in Table 38.2, which also includes citations of selected research reviews.

The rationale for many recommendations in Table 38.2 were derived directly from the various issues discussed above; hence there is little reason for repeating them here. We shall add to those discussions to amplify material that was only summarized above, or to add information not mentioned previously.

Virvou and Katsionis (2008) found that novice players wasted time learning to navigate the game, and hence instructional support in the form of guidance is especially important for them. The desirability of providing pictorial, rather than textual, instructional support derives from the multimedia principle (Fletcher & Tobias, 2005) that the recall of pictorial material is usually more accurate than for textual content, presumably because it reduces the cognitive load for game players (Mayer, Mautone, & Prothero, 2002).

Discovery learning, one form of constructivist instruction, has been sharply criticized from a number of quarters (Kirschner, Sweller, & Clark, 2006; Mayer, 2004). The controversy about the effectiveness of constructivist or explicit instructional approaches has been summarized elsewhere (Tobias & Duffy, 2009) and is beyond the scope of this chapter. It should be noted, however, that both constructivists and their critics recommend guidance, though definitions of the term differ somewhat (Tobias & Duffy, 2009). Similarly, the recommendation to maximize user involvement is widely shared by both constructivists and supporters of explicit instruction though, again, definitions of user involvement vary. Collecting user responses in the game is, of course, vital because it provides clues regarding students' present status and comprehension of the game.

Designing computer games is an extremely complex activity. It is unlikely that any one individual possesses all the skills needed to do this effectively. In agreement with others (Belanich & Orvis, 2006; Jayakanthan, 2002; Leutner, 1993; O'Neil, Wainess & Baker, 2005; Squire, 2005), we continue to recommend that game design be a team process

Table 38.2 Recommendations for designs

Recommendation	Supporting literature
1. Conduct cognitive task analysis to identify the cognitive processes engaged by game and required by task	Brown et al. (1997), Fery and Ponserre (2001), Gopher et al. (1994), Green and Bavelier (2003), Greenfield (1998), Greenfield, Brannon, and Lohr (1994), Greenfield, Camaioni, Ercolani, Weiss, and Lauber (1994), Greenfield, deWinstanley, Kilpatrick, and Kaye (1994), Mayer et al. (2002), Moreno and Mayer (2004, 2005), Okagaki and Frensch (1994), Rosser et al. (2007), Sims and Mayer (2002), Subrahmanyam and Greenfield (1994), Tobias et al. (2011)
2. Provide guidance	
(a) Provide pictorial support	Fletcher and Tobias (2005), Greenfield, Camaioni et al. (1994), Kalyuga, Ayres, Chandler, and Sweller (2003), Lee (1999), Mayer (2001, 2006), Mayer et al. (2002), Moreno (2005), Moreno and Mayer (2005), Rieber (2005), Swaak and de Jong (2001), Sweller (2006)
(b) Encourage reflection about correct answers	Moreno (2005), Moreno and Mayer (2005)
(c) Provide guidance/support for discovery learning	Kirschner et al. (2006), Mayer (2004), Swaak and de Jong (2001), Tobias and Duffy (2009)
3. Use first person in dialogue	Moreno and Mayer (2000, 2004)
4. Use animated agents in interactions with players	Baylor (2002), Moreno (2005), Moreno and Flowerday (2006), Moreno et al. (2001)
5. Use human, rather than synthetic voices	Atkinson, Mayer, and Merrill (2005)
6. Maximize user involvement	Fletcher (2004), Wishart (1990)
7. Reduce cognitive load	Kirschner et al. (2006), Mayer et al. (2002), Sweller (2006)
8. Maximize motivation	Lepper and Malone (1987), Malone (1981a, 1981b), Malone and Lepper (1987)
9. Increase pro-social content and reduce aggressive content	Anderson and Bushman (2001), Anderson and Dill (2000), Fontana and Beckerman (2004), Gentile (2005), Tobias et al. (2011)
10. Revise games and task analyses	Hays (2005), O'Neil et al. (2005)
11. Integrate games w/instructional objectives and other instruction	Leutner (1993), Gremmen and Potters (1997), Sitzmann and Ely (2009), Henderson et al. (2000), Tobias et al. (2011)
12. Keep abreast of emerging research findings	O'Neil et al. (2005), Tobias et al. (2011)
13. Use teams to develop instructional games	Squire (2005), Tobias & Fletcher, 2011a, 2011b

(Tobias & Fletcher, 2007, 2011b; Tobias et al., 2011). In addition to game designers and computer and interface specialists, game development teams should include subject matter experts in the domain to which games are expected to transfer, as well as experts in instructional systems design, cognitive task analysis, and game research. It may be difficult, and certainly costly, to have so many different specialists on a game development team. However, costs of development teams are decreased because many of the specialists mentioned above do not have to be regular team members, but could be consulted as needed.

Final Word

Ensuring learner motivation has always been a critical aspect of good instructional design (Martin & Reigeluth, 1999). The evident attraction of games for a significant portion of the learning population is proving to be equally irresistible to instructional designers. The research is clear; people do learn from games. What we need is a way to design games so that people learn what they need to learn. We need and do not yet have generally effective techniques, processes, and procedures for designing games that reliably achieve intended instructional objectives. Integrating the motivating aspects of games with good instructional design is critical—Kirkley, Tomblin, and Kirkley (2005) proposed a tool facilitating this integration. Such integration is a serious and challenging endeavor, which, if it can be successfully articulated in systematic procedures that reliably achieve instructional goals, will yield sizable benefits for learning technology. At the very least, the effort to meet this challenge should teach us much about using games in instruction and how to design more motivating instruction overall.

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39 Scaffolding: Definition, Current Debates, and Future Directions

Brian R. Belland

Abstract

Instructional scaffolding can be defined as support provided by a teacher/parent, peer, or a computer- or a paper-based tool that allows students to meaningfully participate in and gain skill at a task that they would be unable to complete unaided. The metaphor of scaffolding has been applied to instruction in contexts ranging from literacy education to science education, and among individuals ranging from infants to graduate students. In this chapter, scaffolding is defined and its theoretical backing is explored. Then scaffolding strategies and examples are explored. Trends, findings, and implications of current empirical research are presented and discussed. Current debates in the scaffolding literature are explored, including whether (a) scaffolding needs to be based on dynamic assessment and fading, and (b) domain-specific knowledge needs to be embedded in scaffolding. Finally, future research directions are outlined, including transfer of responsibility, the interaction between teacher scaffolding and computer-based scaffolding, and other scaffolding aspects.

Keywords

Instructional scaffolding • Transfer of responsibility • Non-scaffolding instructional support • One-to-one scaffolding • Computer-based scaffolding • Peer scaffolding

Introduction

Increasing students' higher order thinking abilities is a top priority during the twenty-first century (Bybee, McCrae, & Laurie, 2009; Darling-Hammond, 2010). But how can students increase their higher order thinking abilities? One way is through instructional scaffolding. In this chapter, I explore the scaffolding metaphor, including its definition, theoretical foundations, mechanisms, modalities, current research, current controversies, and future research directions. This chapter is based largely on literature from educational technology and the learning sciences. Due to space constraints, I do not review literature on such interventions as intelligent tutoring systems (Koedinger & Corbett, 2006; VanLehn, 2011) from researchers in the fields of cognitive and computing sciences.

Scaffolding Definition

Wood, Bruner, and Ross (1976) defined scaffolding as just-in-time support provided by a teacher/parent (tutor) that allows students (tutees) to meaningfully participate in and gain skill at problem solving. Recent definitions have also highlighted the role of scaffolding in improving other skills such as argumentation (e.g., Belland, Glazewski, & Richardson, 2008; Jonassen & Kim, 2010) and the understanding of text and other content (e.g., Azevedo, 2005; Linn, 2000). Scaffolding accomplishes this when (a) tutees share an understanding of the instructional goal with the tutor (intersubjectivity); (b) scaffolding is dynamically adjusted

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according to tutee ability; and (c) transfer of responsibility is promoted (Puntambekar & Hübscher, 2005). Intersubjectivity means that a student "must be able to recognize a solution to a particular class of problems before he himself is able to produce the steps leading to it without assistance" (Wood et al., 1976, p. 90).

Hannafin, Land, and Oliver (1999) classified scaffolding in terms of the functions it can fulfill. Scaffolding can help students with strategy, what to consider, how to judge the sufficiency of work, and how to use tools (Hannafin et al., 1999).

Several aspects distinguish scaffolding from simple supports such as job aids. First, scaffolding serves to both simplify processes and highlight their complexity (Reiser, 2004), while job aids serve only to simplify processes (Champion, 1999). Second, job aids typically only address simple procedures (Champion, 1999), while scaffolding can address more complex processes and knowledge (Pea, 2004; Puntambekar & Hübscher, 2005). Third, job aids are typically designed such that individuals will continue to use them (Smith & Ragan, 1999), while scaffolding is designed to be used temporarily while students gain skill at the scaffolded task (Wood et al., 1976).

Scaffolding leads to increased skill by providing just the right amount of support at just the right time, and backing off as students gained skill (Pressley, Gaskins, Solic, & Collins, 2006; Wood et al., 1976). This can happen because scaffolding is contingent on both task and tutee characteristics (Collins, Brown, & Newman, 1989; Wood et al., 1976). There are three types of contingency:

- Instructional contingency—how to support activity
- Domain contingency—what to focus on next
- Temporal contingency—if and when to intervene (Wood, 2003, p. 14)

In order to act contingently, tutors need to dynamically diagnose student ability (Graesser, D'Mello, & Cade, 2009). Such diagnosis allows tutors to modify support based on performance characteristics of the tutee, decide what to focus on next, and gradually remove support as the tutee shows evidence of being able to act more independently (Wood, 2003). Collins et al. (1989) labeled the gradual removal of scaffolding support as fading. Fading is said to promote skill gain through the transfer of responsibility from the scaffold and tutee to the tutee alone. This happens if students incorporate into their schemas processes supported by the scaffolding by generating questions and self-explanations in response to scaffolding (Belland, 2011; Chi, 1996).

However, recent research indicates that fading may not be necessary to promote transfer of responsibility (Belland, 2011). Considering scaffolds as part of a distributed cognition system may allow one to consider how to promote transfer of responsibility without fading based on continual diagnosis. A distributed cognition system consists of individuals and tools that share the burden of a cognitive task (Giere, 2006; Hutchins, 1995). To promote transfer of responsibility, one needs to design scaffolding such that the tutee maintains executive control throughout the functioning of the distributed cognition system. This can be done if students are allowed to "make choices, operate at decision points, and select paths of action" (Belland, 2011, p. 584). Then the scaffold can be removed and the remaining elements of the system can adjust (Belland, 2011).

Theoretical Foundations

The scope of this chapter does not allow for a detailed description of the theoretical backing of scaffolding, but I will contextualize some of scaffolding's theoretical foundations. There are two major theoretical foundations that correspond to two major instructional goals: improving higher order thinking abilities (e.g., Wood et al., 1976) and improving content understanding (e.g., Linn, 2000). Due to space constraints, this chapter focuses only on scaffolding to promote improved higher order thinking abilities such as problem-solving ability and argumentation ability. Readers interested in learning more about scaffolding to promote improved content understanding are directed to Azevedo (2005) and Linn (2000). Readers interested in learning more about scaffolding to promote metacognition are directed to Aleven and Koedinger (2002), Azevedo (2005), and Quintana, Zhang, and Krajcik (2005).

Wood et al. (1976) applied the term *scaffolding* to a process of parents helping infants solve a problem. Wood et al. (1976) did not reference Vygotsky. However, other researchers (e.g., Annemarie Palincsar) soon connected scaffolding and Vygotsky's Zone of Proximal Development (Pea, 2004). The ZPD consists of a set of tasks that students cannot yet independently accomplish but which they can accomplish with assistance (Vygotsky, 1978). To be clear, not all tasks that students cannot independently accomplish are in their ZPDs. For example, solving problems using simple algebraic equations is in the ZPD of most upper elementary school students, who know how to carry out many of the operations required to solve equations like $3x+6=10$. With assistance, such students can meaningfully participate in the solving of a simple algebraic problem. Engineering a nuclear power plant is not in the ZPD of most upper elementary school students, because they cannot meaningfully participate in the task. As students begin to be able to independently perform tasks that were once in their ZPDs, their ZPDs automatically envelop the next level of performance.

Scholars also made the connection between scaffolding and Vygotsky's ideas on the emergence of consciousness and higher order thinking through social interaction (Vygotsky, 1978). According to this perspective, one cannot separate action from the cultural-historical context in which it develops (Kozulin, 1986; Luria, 1976). Every community, be it a country or a specific research laboratory, contains cultural knowledge about how to accomplish certain tasks (Nersessian, 2005). Scaffolding can help students gain the cultural knowledge embedded in the scaffolds (Nersessian, 2005; Sawyer & Greeno, 2009). For example, accepted community norms related to argumentation are contained in argumentation scaffolds. Thus the knowledge that emerges initially in the intermental plane (i.e., in interactions with scaffolds) then reemerges on the intramental plane (i.e., in individual's own cognition; Wertsch & Tulviste, 1992).

Two contextual factors influence students' reception of scaffolding: the extent to which the cultural knowledge contained within scaffolding conflicts with students' existing internalized cultural knowledge, and students' motivation. Expecting scaffolding to impart cultural knowledge is problematic if such knowledge conflicts with students' internalized cultural knowledge (Belland, 2009; Bourdieu & Passeron, 1990). Students will often resist instruction that conflicts with their dispositions (Bourdieu & Passeron, 1990). For example, if students learned that for every problem there is a known algorithm to solve it, they may resist scaffolding that implies that authentic problem solving involves a much more fluid and flexible process.

Student motivation can also impact how students receive scaffolding and engage in inquiry (Belland, Kim, & Hannafin, 2010). However, scaffolding can be designed such that it improves motivation (Pressley et al., 2006).

Scaffolding Mechanisms

Scaffolding mechanisms include (a) enlisting student interest, (b) controlling frustration, (c) providing feedback, (d) indicating important task/problem elements to consider, (e) modeling expert processes, and (f) questioning (van de Pol, Volman, & Beishuizen, 2010; Wood et al., 1976). Enlisting student interest and controlling student frustration highlight (a) the role of scaffolding in creating and sustaining student motivation, and (b) the central role of student motivation in deploying and improving higher order skills (Brophy, 1999; Pino-Pasternak & Whitebread, 2010; Wood et al., 1976). Providing feedback involves informing students of the adequacy of their performance. Indicating important task/problem elements to consider involves telling students what they should focus on during their investigations. Modeling expert processes refers to showing students how an expert would approach solving a similar problem. Questioning involves tutors prodding students to articulate answers that can move them toward completing the task.

Reiser (2004) highlighted two competing mechanisms of scaffolding that can be considered by designers of scaffolding: structure and problematize. Structuring refers to the role of scaffolding in simplifying tasks while still representing the whole task. If a task did not need to be simplified for students to be able to accomplish it, then scaffolding was never needed in the first place. Scaffolding should also problematize the task by indicating to students important concepts to which they should pay particular attention. Ultimately, scaffolding should lead to skill gain, and it is through problematization that this is possible (Reiser, 2004).

Scaffolding Modalities

The predominant K-12 class size of 20–30 students makes one-to-one interactions impractical as a single source of scaffolding (Pea, 2004; Puntambekar & Kolodner, 2005). With the emergence of more powerful computer technologies, some researchers (e.g., Pea, 1985) began to wonder if computer tools could provide the scaffolding function. Similarly, other researchers (e.g., Scardamalia & Bereiter, 1994) wondered if peers of similar ability could provide scaffolding. Along the way, some educational researchers began to wonder if the scaffolding metaphor had become too broad (e.g., Pea, 2004; Puntambekar & Hübscher, 2005; Stone, 1998).

The scope of this chapter precludes a discussion of all ways in which authors have proposed to provide scaffolding. However, there are three main modalities—one-to-one, peer, and computer/paper-based scaffolding. It is important to note that these three modalities are not mutually exclusive, but rather can be combined to form a system of distributed scaffolding that together can serve students' scaffolding needs (Puntambekar & Kolodner, 2005; Tabak, 2004). Table 39.1 shows the scaffolding mechanisms used in each study cited in this section.

For each modality, I (1) provide a definition of the modality and/or subsets of the modality, (2) describe research done with operationalizations of the modality according to school level and subject, and (3) discuss what attention has been paid in the reviewed research to (a) intersubjectivity, (b) customization, and (c) transfer of responsibility.

One-to-One Scaffolding

Definition

One-to-one scaffolding is generally considered to be the ideal scaffolding modality in that it is ideally tailored to individual student needs through instructional, domain, and temporal contingency. One-to-one scaffolding consists of a teacher's contingent support of students within their respective ZPDs (van de Pol et al., 2010; Wood, 2003). Such scaffolding is dependent on the teacher's ability to continually diagnose student ability. One-to-one scaffolding often

Table 39.1 Scaffolding mechanisms in one-to-one, peer, and computer-based scaffolding

	Enlist student interest	Control frustration	Provide feedback	Indicate important problem elements	Model expert processes	Questioning
One-to-one scaffolding						
Gillies and Boyle (2006)			X	X	X	X
Jadallah et al. (2011)			X			X
Maloch (2002)	X		X	X	X	X
Mertzman (2008)			X	X	X	X
Pentimonti and Justice (2010)						X
Raphael, Pressley, and Mohan (2008)			X		X	X
van de Pol, Volman, and Beishuizen (2011)		X	X	X	X	X
Peer scaffolding						
Hakkarainen (2004)			X			X
Kolodner et al. (2003)			X			X
Oh and Jonassen (2007)			X			X
Palincsar and Brown (1984)					X	X
Pifarre and Cobos (2010)			X	X		X
Rubens, Emans, Leinonen, Skarmeta, and Simons (2005)			X			X
van Aalst and Truong (2011)			X			X
Computer-based scaffolding						
Context specific						
Davis and Linn (2000)				X	X	X
Lajoie, Lavigne, Guerrera, and Munsie (2001)				X		X
Lee, Linn, Varma, and Liu (2010)				X		X
Pedersen and Liu (2002–2003)				X	X	X
Sandoval and Reiser (2004)				X		X
Saye and Brush (2002)				X		X
Generic						
Belland (2010); Belland, Glazewski and Richardson (2011)				X	X	X
Cho and Jonassen (2002)				X		
Gijlers, Saab, van Joolingen, de Jong, and van Hout-Wolters (2009)				X		X
Li and Lim (2008)				X		X
Puntambekar and Kolodner (2005)				X		X

includes all of the following mechanisms—(a) enlisting student interest, (b) controlling frustration, (c) providing feedback, (d) indicating important task/problem elements to consider, (e) modeling expert processes, and (f) questioning (van de Pol et al., 2010; Wood et al., 1976). When employing one-to-one scaffolding, fading has been promoted as a method to promote transfer of responsibility for the scaffolded task (Collins et al., 1989; van de Pol et al., 2010).

Use in Elementary Schools

Reading Instruction

When third-grade students focused on surface-level details in a reading, the teacher asked questions that helped students think about the reading from different perspectives and to discover the underlying themes (Maloch, 2002). This led students to be more critical readers and the support could be faded (Maloch, 2002).

Jadallah et al. (2011) examined the process of one-to-one scaffolding in fourth-grade reading discussions. The most frequent scaffolding moves made by the teacher were "(a) asking for clarification, (b) prompting for evidence, (c) praising the use of evidence, and (d) challenging" (Jadallah et al., 2011, p. 208).

Pentimonti and Justice (2010) studied the use of one-to-one scaffolding during read-alouds led by five preschool teachers. Although teachers almost unanimously said that they used scaffolding, few were observed to do so (Pentimonti and Justice (2010)).

However, one-to-one scaffolding in elementary reading instruction can go awry. Elementary teachers engaged in reading instruction provided differential one-to-one scaffolding to students from ethnic minority or low-SES backgrounds (Mertzman, 2008). Often the scaffolding differed from the teachers' stated philosophy for reading instruction (e.g., focused on phonics rather than comprehension). Also, teachers were three times more likely to scold ethnic minority students for wrong answers than ethnic majority students.

Instruction in Various Subjects

Effective elementary school teachers teaching a variety of subjects scaffolded student learning by challenging the perspectives from which students considered problems, prompting students to articulate rationales for actions, and highlighting discrepancies in student thinking (Gillies & Boyle, 2006). They did this through prompting, modeling, and role-playing.

Use in Middle School

Instruction in Various Subjects

Only one of three middle school social studies teachers predominantly formulated scaffolding in response to individual student performance characteristics (van de Pol et al., 2011). Highly engaging middle school teachers of various subjects (science, mathematics, social studies, and language arts) provided one-to-one scaffolding in the form of hints and modeling and explanation of expert strategies (Raphael et al., 2008). These same teachers were found to cover more material at a deeper level than low-engaging teachers, who did not provide scaffolding (Raphael et al., 2008). Similarly, one-to-one scaffolding significantly predicted high engagement among elementary school students during reading instruction (probability = 76 %), while the lack thereof significantly predicted low engagement (probability = 62 %; Lutz, Guthrie, & Davis, 2006).

Intersubjectivity, Customization, and Transfer of Responsibility

Intersubjectivity, or the shared understanding of the task, was not discussed in any covered articles.

Customization of support on the basis of ongoing diagnosis of student ability was discussed in all but one article in this section (Gillies & Boyle, 2006; Jadallah et al., 2011; Maloch, 2002; Mertzman, 2008; Raphael et al., 2008; van de Pol et al., 2011). For example, when a teacher thought that explicit attention needed to be drawn to her use of modeling, she explicitly told students that she would be modeling an important discussion process (Maloch, 2002). But as students gained skill, she would simply participate in the discussion, without explicitly telling students that she was modeling (Maloch, 2002).

Transfer of responsibility was not discussed in all covered literature on one-to-one scaffolding. A teacher at first provided much metalinguistic scaffolding, but as time progressed, the scaffolding shifted to procedural prompts, and thus students assumed greater responsibility for the discussion group (Maloch, 2002). In Jadallah et al. (2011), the primary scaffolding moves were prompting for evidence and praising the use of evidence. As the reading discussions progressed, the teacher (a) prompted for evidence less as students spontaneously used evidence more and (b) increased her praising of students' use of evidence. In van de Pol et al. (2011), teachers for the most part did not engage in contingent scaffolding. Rather, students asked for help and they were provided help with no questions asked.

Peer Scaffolding

Definition

In its original definition, scaffolding was said to involve assistance by a more capable individual (Wood et al., 1976). Other authors advanced the idea that peers can also provide such support (e.g., Gillies, 2008; Pata, Lehtinen, & Sarapuu, 2006). In a classroom of 30 students, peer scaffolding may be a cost-effective way to provide scaffolding to all students. Sometimes students have differing abilities and can help each other move to higher order thinking. For example, elementary and secondary students with stronger English-speaking abilities can help English as a New Language students improve English-speaking ability through a process of questioning and cuing English production (Angelova, Gunawardena, & Volk, 2006; Walqui, 2006).

However, students cannot automatically provide effective peer scaffolding. When they are of similar ability, students often do not have expertise from which other students can benefit in a scaffolding interaction (King, 1998). Similarly, if all students have the same knowledge related to the unit content, they will not automatically know how to critically evaluate each other's work (King, 1998; Mercer, Dawes, Wegerif, & Sams, 2004). To promote effective peer scaffolding, students need to be provided a framework to guide their provision of scaffolding.

Use in Elementary School

Science Instruction

In *Computer-Supported Intentional Learning Environments* (CSILE), students can publish graphical or text notes in a database, which can then be accessed and commented on by other students (Scardamalia & Bereiter, 1994). Before a note is published, it needs to go through a peer review process. During this process, students can attach notes to other students' notes asking for clarification and flagging potential problems. Elementary school students used *CSILE* to guide research projects on force, astronomy, and electricity (Hakkarainen, 2004). The majority of students went from definitions with little explanatory power to definitions with good explanatory power in their second and third research projects, and much of this increase was attributed to peer scaffolding (Hakkarainen, 2004). The peer scaffolding can be distinguished from peer feedback in that it involved both feedback and prompting. Peers drew on principles of scientific inquiry that they had learned through scaffolding embedded in *CSILE* and also that provided by the teacher.

The next generation of *CSILE* is *Knowledge Forum*. Again, students post notes in a database, which can then be commented on and linked to notes by other students. In a study of *Knowledge Forum* in elementary school science, students gained significantly from pre- to posttest and were found to create more scientifically accurate definitions of reproduction through peer critiques (van Aalst & Truong, 2011). Students who provided peer scaffolding drew on principles of scientific inquiry that they had learned through scaffolding embedded in *Knowledge Forum* and also that provided by the teacher.

Use in Middle School

Science Instruction

In the *Learning by Design* model (Kolodner et al., 2003), middle school science students articulate design ideas in a poster session and are expected to critique each other's ideas. This critiquing should not be mistaken for peer feedback, because it involves both feedback and prompting: Peers ask the original designers to justify their decisions, and to explain how they can deduce rules of thumb from the evidence they collected. Peers draw on scaffold prompts they considered while designing their experiments. *Learning by Design* students performed as well as control students in tests of content knowledge but performed significantly better on collaboration and metacognitive skills (Kolodner et al., 2003). Furthermore, average-achieving students who followed a *Learning by Design* approach performed as well on tests as honors students who followed a traditional instructional approach.

Reading Instruction

In reciprocal teaching, middle school teachers model the process of asking a question, summarizing, clarifying, and making a prediction when reading text passages (Palincsar & Brown, 1984). Then, a student follows the same process for the next paragraph. This led to very substantial increases in reading comprehension scores from pre- to posttest among seventh-grade students, and these increases remained stable for a long period (Palincsar & Brown, 1984).

Use in Universities

In *Future Learning Environment* (FLE3), postsecondary students can create knowledge artifacts with the help of a checklist that indicates the important elements thereof (Rubens et al., 2005). Then peers can comment on each other's knowledge artifacts. Preservice teachers who used *FLE3* in online discussions included significantly more evidence in their arguments than control students, who were more likely to simply explain claims (Oh & Jonassen, 2007).

Similarly, in *KnowCat*, university students enrolled in instructional psychology critiqued classmates' reports about particular topics (Pifarre & Cobos, 2010). Students were given guidelines of what to consider in classmates' reports—"content adequacy, personal elaboration of the ideas, organisation of the ideas, presentation strategies, and conclusions" (Pifarre & Cobos, 2010, p. 244). Critiquing led to a significant increase in metacognitive skills, in particular clarifying and monitoring understanding (Pifarre & Cobos, 2010).

Intersubjectivity, Customization, and Transfer of Responsibility

None of the reviewed articles discussed intersubjectivity. None of the articles discussed customization of support that was initiated by peer tutors. However, due to the nature of the reciprocal teaching intervention (Palincsar & Brown, 1984), teachers could intervene if peer tutors were not scaffolding appropriately.

While Kolodner et al. (2003) discussed the idea of transfer of responsibility, transfer of responsibility with respect to peer scaffolding was not isolated. Pifarre and Cobos (2010) noted that as students provided peer scaffolding to each other, they were able to self-regulate their own learning. However, they did not explain exactly how this happened. Using a multiple baseline approach, Palincsar and Brown (1984) demonstrated that students exposed to differing durations of reciprocal teaching all improved during reciprocal teaching, as compared to control students, and then were able to maintain their skill after reciprocal teaching ended. But the specific duration of reciprocal teaching for any individual student was not based on an ongoing diagnosis and Palincsar and Brown (1984) did not explain exactly how the transfer of responsibility occurred. The other covered studies on peer scaffolding did not address transfer of responsibility. The lack of consideration of transfer of responsibility for peer scaffolding may be attributed to the fact that providing the continual diagnosis required for contingency is hard even for teachers (Graesser et al., 2009). To expect peers to be able to engage in continual diagnosis thus may not be reasonable.

Computer/Paper-Based Scaffolding

Computer/paper-based scaffolds can be defined as computer- or paper-based tools that can provide scaffolding. For simplicity's sake, they will be referred to as computer-based scaffolds. Computer-based scaffolds emerged as a solution to the dilemma that teachers in typical K-12 classrooms cannot be expected to provide adequate one-to-one scaffolding to all students in a classroom. Computer-based scaffolding can be developed based on an analysis of the factors that make learning a topic difficult (Baker, Corbett, & Koedinger, 2007) and can be used to supplement one-to-one scaffolding (Saye & Brush, 2002). During inquiry-oriented instruction, computer-based scaffolding can scaffold a classroom of students but the teacher should also roam the classroom to dynamically provide one-to-one scaffolding. Without one-to-one scaffolding provided by a teacher, computer-based scaffolding is ineffective (McNeill & Krajcik, 2009; Puntambekar & Kolodner, 2005; Saye & Brush, 2002; Tabak, 2004). Computer-based scaffolds can be either context specific or generic.

Embedded, Context-Specific Scaffolds

Definition

Context-specific scaffolds are tailored to the content associated with the unit in which they are embedded. Such scaffolds cannot be applied to a new unit without extensive modification. The unit would typically consist of all content and support needed to achieve the associated learning objectives.

Use in Middle School

Science Instruction

In *Web-based Inquiry Science Environment* (WISE), students explore issues related to covered units (e.g., on deformed frogs), and scaffolds help students articulate thoughts on the causes of and potential solutions to the central problems and learn from each other (Linn, Clark, & Slotta, 2003). Lee et al. (2010) compared knowledge integration of middle school and high school science students who used *WISE* to that of students exposed to traditional instructional methods for an entire year. *WISE* students of 24 out of 27 teachers performed substantially better in tests of knowledge integration than students who did not use WISE (Lee et al., 2010). Effect sizes ranged from 0.02 to 1.86.

In the *Knowledge Integration Environment*, middle school science students were exposed to either self-monitoring prompts (i.e., prompts that informed students of standards to assess their understanding) or activity prompts (i.e., prompts that showed students how to complete tasks; Davis & Linn, 2000). Students who received self-monitoring prompts were significantly more likely to explain phenomena using principles and evidence than students who received activity prompts (Davis & Linn, 2000).

Alien Rescue presents middle school science students with a problem scenario that aliens have arrived at Earth and need to find a suitable new home in our solar system (Pedersen & Liu, 2002–2003). Students need to read characteristics of the planets to find an appropriate planet for their assigned aliens. Scaffolds include modeling by experts stating how they would go about addressing the problem. Such modeling helped students generate more relevant questions than students in the control group, who were simply told didactically what to look for (Pedersen & Liu, 2002–2003).

Use in High School

Science Instruction

Bioworld presents high school science students with written medical cases, and provides scaffolds to help students create and test hypotheses about the causes of patient problems (Lajoie et al., 2001). The system also contains information about diseases and associated symptoms and scaffolds to help students assess their confidence in their hypotheses and other decisions. 90 % of students were able to successfully diagnose encountered patient problems (Lajoie et al., 2001).

ExplanationConstructor contains scaffolds that are integrated with specific disciplinary content (Sandoval & Reiser, 2004). For example, in one unit using *Explanation Constructor*, high school biology students explored finch species in the Galapagos Islands. The system contained all text that students read as well as scaffolds that structured the problem solving process and helped to illustrate particularly pertinent information (Sandoval & Reiser, 2004). The scaffolds led students to be able to evaluate their explanations in epistemic terms (Sandoval & Reiser, 2004).

Social Studies Instruction

In *Decision Point*!, high school history students decide what should have been done immediately after the assassination of Dr. Martin Luther King, Jr., to continue the quest for equality (Saye & Brush, 2002). They read primary source documents and used scaffolds to help them with the process. *Decision Point*! led half of the student groups to create effective persuasive presentations in support of their problem solutions (Saye & Brush, 2002).

Generic Scaffolds

Definition

The scaffolds described in this section are designed for students to use as they interact with materials elsewhere within the classroom and beyond. Support contained in generic scaffolds is not geared toward specific content, and as such can be used with a variety of units in a variety of subjects. So for example, generic scaffolds would not ask specific questions about mayflies or how to test for nitrates, but rather would be based around a general process.

Use in Middle School

Science

The *Connection Log* is designed to help middle school students build evidence-based arguments during problem-based learning units (Belland, 2010; Belland, Glazewski, & Richardson, 2011). In one study, lower achieving science students who used the *Connection Log* performed significantly better on a test of argument evaluation ability (ES = 0.61) than lower achieving control students (Belland, Glazewski, & Richardson, 2011). In another study, average-achieving science students who used the *Connection Log* performed significantly better on a test of argument evaluation ability (ES = 0.62) than average-achieving control students (Belland, 2010).

Design Diaries contain questions for middle school students to consider as they are reading expert cases and as they design artifacts. *Design Diaries* also contain space where students can write their responses to prompts. When *Design Diaries* were used in isolation, student responses to prompts were of little depth, but when the tool was used in conjunction with other scaffolds, such as poster sessions, student responses were more in depth (Puntambekar & Kolodner, 2005).

Social Studies

Li and Lim (2008) described an approach to scaffold middle school students' investigation of historical problems. Computer-based scaffolds included an argumentation template and prompts that helped students to decompose the task and activate prior knowledge. The effect of the scaffolds was not isolated, but students who used scaffolds performed well in the inquiry tasks (Li & Lim, 2008).

Use in High School

Science

In the *Collaborative Concept Mapping* tool, high school physics students collaboratively create concept maps to describe a problem (Gijlers et al., 2009). Students using the tool attempted to integrate their ideas with those of groupmates more than students who used a tool that had preformed hypotheses (Gijlers et al., 2009).

Use in University

Economics

Belvedere is a system in which students can create concept maps of arguments (Cho & Jonassen, 2002). It scaffolds students' construction of evidence-based arguments by indicating which argument elements they need and how these generic elements interrelate. College students studying economics who used *Belvedere* produced more claims and evidence than those who did not use Belvedere (Cho & Jonassen, 2002).

Intersubjectivity, Customization, and Transfer of Responsibility

No reviewed scaffold addressed intersubjectivity. Intersubjectivity is likely established by the teacher in many units. However, it would be wise to remind students of the ultimate goal of the scaffolding, because intersubjectivity is ultimately needed when transfer of responsibility is expected to occur (Wood et al., 1976).

One of the issues preventing computer-based scaffolds from offering customization is that authentic, ill-structured problems have multiple possible answers and multiple solution paths (Jonassen, 2000). As such, programming a computer to automatically adjust in response to student input is impossible.

Of the reviewed computer-based scaffolds, only Li and Lim (2008) attempted to fade scaffolding. This was not contingent, but rather followed a predetermined schedule. The only two ways that "fading" has been attempted with computer-based scaffolds is (a) have scaffolds disappear or reduce on a fixed schedule, or (b) have students indicate that they do not need the scaffold any more (Belland, 2011). But neither of these methods seems to capture the essence of fading as Collins et al. (1989) intended.

Summary

An interesting pattern emerged in the reviewed scaffolds in terms of which scaffolding elements each scaffolding modality incorporated. But please note that this section is not intended to be a comprehensive review of the scaffolding literature. Most one-to-one scaffolding (a) provided feedback, (b) indicated important problem elements, (c) modeled expert processes, and (d) questioned. Most peer scaffolding (a) provided feedback and (b) questioned. Most computer-based scaffolding—both context specific and generic—(a) indicated important problem elements and (b) questioned. Not all scaffolding elements were used by each scaffolding modality.

The scaffolding modalities are also striking in that they each promote intersubjectivity, customization, and transfer of responsibility differently. Surprisingly enough, none of the reviewed scaffolds addressed intersubjectivity. Almost all reviewed articles covering one-to-one scaffolding discussed customization (Gillies & Boyle, 2006; Jadallah et al., 2011; Maloch, 2002; Mertzman, 2008; Raphael et al., 2008; van de Pol et al., 2011), but no covered article on peer scaffolding or computer-based scaffolds did. And few articles addressed transfer of responsibility—only two each for one-to-one scaffolding (Jadallah et al., 2011; Maloch, 2002) and peer scaffolding (Palincsar & Brown, 1984; Pifarre & Cobos, 2010), and one for computer-based scaffolding (Li & Lim, 2008).

Scaffolding Design Guidelines

There is a tension in scaffolding design in that some argue that scaffolding needs to be developed in design experiments in particular contexts (e.g., Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003), while others argue that scaffolding principles exist to support performance in a particular content domain (e.g., Kali & Linn, 2008; Quintana et al., 2004). Many authors have proposed design guidelines that are said to underlie effective scaffolds (e.g., Belland et al., 2008; Quintana et al., 2004; Reiser, 2004). In the last version of this Handbook, Kali and Linn (2008) proposed four meta-design guidelines for scaffolding science inquiry:

- Make science accessible
- Make thinking visible

- Enable students to learn from each other
- Promote self-directed learning

The meta-guidelines were accompanied by pragmatic principles and examples of their implementation (Kali & Linn, 2008). Because design guidelines were covered in the previous version of the Handbook, this chapter does not discuss guidelines in depth. Interested readers should refer to:

- Kali and Linn (2008) and the Design Principles Database (n. d.) for an overview of design principles
- Reiser (2004) for principles on how to balance simplifying tasks and drawing attention to particularly important content
- Quintana et al. (2004) for scaffolding guidelines in science inquiry
- Belland et al. (2008) and Jonassen and Kim (2010) for guidelines for scaffolding argumentation

Some question if research evidence supports the notion that the same design principles that work in one context can be generalized to different contexts, even those dealing with the same subject and grade level but simply in different schools. In his introduction to the special issue of the *Journal of the Learning Sciences* that also contained Reiser (2004) and Quintana et al. (2004), Pea (2004) argued against the idea of universal design principles for scaffolds. Rather, he noted that scaffold design theory needs to:

- Predict what types of support will be sufficient for enabling a student to perform a specific task
- Distinguish between students at different developmental levels
- Account for how to combine different types of scaffolds
- Consider the role of human scaffolding (Pea, 2004).

Current Debates

A key controversy regards what distinguishes a scaffold from other instructional supports. When one mentions the term *instructional scaffolding* it is not immediately clear what is meant. There are many questions about which different scaffolding researchers would give different answers, including whether (a) scaffolding needs to be based on dynamic assessment and fading, and (b) domain-specific knowledge needs to be embedded in scaffolding.

Dynamic Assessment and Fading

The original definition of instructional scaffolding clearly indicates that scaffolding is dynamic (Wood et al., 1976). Most would agree that dynamic customization of support is a key attribute of teacher-provided scaffolding (e.g., Conner & Cross, 2003; van de Pol et al., 2010; Wood, 2003). Dynamic customization of support is closely tied to dynamic assessment, defined as teachers' abilities to dynamically assess students' current ability levels by asking questions (Ruiz-Primo & Furtak, 2006). Teachers can then use that information to customize instructional messages for students. This seems very straightforward when talking about teachers, though it should be noted that dynamic assessment is not easy (Ruiz-Primo & Furtak, 2006). But things become more muddled when discussing computer-based and peer scaffolding. A key factor that inhibits dynamic customization of computer-based scaffolds is computer-based scaffolds' inability to engage in dynamic assessment (Belland, 2011; Pea, 2004; Puntambekar & Hübscher, 2005). That is, when computer-based scaffolding supports, for example, ill-structured problem-solving ability, it cannot dynamically assess student ability on the basis of student actions because there are a large number of correct steps that a student could take at any given time in the problem solving process (Belland, 2011). For example, if students are exploring how to optimize the water quality of their local river, there are many aspects of the problem (e.g., phosphate concentration, different entities that use the river) that they could investigate. They can investigate these aspects in many different orders. A computer cannot automatically assess if a student is on the right path if there are hundreds of potentially correct solution paths. As noted, due to length limitations, this chapter does not cover research done on Intelligent Tutoring Systems. Intelligent Tutoring Systems can engage in dynamic assessment, and thus dynamic customization, because they are often based on set procedures such as programming a VCR (Kalyuga & Sweller, 2005; Koedinger & Corbett, 2006; VanLehn, 2011). The key difference between Intelligent Tutoring Systems and scaffolds to support authentic problem solving—the ill-structuredness of the problem solving they can support—also can explain the difference in the capacity to dynamically customize support.

It remains an open question as to whether computer-based scaffolds need to exhibit dynamic assessment to be termed scaffolds. Within the scaffolding framework, dynamic assessment is intended to help the teacher provide just the right amount of support at just the right time to students. Several potential dangers of not dynamically adjusting scaffolding support have been noted. First, some authors caution that by failing to dynamically adjust support, designers may fail to promote students' ability to independently perform the supported task (e.g., Pea, 2004). Second, some authors note that failure to dynamically assess student ability may cause cognitive overload on the part of students who can already accomplish portions of the task effectively (e.g., Kalyuga, 2007; Schnotz, 2010).

Closely tied to the issue of dynamic assessment and customization is fading. Fading can be defined as the gradual removal of scaffolding support as students show evidence of being able to accomplish the scaffolded task independently

(Collins et al., 1989). Fading was thus said to promote the transfer of responsibility from the scaffolder to the scaffoldee (Collins et al., 1989). Many authors have lamented the lack of attention to fading in computer-based scaffolds (e.g., Pea, 2004; Puntambekar & Hübscher, 2005). When discussing scaffolding provided by a person, the mechanism by which fading was said to promote transfer of responsibility was never carefully defined (Belland, 2011; Lin et al., 2012). That is, no one to my knowledge described what fading caused to take place in a student's head that resulted in the transfer of responsibility. Rather, the focus was always on dynamic assessment: If the teacher could gather evidence that the student could perform the task independently, then the support could be removed. Obviously, the limited ability of computer-based scaffolds to provide dynamic assessment calls into question the appropriateness of the fading metaphor for the promotion of transfer of responsibility with computer-based scaffolds. Indeed, when authors implement fading of computer-based scaffolds to support ill-structured problem solving, what they describe may not fit the original definition of fading in that it (a) is based on students indicating that they do not need the support any more (Metcalf, 1999) or (b) simply proceeds according to a predefined schedule (McNeill, Lizotte, Krajcik, & Marx, 2006). The question is: Can fading be divorced from dynamic assessment by a more capable other? If it is divorced from such dynamic assessment, then is it fading as Collins et al. (1989) had originally described? Assessment by the students themselves is problematic because students often cannot accurately assess their own understanding (Graesser et al., 2009).

It is important to take a step back to consider the issue from the perspective of instructional goals and instructional techniques. For example, customization based on ongoing diagnosis of student ability is an instructional technique. Researchers need to focus on the instructional goal of transfer of responsibility (Belland, 2011). A re-envisioning of scaffolds as part of a distributed cognition system may be in order. If this is done, and scaffolds are designed to ensure that students maintain the executive control over the target task throughout the instructional activity and students engage mindfully, then transfer of responsibility may be promoted (Belland, 2011).

Domain-Specific Knowledge

Another issue of contention is the extent to which scaffolds need to incorporate domain-specific knowledge. In traditional, one-to-one scaffolding, the issue of whether there should be domain-specific knowledge is not as crucial since such support is contingent. That is, the teacher or the parent determines exactly what support the student needs at any given time and provides exactly that. If the needed support includes domain knowledge, then the teacher/parent can provide it. However, computer-based scaffolds are designed before students use them. As such, designers need to determine whether to incorporate domain-specific knowledge. Many computer-based scaffolds include domain-specific knowledge (context-specific scaffolds; e.g., McNeill & Krajcik, 2009). There is some evidence that generic prompts are more effective in certain cases. For example, Davis (2003) found that students who used generic scaffolds engaged in more productive reflection. However, McNeill and Krajcik (2009) found that students who used context-specific scaffolds wrote better arguments than students who used generic scaffolds, but only when the teacher effectively provided one-to-one scaffolding supporting students' understanding of a generic argumentation framework.

Examining individual studies is unlikely to provide a definitive answer on whether a generic or a context-specific approach is better. Meta-analysis (Cooper & Hedges, 1994) or meta-synthesis (Finfgeld, 2003) may help. Some colleagues and I recently performed a pilot meta-analysis of scaffolding research in STEM education. One pertinent finding was that there was no difference in cognitive student outcomes between context-specific and generic scaffolds (Belland, Walker, Leary, & Olsen, 2012).

If it is true that generic and context-specific scaffolds lead to the same initial cognitive learning outcomes, then it may be worthwhile to think of other considerations. For example, many have highlighted the importance of students investigating authentic problems (e.g., Chinn & Malhotra, 2002). By building generic scaffolds, scaffold designers may build tools that can be more flexibly applied and used with different, locally authentic problems.

However, in the end, the research evidence is not overwhelming in favor of generic or context-specific scaffolds.

Future Directions

Transfer of Responsibility

Further theoretical and empirical studies are needed to elucidate how transfer of responsibility can be promoted when using scaffolding. The fact that Collins et al. (1989) proposed fading as central to scaffolding does not mean that it needs to continue to be used in scaffolding if a satisfactory operationalization cannot be found (Belland, 2011). Rather, examining scaffolding from multiple perspectives/disciplines may serve to shed new light on scaffolding and lead to new insights (Fee & Belland, 2012). But of course, theoretical studies are not enough: Empirical studies are needed as well. Close ethnographic studies of students while using scaffolding and after may help to shed light on transfer of responsibility. Two perspectives that may be particularly helpful for this line of research is the actor-oriented transfer perspective (Lobato, 2003) and the preparation for future learning perspective (Bransford & Schwartz, 1999).

Intersection Between One-to-One Scaffolding and Computer-Based Scaffolding

There is a clear need for more research on the intersection between one-to-one scaffolding and computer-based scaffolding. Researchers have called attention to the importance of this relationship for a long time (e.g., Krajcik et al., 1998; Saye & Brush, 2002). But little is known about the underlying mechanism by which one-to-one, contingent scaffolding influences the impact of computer-based scaffolds, and vice versa. Further knowledge about this mechanism, and how it may vary in different instructional contexts and approaches, would help teachers and designers understand how they can most help students learn.

Other Scaffolding Aspects

When a designer sits down to create scaffolding, one stumbling block is the large number of scaffolding frameworks and their associated advice, which is sometimes contradictory. There is a need for a more comprehensive treatment of scaffolding strategies that can inform designers. As noted above, one way to do this is through the use of meta-analysis and meta-synthesis. Meta-analysis would allow researchers to see how the magnitude of effects on learning outcomes is impacted by the use of various strategies. However, a clear limitation of meta-analyses is that they can only synthesize a certain type of quantitative research that employs control groups (Cooper & Hedges, 1994). There is a large quantity of scaffolding research that does not fit this criterion. Meta-synthesis can allow researchers to systematically build theory from qualitative and quantitative research findings (Finfgeld, 2003). However, even with careful meta-analysis and meta-synthesis, researchers will not likely be able to find a scaffolding approach that works in all contexts. Put simply, scaffolding is used to support many different learning outcomes and in conjunction with many different instructional approaches. Variation in scaffolding approaches is to be expected. But a systematic review of the scaffolding literature may indicate pertinent future lines of research—both theoretical and empirical.

Conclusion

Many authors advocated a shift from a focus on declarative knowledge to a focus on critical thinking (e.g., Bybee et al., 2009; Hurd, 1998; Kuhn, 1999). Scaffolding can play a key role in building students' critical thinking abilities by supporting students as they engage in complex processes rather than teaching them didactically needed skills before engaging in complex processes (Lee & Songer, 2000; Linn, 2000; Sinatra, 2010). When developing scaffolding interventions, it is important to remember the key scaffolding modalities—one-to-one, peer, and computer-based—and to consider how such modalities can be combined into an overall distributed scaffolding strategy (Puntambekar & Kolodner, 2005; Tabak, 2004). It is also important to remember that scaffolding's transition from informal interactions between parents and their children to formal instruction and to different modalities such as computer-based and peer scaffolding was not theoretically neutral. There are many unanswered questions about scaffolding, including how transfer of responsibility can be promoted, and whether scaffolds need to contain domain-specific knowledge. Further research is needed to address these questions.

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Support Device Usage

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Abstract

Learning environments typically confront learners with a number of support devices. These support devices aim at helping learners in their learning; they provide a learning opportunity. As suggested by Perkins (Educational Researcher 14:11–17, 1985), it can be assumed that in order for these support devices to be beneficial (1) the opportunity has to be there, i.e., the support device has to be functional; (2) the learners have to recognize this opportunity, and (3) the learners have to be motivated to use the opportunity or the support device.

Given that the use of the devices may strongly affect the effectiveness of learning environments and that usage seems to be problematic (Clarebout & Elen, Computers in Human Behavior 22:389–411, 2006), usage is a key issue for instructional design. This chapter reviews recent research on the impact of different learner variables on support device usage. First the functionalities and categorization of support devices is discussed, followed by an overview of different learner variables and their effect on support device usage. Next, the interactions between these learner variables and specific support device characteristics are discussed. In conclusion current issues with respect to research on support device usage are discussed and possible solutions to encourage support device usage are introduced.

Keywords

Support devices • Support device usage • Learning opportunity

Introduction

Learning environments typically confront learners with a number of support devices in addition to the actual learning tasks (Elen & Clarebout, 2006). Different terms are used to refer to these support devices, such as: adjunct aids (Andre, 1979; Elen & Louw, 2006; Jonassen, 1985), scaffolds (Azevedo & Hadwin, 2005; Hannafin, Land, & Oliver, 1999; Saye & Brush, 2002); tools (Bera & Liu, 2006; Clarebout & Elen, 2006); and support devices (Portier & van Buuren, 1995; Martens, Valcke, & Portier, 1997). In this text, we use the general term "support devices" to refer to those instructional stimuli that are deliberately integrated into or added to the learning task in view of fostering learning (Elen & Clarebout, 2006). Support devices provide learning opportunities.

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However, their effectiveness depends on students' ability and motivation to use these support devices and, more specifically, use them in line with the instructional intentions (Lowyck, Elen, & Clarebout, 2004; Winne, 1982, 1987). In other words, the instructional effectiveness of these devices relies on students' usage. Therefore, gaining insight into students' support usage is crucial for instructional design.

There are two options to integrate support devices in a learning environment (Elen & Clarebout, 2006). A first option is to add the support devices to the learning tasks at hand and allow the learners to decide themselves whether or not to use them (non-embedded support devices). This option assumes heterogeneity among learners. Hence, not all available tools are beneficial for all learners working in that learning environment. By allowing learners to select and use the available devices possible negative effects (e.g., expertise reversal effect: Rey & Buchwald, 2011) are avoided. Giving learners the choice is a way to make instructional support "adaptive to the learners' needs." This learner control is assumed to be beneficial for students' interest, motivation and engagement with the topic (Lepper, 1985). However, the aforementioned rationale assumes that learners are able to make best choices according to their needs for accomplishing their learning tasks. Unfortunately, empirical evidence reveals that learners experience difficulties in determining the benefits of support devices. Research shows that giving learners this control often leads to suboptimal use of support devices, namely, no-use (Clarebout & Elen, 2006) or in some cases overuse (i.e., gaming the system; Aleven, McLaren, Roll, & Koedinger, 2006).

The second option is to integrate the support devices in the learning tasks at hand (embedded support devices). In this option, the learning environment is designed in such a way that the learners are induced to the devices. While this approach results in a 100 % usage, it does not guarantee that the devices will be used as intended (quality of usage). Illustrative in this respect is the study of Greene and Land (2000) where learners were obliged to use guiding questions stimulating evaluation and supporting reflection during project development. Students in this study were obligated to answer the questions at the beginning and the end of each session and whenever they thought they were confused. However, rather than use the questions as a tool to aid cognition, learners just used them to list visited Web sites. Similar results were reported by Clarebout, Horz, Schnotz, and Elen (2010), who found that when support devices were embedded quality of usage was less than when support devices were not embedded. Hence, it seems that when support devices are imposed to the learner, not all learners perceive their benefits and/or have the ability or motivation to use these devices as intended.

Whether embedded or non-embedded, learning effectiveness of support devices seems to depend on multiple factors. Hence, a clearer insight into the process of support usage and the variables that influence this is needed. An interesting framework in this respect is the framework proposed by Perkins. Perkins (1985) suggested that support devices are only beneficial when (a) there is an opportunity, i.e., the support device is functional for the learning task at hand, (b) learners recognize this opportunity and (c) learners are motivated to spent effort and time in using this opportunity. In this chapter, we focus on these conditions. Specifically, the contribution focuses on the different learner variables that may influence support usage. In order to get a clear view on what support devices can aim at, the categorization and functions of support devices are briefly discussed.

Functions of Support Devices

In general, support devices aim at supporting learners in their learning process. Nevertheless, devices differ in the kind of learning opportunity they provide for learners. For example, an adjunct question (Andre, 1979) focuses on supporting deep-processing of the content whereas a discussion board (Nutta, 2001) pertains to augmenting critical processing. In order to compare findings from different studies, it is hence necessary to have a classification system that categorizes the different types of support devices dependent on their functionality for the learning process. In this respect, the classification scheme of Hannafin et al. (1999) makes a distinction between *information, cognitive, and scaffolding* support devices. *Information* support devices provide the content in a different way (e.g., in a structured or elaborated way), they provide information that learners can use to construct their mental models, formulate hypotheses or solve problems. These can be documents, graphics, video or animations helping learners to understand the problem. *Cognitive* support devices allow learners to interact with the content. These devices support students in processing, assessing and communicating the concepts under study. Discussion boards, concepts maps and exercises are examples of cognitive tools. Scaffolding support devices focus on guiding learners' learning process by providing guidance on (a) what to consider when solving a problem, (b) on how to think about the problem under study, (c) how to utilize support devices and (d) how to approach the problem.

Compensating, Supplanting or Inducing Knowledge and Skills

Basically, the different kinds of support devices as classified by Hannafin et al. (1999) are directed towards (a) compensating or supplanting for domain specific knowledge and cognitive skills, or (b) inducing cognitive within learners by supplanting or compensating for metacognitive skills. *Compensating support devices* can be defined as devices that are focused on a learners' zone of proximal development as introduced by Vygotsky (1962), i.e., these devices aim at supporting learners in their knowledge and skills so that eventually they can perform the activity themselves. *Information support devices* (Hannafin et al., 1999) are focused on compensating for domain knowledge since they provide the content in a specific way (e.g., a text with information, glossary: Chapelle & Mizuno, 1989; Fischer, Troendle, & Mandl, 2003, Weblinks to other resources: Lust, Vandewaetere, Ceulemans, Elen, & Clarebout, 2011). These information tools provide this knowledge so that learners can continue their learning task.

Additionally, *scaffolding support devices* (Hannafin et al., 1999) are also focused on compensating for cognitive. For instance adjunct questions (Andre, 1979; Rowe, 1986) may provide guidance on what to consider within the learning task. They may support students in analyzing and structuring the specific domain. Reflection prompts, a planning and worked-out examples (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Horz, Winter, & Fries, 2009; Renkl, 2002) guide students in planning and orienting themselves within the learning task.

While these support devices can compensate for domain specific knowledge or cognitive skills, they can also supplant this knowledge and skills; either because the learner is not yet able to perform a certain skill or because it is not the focus of the learning task itself (Clark, 1990; Salomon, 1984). For instance, learners may know perfectly how to count, divide, multiply, but when working on a learning task a calculator is put to their disposal to supplant these skills. This allows the learners to concentrate on the key-activities of the learning task at hand.

Inducing support devices on the other hand are focused on inducing particular cognitive through metacognitive support. They are focused on activating the internal cognitive processes needed for effective learning (Gagné, 1985). In this way, these tools empower students to extend thinking and to process higher order conceptions, they support cognitive processing through metacognitive support, i.e., support in controlling once own cognitive processes. These kinds of support devices are labeled the *cognitive support devices* in the classification of Hannafin et al. (1999). While scaffolding support devices have the aim to support learners in their cognitive processing so that they can perform the activity themselves, this is not necessary the case for cognitive support devices that merely emphasize skills that are already acquired. Cognitive support devices induce particular processing strategies by providing means for manipulation, hypothesizing, experimenting, reflection, and interpretation. For instance a mind map (cognitive support device) induces comprehensive processing of the content whereas a concept map (scaffolding support device) illustrates a comprehensive overview of the content.

Influence of Learner Variables on Support Device Usage

In this part we briefly discuss research on different learner variables that are assumed to influence on learners' support device usage. In addition to a context-condition (the opportunity has to be functional) Perkins (1985) stressed also two learner related conditions in order for support devices to be beneficial. First of all, learners need to perceive the learning opportunities as provided by the support devices (Perkins, 1985). This condition relates to students' instructional knowledgeability which entails that the learner is aware of the device-functionality and that (s)he can use this device in relation to the learning task (Perkins, 1985). Consequently, this condition presupposes students' sufficient metacognitive knowledge (instructional conceptions) and skills (self-regulation). Second, learners need to be motivated since it influences the effort learners invest in using support devices (Perkins, 1985). Consequently, in the next part we focus on prior knowledge, metacognition, and motivation as learner variables.

Prior Knowledge

Research on the relation between prior knowledge and support device usage generally does report a relationship between prior knowledge and support device usage. However, research is not conclusive as the evidence points in different directions. A first group (Hoskins & van Hooff, 2005; Iiyoshi & Hannafin, 1998; Portier & van Buuren, 1995; Martens et al., 1997) stresses the positive impact of prior knowledge. High prior knowledge students more frequently used the support devices than low prior knowledge students. When looking at the quality of support device use, meaning using the support device at the right moment, a positive relationship was retrieved as well (Schnotz, Picard, & Hron, 1993; Wood & Wood, 1999). A second group of scholars, however, report a negative relationship between prior knowledge and the quality of support device usage (Elshout, Veenman, & Van Hall, 1993; Renkl, 2002). To complicate matters, Liu et al. (2009), and Jiang, Elen, & Clarebout (2009) found no relationship between prior knowledge and support device usage, while Viau and Larivée (1993) report a curvilinear relationship.

From the different studies it seems that he expected effects between prior knowledge and quantity of tool-use could mainly be revealed in ecological learning environments. A possible reason could be that in these learning environments, student differences in prior knowledge were more prominent. In contrast to experimental studies that confront learners often with learning tasks (and hence content) that is not related to their study and interest, which may have caused a state of demotivation in which prior knowledge was not really activated. Based on these studies, it cannot be concluded that there is an interaction with a specific kind of support device. In the study of Hoskins and Van Hoof (2005) an effect was found with the discussion board (cognitive tool); however, no effect was found with the practice quizzes (also cognitive tools). Nevertheless, it seems that students with high prior knowledge were attending to tools that supported (compensating or inducing) higher order cognitive and metacognitive skills (Hoskins & van Hooff, 2005). As a post hoc explanation one could refer to cognitive load theory to explain these findings. The additional learning aids focusing on higher order skills may have required too high cognitive demands for learners with low prior knowledge, so these students are unable to cope with the additional processing the scaffolds demand.

Metacognition

One of the conditions on effective support device usage is that a learner has to be instructional knowledgeable. This knowledgeability refers to students' instructional conceptions on the one hand, and their self-regulation skills on the other hand. Instructional conceptions are ideas, concepts and theories learners have about (components of) the learning environment (Lowyck et al., 2004). According to the cognitive mediation paradigm (Doyle, 1977; Winne, 1982), instructional interventions such as support devices will only be used adequately when students' conceptions regarding tool-functionality match the intended functionality as given by designers. Students need to know the relation between the support devices and their learning, and know how to handle the support devices to foster their learning (Elen, Lowyck, & Proost, 1996). Empirical evidence supports this argument. In multiple studies it was revealed that students' ideas on the tool's functionality influenced the way they used the available tools (Clarebout & Elen, 2008; Marek, Griggs, & Christopher, 1999; Sarfo & Elen, 2007; Winne, 1985, 2004). For instance in the study of Marek et al. (1999), students were less inclined to use adjunct aids when these support devices required an elaborated study pattern. In a more recent study of Huet, Escribe, Dupeyrat, and Sakdavong (2011) a positive relation was found between students' perceptions regarding help-seeking and their actual help-seeking behavior as revealed through usage of on-line support devices. Only when students perceived the benefits of seeking help for their learning, they were willing to use help. Contrary to this, the study of Clarebout and Elen (2008) revealed a negative relation between students' conceived functionality and their tool-use. Moreover, students who conceived the available tools as functional for their learning used the available tools less frequently.

Correctly conceiving the support device functionalities is not enough. Especially with non-embedded support devices, a learner needs to make the right decision on when to use a specific support device. Thus, the second aspect of instructional knowledgeability refers to students' self-regulation skills since learners with self-regulation skills are assumed to be more capable of monitoring and adjusting their learning process (Clark, 1990; Greene & Azevedo, 2007; Horz et al., 2009; Winne & Jamieson-Noel, 2002). A number of studies investigated self-regulation as the learner variable for which a support device compensates. These studies stress the importance of self-regulation skills when the use of support devices is at stake (Manlove, Lazonder, & de Jong, 2009; Narciss, Proske, & Koerndle, 2007; Winters, Greene, & Costich, 2008). However, the actual influence of self-regulation on the use of support devices has been studied to a lesser extent. One of the few studies that did investigate the influence of self-regulation on support usage—with the self-regulation scale of Vermunt (1992)—found no significant relationship (Clarebout & Elen, 2008, 2009).

Motivation

In addition to instructional knowledgeability, a learner has to be considerably motivated to spent effort and time in using the support devices (Perkins, 1985). In this respect, two motivational variables have been of interest: goal orientation and self-efficacy.

Aleven, Stahl, Schworm, Fischer, and Wallace (2003) indicated that one factor of major interest in the study of support device usage is goal orientation. This is based on previous research on help-seeking (e.g., Newman, 1998; Ryan, Pintrich, & Midgley, 2001), where it was found that learners' goal orientation seemed to influence their help seeking behavior. For instance, mastery goal orientation seems to increase the probability of requesting help, whereas performance goal orientation seems to be linked to asking for the right answer, rather than asking for support in finding the answer. Abreton (1998) found mastery goal oriented students to ask more often for hints (instrumental help) to solve a problem by themselves, whereas performance goal oriented students tend to ask for help simply to get the right answer (executive help). While in the help seeking literature, mainly requesting help from a human being was addressed, the study of Ryan and Pintrich (1997) revealed that mastery goal orientated students also were more inclined to use support devices. Depending on students' goal orientation students showed a different usage pattern. In line with the help seeking literature Clarebout and Elen (2009) hypothesized that mastery orientation would increase the use of support devices; but results revealed that learners with more mastery goal orientation used tools less. Huet et al. (2011), found a significant negative correlation between high levels of both performance approach and performance avoidance and quantity of tool use, more specifically frequency of tool use. Learners with high performance approach and avoidance accessed the tools less frequently. However, there were no observed effects of master approach orientation. In two other studies, Jiang and Elen (2011) observed that goal-orientation did not only influence the quantity of support devices usage, but also the quality. Following Elliot and McGregor (2001), an additional distinction was made in these studies between mastery/performance avoidance and approach,. It seemed that both mastery and performance avoidance had an influence on the time spent on support devices. Furthermore, avoidance goal was also negatively associated with the quality of the support device usage. Mastery and performance approach goals seemed not related to variation in tool use.

The second motivational variable that has been focused upon is self-efficacy. On the one hand, some studies (Liaw, Huang, & Chen, 2007; Tella, Tella, Ayeni, & Ogie, 2007; Waldman, 2003; Weiss, Schreure, Jermias-Cohen, & Josman, 2004) revealed a positive correlation between students' self-efficacy and the frequency of the use of various support devices (e.g., bulletin board, online discussion), suggesting that students with high self-efficacy will be more likely to use the support devices. On the other hand, such relation was not found in all studies. For instance, in Jiang and Elen's study (2011) the self-efficacy questionnaire measured both performance self-efficacy (i.e., expectancy for success) and learning self-efficacy (i.e., the judgments of one's ability to accomplish a task and confidence in one's skills to perform a task). Only learning efficacy was found to be an influential variable in terms of quality of support use (Jiang & Elen, 2011). No support was obtained to confirm the hypothesis that performance efficacy could be influential. One reason may be that efficacy expectations (learning efficacy) are more predictive of performance and choice (how to use supportive devices in this case) than are outcome expectations (performance efficacy).

Interaction of Type of Support Device and Learner Variables on Support Device Usage

In the previous parts we systematically addressed specific learner variables. However, when looking at a learner these different variables coexist and mutually influence one another. The question then becomes how these learner variables interact and how profiles can be formed of learners based on these variables. For instance, a study of Clarebout, Horz, Elen, and Schnotz (2010) revealed that when students have high prior knowledge and low self-regulation skills they will use the support devices in an equal way as students with low prior knowledge and high self-regulation skills. On the other hand when students have low prior knowledge and low self-regulation skills they use the support devices to a lesser extent. It seems that compensation mechanisms between the different variables might play a role.

In addition, whether or not support is embedded also influences higher self-regulated learners' tool use behavior. It was found that when using tool was obligated, high self-regulators used the support devices in significantly less depth than those who had choice (non-embedded).

Some evidence has been found that interaction effects occur between specific learner variables and different types of support. Chapelle and Mizuno (1989) for instance found that ability had an effect on support device usage, but only for the additional information resources (consultation of facts-tool) and not for cognitive tools. Additionally, when comparing the results for the influence of prior knowledge of different studies, the contradictory results might be related to the kind of support device under investigation. In the Renkl study (2002), low prior knowledge students demanded more frequently instructional explanations (cognitive tool), while Viau and Larrivée (1993) found a curvilinear relationship between prior knowledge and the use of an elaboration tool. The extent to which support is embedded (whether students were asked to use particular devices to accomplish specific learning activities) may also moderate the impact of prior knowledge on usage quantity. For instance, Jiang and Elen (2011) found that the variance in usage time that prior knowledge accounted for increased when the level of embedding decreased (students have more freedom to choose how they can use support devices).

Summary and Discussion

This chapter provided an overview of different learner variables influencing support device usage and the interaction with the kind of support devices. From this overview, it becomes clear that learner variables play a role and that support device usage is a complex issue. From an instructional design perspective, an important question is how to enhance students' adequate support usage. Providing advice on the use of support devices can have a positive effect on the usage. Students who received instructional cues or encouragement to use certain devices, used the available support devices more compared to students who did not receive these cues or encouragement (Carrier, Davidson, & Williams, 1985; Lee & Lehamn, 1993). However, such "meta" support can also be ignored by students (Carrier et al., 1985).

An interaction effect on the kind of advice and learners' instructional conceptions was found in a study of Clarebout and Elen (2008). Learners who conceived the support devices as functional show that providing advice also interacts with learners conceptions on these support devices. For learners who do not conceive support devices as being functional to their learning, advice on the use of these support devices with regular intervals seems advocated, while for learners who do conceive support devices as functional, adaptive advice on support devices seems more advocated. The latter means that they receive only advice when at a certain moment they do not use specific support devices, while this would be beneficial at that moment in their learning process. However, the effect of this advice was only found for the information support devices, not for the cognitive or the scaffold support devices. In line with Merrill's work (1983) one could say that advice was effective for primary presentation forms, but not for secondary ones. Advice seems to matter for those components that are at the core of the learning task, but not for those that mainly facilitate learners' processing of the information.

While providing advice would be one option, another option suggested by Gräsel, Fischer, and Mandl (2001) is training in the use of support devices. Their study revealed that students who received a strategy training made more adequate use of information support devices and scaffolds.

However, encouraging the use of support devices does only make sense when the support devices are functional for the learners, which seems not always evident (Clark & Estes, 2002). When looking at the first condition that Perkins (1985) mentions, he indicates that the support devices need to be functional for learners. When a designer would be 100 % certain that a support device is functional, one may wonder why the option should be left to the learner to decide on the use of this support device. Indeed, when obliging learners to use the support devices, one is certain they actually use it. As indicated, this does not provide a guarantee that the support devices will be used in an adequate way (Clarebout, Horz, Elen, & Schnotz, 2010; Greene & Land, 2000). Of course, one could argue that it is up to the instructional designer to design a support device that cannot but be used adequately. But given that one learning environment has to serve different learners this seems an impossible task. Hence, further investigating the effect of training and informing learners on considerate use of support devices seems a more feasible option, unless intelligent tutoring systems develop in such way that they can actually create an adaptive learning environment. Some promising results may come from the learning analytics research, where learner variables are induced based on data mining techniques rather than questionnaires (e.g., Fournier, Kop, & Sitlia, 2011).

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Section V
Domain-Specific Strategies and Models

M. David Merrill and Jan Elen

This fifth section of the *Handbook* is aimed at providing the educational technology research community with reviews of research on domain-specific instructional/learning strategies and models. This section has been added based on the very positive feedback to the chapter on domain-specific strategies in the 3rd edition of the *Handbook* (Spector, Merrill, van Merriënboer, & Driscoll, 2008). Because this section is entirely new, there is no duplication with previous editions, and the research findings and perspectives reported in these chapters are new. The domains covered in this section include science, healthcare, mathematics, engineering, social studies, visual arts, and literacy. There are of course other domains in which educational technology plays a major role (e.g., language learning), and we expect that additional domains will be covered in future editions of this *Handbook*.

The section begins with Ji Shen and colleagues reviewing research on technology-enhanced instruction in science education. Of particular focus is both qualitative and quantitative modeling and associated scaffolding strategies related to the cognitive, social, and curriculum aspects of learning science, particularly in K-12 settings. The need to promote systems thinking, model-based reasoning, and scientific exploration are discussed in the context of a number of research studies involving technology-based systems such as River City, Model-It, and Molecular Workbench. The authors note that in spite of such powerful learning environments there is still little evidence of effective integration in science education curricula—educational practice continues to lag far behind the technology and the research findings associated with these science education learning environments.

The chapter by Richard Clark on cognitive task analysis in healthcare tells a somewhat different story. Perhaps because healthcare involves life and death issues and the medical education community is generally well funded, the impact of educational technology in this domain is more pervasive. In any case, the focus is on how cognitive task analysis (CTA) has been adopted in healthcare education and has resulted in many positive and sustained outcomes. Medical trainees are highly motivated to develop expertise, and the CTA method discussed in detail in this chapter shows how expertise can be analyzed and used to effectively inform the instructional design process. The example elaborated in detail involves surgery. While educational technology has been wholeheartedly embraced by the medical community, the use of CTA has yet to achieve its full potential, according to Clark.

The chapter by Verschaffel and Greer on mathematics education reports considerable maturation of the field and its use of technology to support learning. The chapter opens with a declaration of independence that emphasizes that mathematical knowledge and its acquisition are domain specific and cannot benefit all that much from domain-independent theories of learning, cognition, or technology integration. While this bold statement appears defensible, it may be somewhat misleading. The CTA procedures discussed by Clark can and have been applied to mathematics education. Moreover, experienced instructional designers readily admit that the content and its mastery are paramount. While it is important to recognize the domain specificity of mathematics knowledge, the same claim can be made for knowledge in almost any field. The risk of overemphasizing domain specificity is the further fragmentation of educational technology and instructional design expertise, resulting in the creation of academic and practitioner silos that are self-limiting. Just as instructional design practitioners can benefit from design expertise in other domains such as architecture, mathematics education can certainly benefit from educational technology expertise developed in other domains. The discussion by Verschaffel and Greer on realistic mathematics education, design research, higher order reasoning, and other topics demonstrates an awareness of the value to be gained by looking outside the specific domain

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of mathematics to find appropriate methods and strategies to enhance the development of mathematical reasoning.

The chapter by de Graaf and Kolmos addresses the role of technology in promoting innovation and supporting research in engineering education. Most of the discussion is focused on engineering education research in Europe and North America, which provides a rich set of cases and research studies. The authors provide a research agenda for engineering education towards the end of this chapter that will be useful for the editors of the fifth edition of this *Handbook*. They also lament the fact that within the engineering academic community, the value of engineering education research is not generally as highly valued as research on specific engineering efforts. This is also true in other domains and remains a challenge for serious educational researchers working in any domain.

The chapter by Green, Ponder, and Donovan on educational technology in social studies education addresses the fact that twenty-first century skills include technology skills and are often an important aspect of social studies education. In a sense, then, this chapter is about research on the use of technology in a domain where those technologies are an important and featured aspect of the curriculum. As the authors note, the primary purpose of social studies is to help students develop into responsible citizens able to make informed and reasonable decisions. In an important sense, then, this notion of civic competence involves, among other things, developing twenty-first century skills. Because social studies as a discipline is relatively young, and because the knowledge and skills involved in becoming a responsible citizen change rapidly, research in this area is particularly interesting but often challenging, as the authors note. As in other domains, there is a movement away from teacher-centered approaches to more student-centered approaches.

The chapter by Lockee and Wang on visual arts education addresses the fact that images represent a long-standing aspect of being a person and play a central role in culture and society (dating back to petroglyphs and now evident in such forms as Facebook and YouTube). Given the centrality of images and visual representations, the importance of visual arts education should be obvious. Modern digital learning environments benefit significantly from the images and other media included almost as a necessity to support learning or as direct objects of learning. This chapter provides a short history of visual arts education and then treats in detail the influence of digital technologies in the visual arts. The twenty-first century skills discussed in the previous chapter on social studies education certainly include skills related to interpreting visual representations. This chapter goes further by discussing how to develop skills in creating visual representations for a variety of purposes, and what research on visual arts education, which is still in its infancy, has shown.

The final chapter in this section by Connor, Goldman, and Fishman addresses research on technologies that support students' literacy development from preschool settings through high school. There has been a great deal of research over the years in this area, and technology has come to play a central role in supporting the development of literacy (reading and writing skills). The authors include the role of technology in assessing literacy skills, which is a most welcome addition to the research in this area. Computer-based assessments are common in many domains, and the role of technology in supporting assessments and evaluation is appropriately treated by the authors. The authors also address the important role that technology plays in teacher professional development. Overall, the authors report highly encouraging outcomes, which perhaps should not be a surprise given the long-standing emphasis placed on literacy development in the form of training, research, and technology support.

We believe that this domain-specific research section of the *Handbook* will continue to expand and be an important part of future editions. Educational technology is obviously multidisciplinary (cutting across and being applied in many different domains), inherently interdisciplinary (requiring multiple disciplines for effective design, development, and deployment), and increasingly transdisciplinary (crossing and including multiple disciplines in a holistic manner—a kind of meta-discipline composed of and created within other disciplines) (Spector & Anderson, 2000; Spector, 2012).

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* An asterisk next to a reference entry throughout this Handbook indicates a reference that the author(s) considers to be central to the topic.

41 Technology-Enhanced, Modeling-Based Instruction (TMBI) in Science Education

Ji Shen, Jing Lei, Hsin-Yi Chang, and Bahadir Namdar

Abstract

In this chapter, we review recent research and development in technology-enhanced, modeling-based instruction (TMBI) in science education. We describe the cognitive, social, and curriculum-design aspects of science learning promoted in these environments. We emphasize the continuum of qualitative to quantitative modeling, the computational mind, and the system thinking that are critical for scientific modeling. We illustrate typical collaborative learning in TMBI science education settings. We highlight scaffolding strategies relevant to TMBI in science curricula.

Keywords

Model • Model-based reasoning • Computational modeling • System thinking

Introduction

Scientists develop conceptual, physical, representational, and computer models to explore the nature. These models may represent a particular aspect of a phenomenon, delineate the interacting components of a system, and quantify the relationships among relevant variables to help explain and predict an event (Clement, 2000; Gilbert, 1993). Scientific models may evolve over time, some were refined and others abandoned. They have become fundamental elements in scientific language.

Modeling-based instruction (MBI) is an innovative way for science teaching and learning that encourages students to use, create, share, and evaluate models to represent and explain scientific processes and phenomena. It has been studied and implemented in the last three decades and has demonstrated effectiveness in improving students' conceptual understanding, critical thinking, and inquiry skills in science (Hart, 2008; Hestenes, 1987; Khan, 2007; Lehrer & Schauble, 2006; Passmore & Stewart, 2002; Schwarz et al., 2009; Sell, Herbert, Stuessy, & Schielack, 2006; White, 1993; Windschitl, Thompson, & Braaten, 2008). Typically, a MBI approach has the following features: (1) MBI engages students to actively participate in learning as they build, test, and modify their own models (Hestenes, 1987; Penner, Gilles, Lehrer, & Schauble, 1997; Schwarz et al., 2009; White, 1993), resembling what scientists do in their fields as they constantly build and test scientific models (Gilbert, Pietrocola, Zylbersztajn, & Franco, 2000; Schwartz & Lederman, 2005; Tomasi, 1988; Zhang, Liu, & Krajcik, 2006); (2) MBI employs multiple ways of representations and alternative models including physical models, computerized visualizations, graphs, mathematical formula, and human role-play models that may

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reach a diversity of learners with different learning styles (Ardac & Akaygun, 2004; Kozma, Chin, Russell, & Marx, 2000; Mayer 2005; Shen & Confrey, 2007, 2010); (3) MBI facilitates a peer-learning community as students build models together, communicate their models to peers, and evaluate alternative models to help themselves better understand complex science topics (Gilbert & Boulter, 1998; Papert, 1991; Lehrer & Schauble, 2006; Tobin, 1993).

The fast development of information communication technology not only greatly expands the variety of media available for modeling opportunities for science learning, but also dramatically transforms traditional learning environments of MBI. Many technology-enhanced, modeling-based instruction (TMBI) environments have been developed for K-12 science instruction (Barab, Hay, Barnett, & Keating, 2000; Frederiksen, White, & Gutwill, 1999; Levy & Wilensky, 2008; Linn & Hsi, 2000; Perkins et al., 2006; Stratford, Krajcik, & Soloway, 1998; Wieman, Adams, & Perkins, 2008; Wu, 2010; Wu, Krajcik, & Soloway, 2001). These TMBI environments empower students to model a wide range of science phenomena, especially those often too small to see, too abstract to represent, too complex to comprehend, or too dangerous to explore in real life. These environments also build new forms of collaboration so that students can build models together within or across classes (Gobert & Pallant, 2004; Linn & Eylon, 2011). Furthermore, many of these environments are able to provide instant feedback and automated scaffoldings. This makes learning experience more student-centered, as students can manage their own learning pace and receive individualized instruction (Hannafin & Land, 1997).

In this chapter, we review the latest development of the technologies and pedagogies related to TMBI in science education. We use examples that have empirically proven to be effective in helping students learn science. We organize our chapter in four themes: promoting scientific exploration, facilitating model-based thinking, enhancing collaborative modeling, and designing scaffolded TMBI. The first three themes concern the kinds of learning TMBI promotes; the fourth theme focuses on design features utilized in TMBI curricula to support students' learning in science.

Promoting Scientific Exploration

To promote students' exploratory learning in science (Bransford, Brown, & Cocking, 2000; White, 1993), many computer models developed as science instructional materials have built-in features to allow students inquiry about the phenomena they are investigating. These features afford differentiated instruction and allow students' self-exploration that is a key characteristic of science practice (National Research Council, 2011).

One good example is the PhET Interactive Simulations developed at the University of Colorado, Boulder (http://phet.colorado.edu/). PhET simulations started with physics topics but now include other disciplines such as math, biology, chemistry, and earth science. PhET simulations are open-source, stand-along programs, typically written in Java or Flash. These simulations have been translated in many languages and used worldwide. They help students visualize and test scientific models and practice inquiry learning (e.g., Perkins et al., 2006; Wieman et al., 2008). These simulations can be used as different types of activities or assignments (Wieman, Adams, Loeblein, & Perkins, 2010).

Adams, Paulson, and Wieman (2009) investigated how students engage in interacting with the PhET simulations when provided with different levels of guidance. They conducted over 250 think-aloud interviews with more than 100 students. During the interviews, students were asked to think out-loud as they explored the computer models with four levels of guidance (no instruction, driving questions, gently guided, and strongly guided). They found that students' exploration of a simulation was highly dependent on the features of the simulation: If a simulation is too complicated, students may not be able to make sense of it; if a simulation is not fun, students may only engage for a very short period of time; only when a simulation is at a level that a student finds both intriguing and manageable, then the student sustains his/her exploration. For those well-designed simulations, it was found that students showed optimum engagement when they were provided with minimal guidance, partially because they were seeking answers to their own questions. On the contrary, when provided with cook-book guidance, students lost ownership of the inquiry and gained very limited understanding of the simulation.

Podolefsky, Perkins, and Adams (2010) observed and interviewed how college students interacted with PhET simulations with minimal explicit guidance, and documented two cases on how students worked with a particular simulation, *Wave Interference*. This simulation allows students to manipulate and observe interference of waves in three contexts: water, sound, and light (Fig. 41.1). Students may choose different tabs of contexts, different objects to show, different measurement tools to use, and different variables to manipulate. The study examined how students took advantages of the computer simulation to make progress towards developing a scientific model of wave interference. Given the flexibility of the PhET simulation, the students followed different exploration paths, similar to how scientists investigate natural phenomena. On the other hand, built-in features of the simulation and real-time feedbacks guided students' self-exploration and made their learning more successful. When interacting with the wave simulation, the students made connections between the real world and abstract representations and among multiple representations. These students also built analogical reasoning

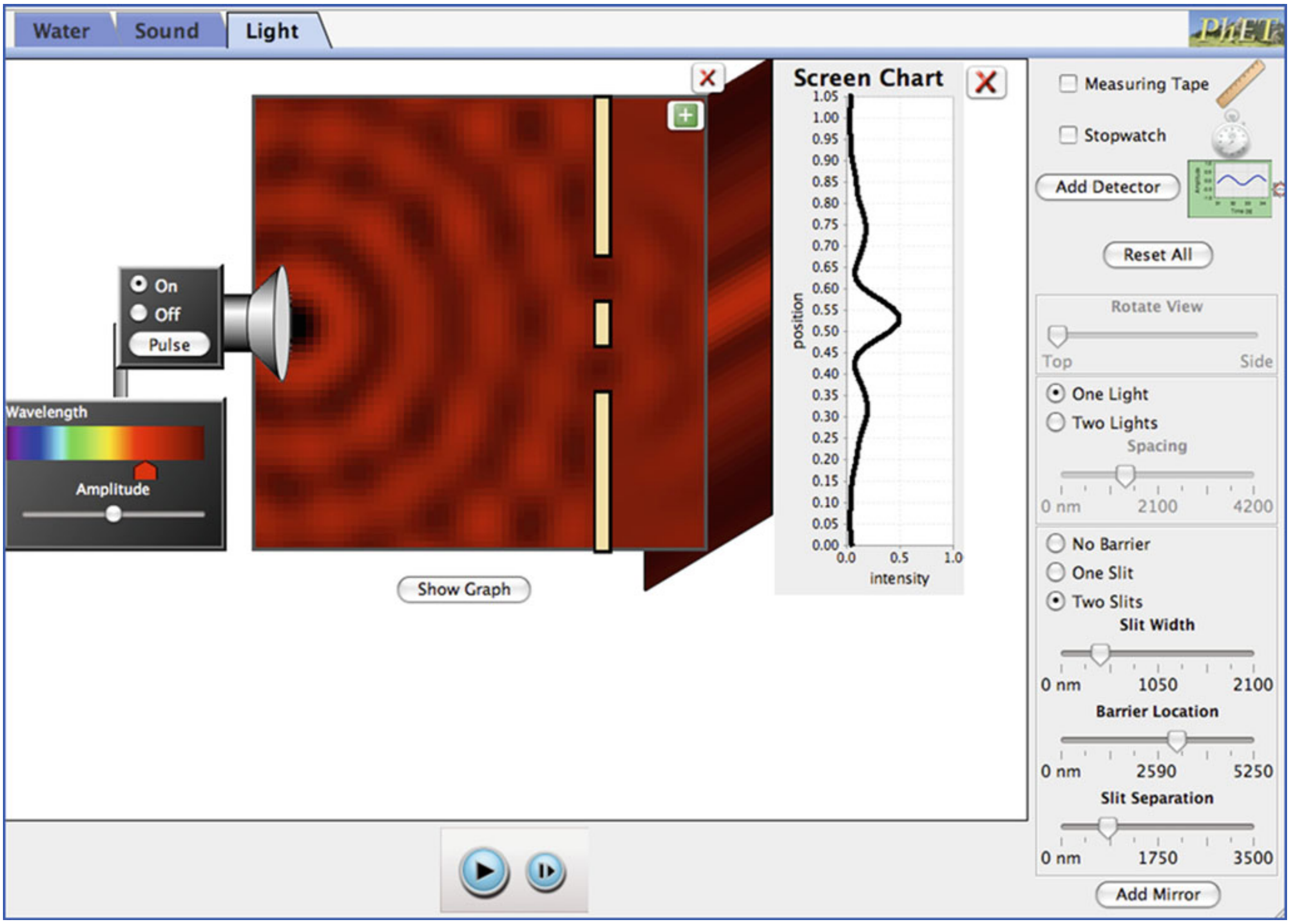

Fig. 41.1 A snapshot of the PhET wave interference model

among different contexts, critical in developing modeling competency (Lehrer & Schauble, 2006).

Another good example is River City, a multiuser virtual environment (MUVE) developed at Harvard Graduate School of Education (http://muve.gse.harvard.edu/muvees2003/) to enhance middle school students' motivation and inquiry learning in science (Nelson, Ketelhut, Clarke, Bowman, & Dede, 2005). It is a 17-h curriculum centered on inquiry as defined by the National Science Education Standards (National Research Council, 2000). In River City, students go through forming scientific hypotheses and conducting virtual experiments to test their hypotheses about what causes an outbreak illness of residents in a virtual town—a complex computer model of a human–nature system that involves the knowledge of ecology, health, biology, chemistry, and earth science. Typically with River City, students work in small groups of 2–4 and interact with each other's avatar, digital artifacts, tacit clues, and computer-based agents.

A number of studies have showed that River City curriculum increased student motivation (e.g., Ketelhut, Dede, Clarke, & Nelson, 2006), content knowledge (e.g., Ketelhut et al., 2006) and inquiry skills (e.g., Ketelhut, Nelson, Dede, & Clarke, 2006). Ketelhut (2007) investigated whether the scientific inquiry behaviors of students are developed while they are engaging in the inquiry-based project and how self-efficacy is related to students' scientific inquiry behaviors. The findings indicated that the students conducted scientific inquiry using River City, and that the total number of inquiry behaviors increased over time. Moreover, it was found that the high self-efficacy students engaged in more scientific inquiry behaviors than those with low self-efficacy. Ketelhut et al. (2006) implemented River City with approximately 2,000 students in 2004 and examined whether students engaged in inquiry learning in River City and what types of implementation of River City had more effects on student learning. Results indicated that the students using River City not only were engaged in scientific inquiry, but also showed a higher quality in inquiry than the control students. To assess inquiry learning in River City, Ketelhut and Dede (2006) developed an alternative method (Letter to the Mayor) and found that it was able to offer a better account of students' inquiry learning than traditional tests.

Facilitating Model-Based Thinking

TMBI environments may facilitate a habit of mind of model-based thinking. Model-based thinking overlaps with other critical thinking processes, but has its own unique characteristics. Here we highlight three interlinked aspects of model-based thinking.

Qualitative and Quantitative Modeling

Scholars have emphasized the importance of using qualitative thinking in modeling (Bredeweg & Forbus, 2003; Forbus, 1984). This approach focuses on conceptual aspects of science learning (Li, Law, & Lui, 2006), and stresses that qualitative understanding provides a solid ground for the development of quantitative reasoning (Bredeweg & Forbus, 2003). Hestenes, a pioneer of MBI in physics education, on the other hand, emphasizes the importance of mathematical models when speaking of modeling in physics (Hestenes, 1987). Mathematical models refer to mathematical representations including symbolic, graphic, and other forms of the real-world situations and quantitative thinking is a critical component of mathematical formalism. There have been many programs developed to facilitate students' qualitative or quantitative modeling, or both.

An exemplar qualitative TMBI is Model-It, developed by the Center for Highly Interactive Computing in Education (http://hi-ce.org) at the University of Michigan. Targeting middle and high school students, Model-It can be used to build and test qualitative models of scientific phenomena (e.g., Stratford et al., 1998; Zhang et al., 2006). Three modes (plan, build, and test mode) are built in the tool to scaffold users' qualitative thinking in modeling. In the planning mode, students create objects and define associated variables. In the building mode, students set the relationships between the variables verbally or graphically. In this process, students only use qualitative relationships (e.g., as variable *A* increases, variable *B* decreases). In the testing mode, students may change the values of the variables and see how the model works. Also, in this process, variables only change among a few hierarchical levels.

Many studies have supported that students are able to build quality models using the Model-It program. Stratford et al. (1998) found that students engaged in four types of activities using this modeling program: (a) analyzing (decomposing a system under study into parts), (b) relational reasoning (exploring how parts of a system are causally linked or correlated), (c) synthesizing (ensuring that the model represents the complete phenomenon), and (d) testing and debugging (testing the model, trying different possibilities, and identifying problems with its behavior and looking for solutions). Studying how content experts using Model-It, Zhang, Liu, and Krajcik (2006) found that experts started modeling with a clear focus expressed as an object and a factor, and then proceeded with a linear sequence including planning, building, and testing. Experts tend to spend a long time in planning, thinking through the whole factors and the relationships among factors before they represent their mental models in the program.

Similarly, many TMBI programs have been developed to enhance students' quantitative thinking in learning science (Liu, 2006; Simpson, Hoyles, & Noss, 2006; Stern, Barnea, & Shauli, 2008). For instance, Sins, Savelsbergh, van Joolingen, and van Hout Wolters (2009) describes a study investigating the relationship between students' epistemological understanding of models and modeling (i.e., nature of models, purposes of models, process of modeling, and evaluation of models) and their underlying cognitive processes (deep vs. surface). In the setting, 26 students worked in dyads on a computer-based modeling task on mechanics—modeling the movement of an ice skater. The students used Powerism® constructor Lite version, a free modeling tool based on system dynamics approach (similar to STELLA, a well-known commercial system dynamics modeling tool). The environment has five model building blocks: stocks, rates, auxiliaries, constants, and connectors. Specifically, a *Stock* represents a quantity that can increase or decrease (i.e., a variable) and a *rate* determines how quickly the quantity in stock will change. Qualitatively, students may add, delete, and move around the elements; quantitatively, they can manipulate the rates and numbers of these elements (e.g., assign a value for velocity of the ice skater) and adding formulas. A Powerism® model with assigned quantities and rates can be run automatically and computing results through generating corresponding differential equations. The computed results are displayed as graphs or tables. Overall, the study confirmed the positive correlation between students' epistemological understanding and their cognitive processes. It was found that most students actually employed surface cognitive processes. For instance, the most common surface process found in the study involved quantifying a model without referring to its background physics knowledge. Many students who had a lower epistemological understanding tended to focus only on the visual aspect of their models.

Note that there is no clear cut between the qualitative and quantitative modeling continuum and a high modeling competency requires both. Indeed many TMBI programs are able to nurture both processes in science learning (Komis, Ergazaki, & Zogza, 2007; White, 1993). Qualitative modeling can help students visualize the main modeling elements and see the core connections, and therefore building foundations for a more precise quantitative description; quantitative modeling engages students in manipulating variables and their connections quantitatively, and therefore leading towards mathematical formulation.

Computational Habit-of-Mind

As scientists nowadays rely heavily on computers to solve complex problems, computational thinking (Papert, 1996) becomes a critical skill students need to develop in math and science education. Wing (2006) defined computational thinking as the ways in which computer scientists think about world, solve problems, and design systems. She pointed out that equating computational thinking with computer programming was a narrow-minded interpretation. Instead, defining features of computer thinking include thinking at multiple levels of abstraction, being fundamental, human-based problem solving, complementing and combining mathematical and engineering thinking, and applying computational concepts to live everyday life (Wing, 2006).

In science learning, students may use a computer-modeling program to conduct computational experiments. Molecular Workbench (MW) software (http://mw.concord.org/modeler/), developed by the Concord Consortium, is such a tool (e.g., Pallant & Tinker, 2004; Xie & Tinker, 2006) (Fig. 41.2). MW is a java-based modeling environment that provides visual, interactive computational experiments and models for teaching and learning science (Xie, 2010). MW focuses on the molecular and atomic interactions that span a range of topics in physics, chemistry, and biology. Its computational algorithm relies on molecular dynamics and quantum dynamics simulation methods (Xie et al., 2011). Students can create their own models to simulate and experiment with molecules and predict real world events. A pilot study shows that general and physical chemistry students are able to create novel computational experiments to explore deeply chemistry phenomena and principles including ionic bonding, purification, and fuel cells (Xie et al., 2011).

Computational modeling can be taught to young students. For instance, Papaevripidou, Constantinou, and Zacharia (2007) investigated how fifth graders built computer models to study marine ecology. They used an object-based modeling tool, Stagecast Creator (SC), in which students set rules to control certain behaviors of characters through graphical programming tools (e.g., dragging the character to a new position) without using syntactic programmable language. Students are also able to define variables to create a rule for determining or controlling an action. For instance, student can assign a number for her/his character's energy consumption with its one unit movement. The study showed that after the unit, students enhanced their modeling skills by using SC. For instance, they shifted their focus from creating descriptive representation of the phenomena to creating more complex models that showed processes, interactions, and relationships among the component of the phenomenon. Also, the students who had the computational modeling experience provided more comprehensive description of casual interactions from a given model, specified criteria to the appreciation of the models, and used iterative and continuous procedure of model revision and refinement.

System Thinking

As scientists are building models to simulate and interpret more and more complex systems in nature and the society (e.g., a particular ecosystem, a corporation management system), students need to develop system thinking in understanding the complexity of science phenomena (Kauffman, 1995; Wilensky & Resnick, 1999; Zhang et al., 2006). Characteristics of system thinking may include perceiving a system as being consisted of many elements that interact with each other, understanding a change of one element in a system may result in changes of other elements and even the whole system, and embracing that the relatively simple behavior of individual elements may be aggregated through some mechanism (e.g., statistical methods) to explain the complex system at the collective level.

Many TMBI environments can help students develop system thinking (Bravo, van Joolingen, & de Jong, 2009; Wilensky & Reisman, 2006; Wu, 2010). Note that system thinking is a more encompassing term that includes system dynamics modeling, as some of the aforementioned programs illustrate (e.g., Model-It, Stella, Powerism®). Another good example of TMBI promoting system thinking is the NetLogo, an agent-based modeling tool that simulates complex and decentralized systems (e.g., Wilensky & Rand, 2009) (Fig. 41.3). In NetLogo, individual entities can be programmed to operate independently, but follow the same set of rules (e.g., to represent a flock of birds in NetLogo, each "agent" representing a bird follows a set of independent rules). These rules include descriptions on how the agents interact with each other (e.g., when two "birds" come close to a certain distance apart, they move away from each other to avoid clash). Thus, NetLog is able to show not only systems perceived at different levels (e.g., micro- and macro-), but also how these different levels relate to each other (e.g., interactions of individual agents lead to emerging collective behavior).

Levy and Wilensky (2009a, 2009b) described a curriculum using NetLogo on gas laws and kinetic molecular theory in chemistry—the Connected Chemistry Curriculum (chapter one, henceforth, CC1). The curriculum aims to help students make connections among four levels of access to a system (submicroscopic, symbolic, experiential, and macroscopic) in order to gain knowledge in three spheres (conceptual, mathematical, and physical). In this modeling environment, students begin from a submicroscopic level and explore the movement of a single particle, and then move towards forming a system view of the chemical world. The studies found that after the CC1, students gained a deeper understanding of particulate nature of gas laws and the kinetic

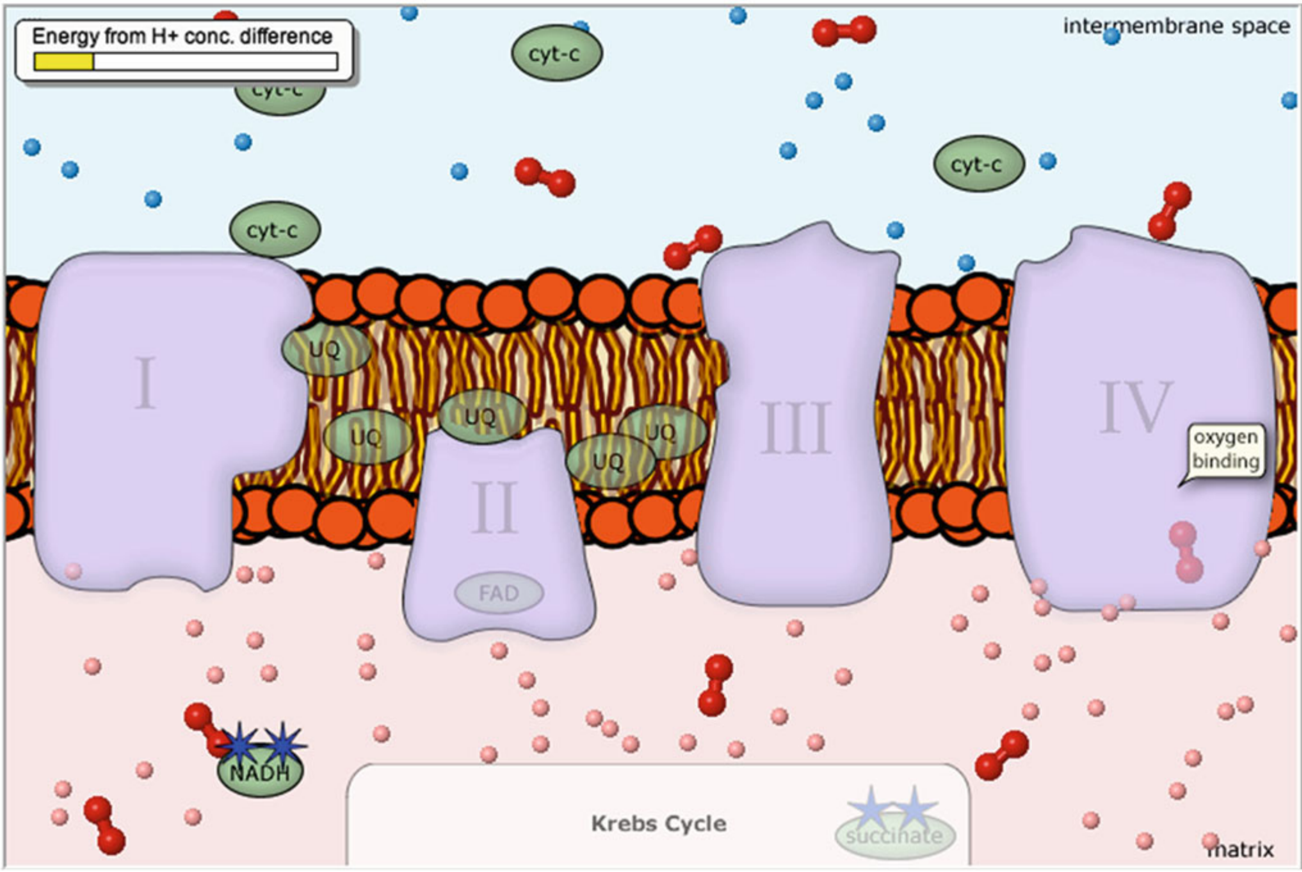

Fig. 41.2 A snapshot of the Molecular Workbench model on the electron transport chain

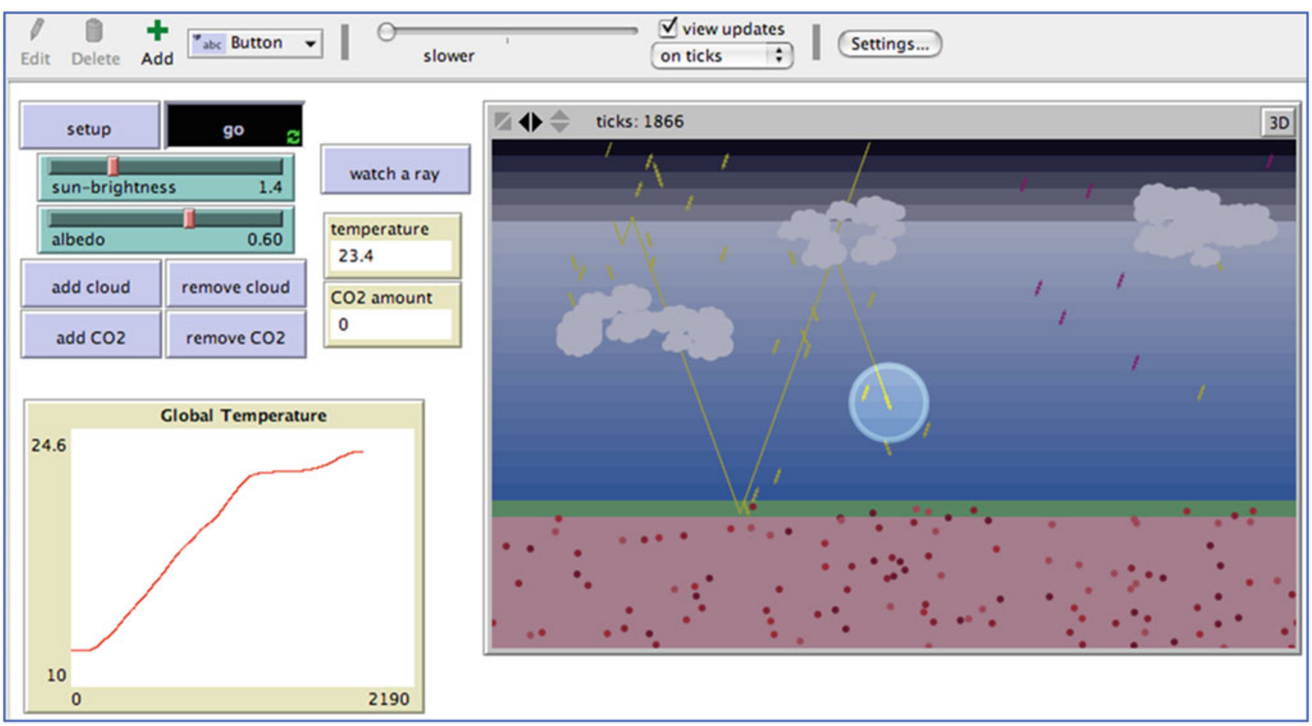

Fig. 41.3 A snapshot of a NetLogo model on global warming

molecular theory and a higher ability in connecting the submicroscopic level and the macroscopic world. It was found that the students had a greater success when the assessment was embedded in the process of modeling rather than in the post-test questionnaire. It was also found that students' epistemic understanding of the nature of models was enhanced (e.g., multiple models can be used to represent the same phenomenon; a model is not a replica of the referent).

As we discussed above, students develop qualitative and quantitative modeling skills, computational habit-of-mind, and system thinking while using TMBI programs. An important note is that although we used different TMBI programs to highlight different aspects, many of these programs can facilitate a set of these thinking skills as they are all intertwined with each other.

Enhancing Collaborative Learning

Collaboration is critical in MBI because scientific knowledge as a collective is socially constructed and students need to engage in social interaction to develop and revise their own understanding of science phenomena (Komis et al., 2007; Penner, 2001).

Students often work in a mixture of collaborative forms in a TMBI environment to share resources or strengthen modeling practices (Barab et al., 2000). For instance, Birchfield and Megowan-Romanowicz (2009) described the SMALLLab, a mixed-reality environment on geologic evolution for high school students. The students worked with each other face-to-face through interacting with the environment and some specially developed handheld devices (e.g., glow ball). The class was then divided into different groups, each group in charge of different roles. The modeling activity involved co-building "layer cake" of earth crust. It was found that the interaction between students in the experimental group increased 33 % compared to a control group. Also, the students who received the intervention outperformed on earth science content tests than their counterparts in the control group. One important message was that more of the gains came from the open-ended explanation tests than the multiple-choice test.

Ioannidou et al. (2010) described a modeling technology, Mr. Vetro, that they implemented with high school students on the topic of human physiology. Students collaborated in small groups and whole class. Each group controlled a wireless connected computer simulation (e.g., one group is in charge of the heart), and the data collected from each group fed into a central composite simulation (in this case, it is a blood-centric representation of the body). The groups needed to coordinate with each other to maintain a healthy state of a human body. In this activity, students visualized human organs through computer models, manipulated physiological variables that affect the complex system of a human body, and coordinated with each other to maintain a satisfactory outcome of the system. The research showed that Mr. Vetro class was more inquiry-based than the comparison class based on class observation and teacher interviews; In terms of student learning in content, Mr. Vetro classes outperformed the comparison classes. Specifically, Mr. Vetro classes did much better than the comparison classes for definition and open-response items. Results also showed a positive impact on students' attitudes toward biology and personal relevance.

As the information communication technology allows long distance collaboration, many TMBI environments have incorporated collaboration schemes beyond classroom constraints. Gobert and Pallant (2004) described a science unit on plate tectonics using the WISE platform (Linn, Lee, Tinker, Husic, & Chiu, 2006). In this unit, students may see, manipulate, construct, and evaluate computer models of plate-tectonic related phenomena (e.g., earth quake, volcano). In the unit implementation, the unit facilitated face-to-face collaboration within pairs of students in the same class and between classes from the two coasts in the USA. The groups of students from different coasts critiqued and evaluated each others' models using the online discussion feature in WISE. Therefore, the collaborative experiences were built into an authentic modeling process for the students. It was found that students' understanding of the nature of models deepened after the unit and those that with a more sophisticated understanding of the nature of models had greater content learning gains.

Simpson et al. (2006) developed a computer programming and video gaming tool, ToonTalk, to help students learn kinematics. Students worked in small groups and dyads to construct video games, write programs, and model motions with graphs. Students also worked in a project to share, communicate, and collaborate with peers from a different country through a Web-based collaboration system where students can post statements and make comments. They found that the students improved their understanding of motion after the unit. Their learning was enhanced by the collaboration opportunity in that the students were engaged in sharing models and challenging peers cross-site, which led to more animated face-to-face discussion among local participants.

Collaborative TMBI also faces many challenges. First, the role of collaboration in a TMBI environment in terms of individual student learning outcome is contested: e.g., students may see collaboration as an opportunity to reduce workload (Barab et al., 2000); students get less opportunity to manipulate the technology (Metcalf & Tinker, 2004). Even though collaboration is an important aspect in MBI, collaboration itself rarely enters the equation of outcome measurement. Also, focusing solely on procedure (e.g., problem-solving) may discourage group members' attention to content, thus sidetracking students from the main learning task (Krange & Ludvigsen, 2008). Research suggests that students actually spend more time on some particular modeling processes such as linking model elements that requires more peer support (Komis, Ergazaki, & Zogza, 2007). Many TMBI environments afford manipulation of multiple variables, which require students to collaborate with each other to make sense of the interconnection among these variables (Komis et al., 2007; Manlove, Lazonder, & de Jong, 2009). More research is needed to examine carefully how collaboration occurs during the modeling processes and how it can be facilitated by computer technology.

Designing Scaffolded TMBI

Students need cognitive and procedural supports in order to carry out scientific inquiry in learning environments that have interactive, dynamic computer models (Linn, 2006; Quintana, Zhang, & Krajcik 2005). These support, or scaffold, may help learners focus on the key aspects of a model, distribute the cognitive load, provide relevant resources and background information, assess student learning in-situ and provide instant feedbacks (Adams et al., 2009; Collins, Brown, & Newman, 1990; Jonassen & Reeves, 1996; Linn, Davis, & Eylon, 2004). Scaffolds may also function as a way to help students problematize the subject matter they are learning (Reiser, 2004). For example, a study engaging students in evaluating peer-generated dynamic models of chemical reactions at the molecular level significantly enhanced student understanding of the subject. Detailed scripts and prompting questions were provided as scaffolds (Chang, Quintana, & Krajcik, 2010). Without such scaffolds students may evaluate their peer's work superficially without providing substantive criticism. While acknowledging the important role of teachers for the success of student learning, we here focus our discussion on the *explicit* scaffolds that a learning system may provide (for implicit scaffolds, see, e.g., Podolefsky et al., 2010).

Scaffolds embedded in a learning environment need to be well aligned with the learning theory upon which the environment is built, and need empirical evidence to demonstrate their effectiveness. One successful example is the Web-based Inquiry Science Environment (WISE) system that has built on years of research and development (Linn, Clark, & Slotta, 2003; Linn & Eylon, 2011; Linn & Hsi, 2000; Slotta & Linn, 2009). WISE is a powerful, open-source online learning environment that supports guided inquiry, embedded assessments, peer collaboration, interactive computer models, and teacher customization. The latest version, WISE 4.0, has been developed since 2008 and incorporates new features such as Energy Stories, MySystem, IdeaManager to diagnose and support students' integrative understanding of important science concepts.

WISE projects are designed to help students learn core science concepts and achieve knowledge integration (KI) (Linn, 2006). These standards-based curricula are developed through teams of content experts, school teachers, educational researchers, and computer scientists with iterations of refinement and revisions. WISE curricula are equipped with research-based scaffolds that help students' knowledge integration processes including eliciting ideas, adding new ideas, distinguishing similar ideas, and sorting out ideas (Linn, 2006). Here we elaborate on a few important scaffolding strategies related to scientific modeling.

Research indicates that students may have difficulties to attend properly to the complex information of a scientific model (Lowe, 2004). They may not have shared experience, competency or knowledge as the producer of the scientific model to successfully perceive information represented in the model (Kress & van Leeuwen, 1996). Therefore, it is important to design scaffolds in TMBI environments that provide hints or help focus students' attention on key aspects of a model. For example, a WISE unit "*Thermodynamics: Probing Your Surroundings*" (Clark, 2006; Clark & Sampson, 2007, 2008) incorporates a particulate model that shows how heat transfers between two objects at the particulate level (Xie & Tinker, 2006), accompanied with a temperature graph that shows how the temperature of the objects changes as time goes by (Fig. 41.4a). To guide students' learning with the model and graph, prompting questions embedded in the unit ask students to predict, observe, and explain the results from the model (Fig. 41.4b). The prompting questions asking students to predict how the speeds of the particles change by temperature give students a heads-up before their observation that they need to pay attention to the motion of the particles in the model. After students observe the dynamic molecular model, prompting questions require students to explain the results from the model. The prompting questions are content specific. For example, one question asks "what happened to the molecules of the objects when a hot object was placed on top of a cold object." They provide check points for students to reflect on whether they have paid attention to and comprehended the key aspects of the model. A study examining students' responses to the prompts indicates that students developed integrated understanding of heat transfer at the particulate level after learning with the model and embedded scaffolds (Chang & Linn, in press).

Students also need explicit scaffolds to help them productively engage in scientific modeling practices (McElhaney & Linn, 2011; Schwarz & White, 2005). For example, the molecular model in the WISE *Thermodynamics* unit was revised to include features that allow students to conduct experiments using the model. Students can change the temperature of the two objects, the material of the objects, and the time the objects put in touch with each other. However,

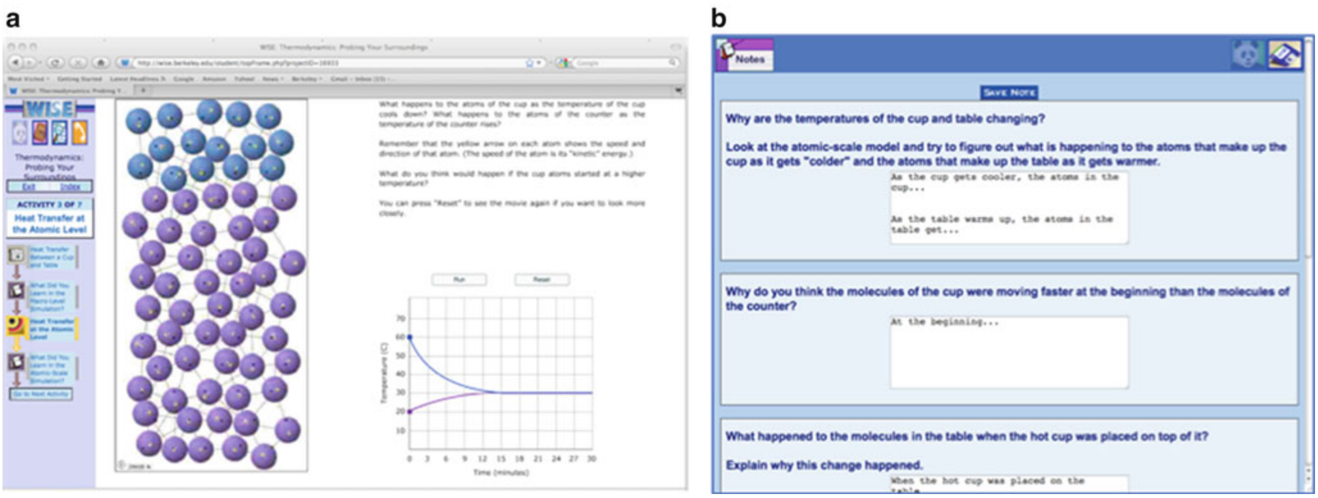

Fig. 41.4 Snapshots of the *Thermodynamics* unit: (**a**) the dynamic molecular model showing heat transfer between two objects; (**b**) embedded prompts guiding students learning from the model

students may conduct experiments using computer models purposelessly or mindlessly (McElhaney & Linn, 2011; Parnafes, 2007). To help students develop criteria about how to conduct scientific experiments using the thermodynamics model, a critique activity was designed to engage students in critiquing a fictitious student's experiment with the model (Chang & Linn, in press). Prompting questions are used to guide students to critique the purposefulness and methodology of the fictitious student's model experiment. The incorporation of the critique activity builds on a perspective on scaffolds that students need support not only structuring but also problematizing or contextualize the learning task (Reiser, 2004; Shen, 2010). The implementation results supported that the students who used the critique activity designed better experiments and developed more integrated understanding of the scientific model than those who did not engage in a critique activity (Chang & Linn, in press).

Scaffolds may also be designed to help students construct abstract explanatory models based on intuitive models and prior experience. Shen and Linn (2011) described a WISE unit for high school students to develop a scientific explanatory model of electrostatics. They carefully delineated cases on how students' explanatory models of induction evolve over time. They employed key KI design principles such as making thinking visible and making science accessible to help students retrieve their prior knowledge, make sense of the computer models, and link these models with hands-on experience. The built-in scaffolds in the unit proceed from basic charge-based explanatory model, to particle-based model, then to energy-oriented model. The results showed that after the unit, students were able to integrate different levels of models and offer better explanation of everyday experience and observation related to electrostatics.

Conclusion

In this chapter, we reviewed a number of high quality programs and studies focusing on providing computer-based environments for students to learn science through modeling. These TMBI environments, given appropriate scaffolding, have demonstrated effectiveness in enhancing students' modeling-based thinking including qualitative and quantitative modeling, computational thinking, system perspectives, and help diversify and strengthen students' collaborative learning in science.

Despite the rapid development, technologies are still poorly integrated into science education curricula (Songer, 2007). There are many challenges as how to best utilize these programs and implement in different school contexts. Scaling-up research-proven TMBI programs is both a meaningful and urgent next step.

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42 Cognitive Task Analysis for Expert-Based Instruction in Healthcare

Richard Clark

Abstract

This chapter presents an overview of the rationale and evidence for the use of cognitive task analysis (CTA) in healthcare including the following: It presents a brief history and definition of CTA, the reason it is being adopted for healthcare education, evidence for its learning benefits when used in evidence-based instructional design and medical simulators, an example of how one of the evidence-based CTA methods was implemented in healthcare, and suggestions for future research. The point is made that when evidence-based CTA methods are used, learning from CTA-based healthcare instruction increases an average of 45 % when compared with current task analysis methods.

Keywords

Cognitive task analysis • Instructional design • Training • Expertise • Decision making • Front-end analysis • Simulation

Introduction

Cognitive task analysis (CTA) is a term that describes approximately 100 different strategies developed in many different nations for identifying, analyzing, and structuring the knowledge and skills experts apply when they perform complex tasks (Schraagen, Chipman, & Shalin, 2000; Yates & Feldon, 2008; 2011). CTA is "cognitive" in the sense that it attempts to identify the mental processes and decisions that experts use to achieve a goal and/or solve a complex problem. CTA focuses on "tasks" that people are required to perform. And CTA is an "analysis" system in that it permits the description, categorizing, and organizing of the cognitive processes and decisions that are captured (Clark & Estes, 1996). This review is further limited to CTA strategies that are evidence based, peer reviewed, designed to support instruction or simulators, and intended to be applied to healthcare education.

A Brief History of CTA

The systematic analysis of tasks has been a common feature of instructional planning for many decades. CTA has its origin in the ergonomics movement started in the late 1800s and the development of behavioral task analysis of manual labor jobs in the early twentieth century in the United States by the scientific management researchers Frank and Lillian Gilbreth (Gilbreth & Gilbreth, 1919), the couple who were the subject of the book and movie "Cheaper by the Dozen." These early task analysis methods resulted in significant increases in technology, training, and performance including the development of the QWERTY keyboard, a 300 % increase in bricklaying, and increases in emergency room efficiency and effectiveness.[1] Yet in the 1970s, as cognitive psychology

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[1] For a more detailed history of CTA, consult Hoffman and Militello (2009).

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developed, it became obvious that more was necessary. Behavioral task analysis was not able to capture work in the form of the critical and complex mental decisions and analytical strategies because they could not be directly observed. CTA was developed to add cognitive elements of work to the analysis of all expertise.

After the publication of Schneider and Shiffrin's (1977) analysis of automatic and controlled cognitive processing it became obvious that an additional barrier to capturing expertise is that it is largely automated and nonconscious. Experts are largely unaware of how they decide and analyze problems in their specialty area (see for example the review by Clark & Elen, 2006). Thus CTA was needed to help identify more of the specific, operational elements of expert's cognitive processes. It also gradually became clear that while experts who teach provide nearly all healthcare instruction, they may be unaware of a majority of the critical decisions and analysis strategies their students need.

Expertise

Expertise, by its nature, is acquired as a result of continuous and deliberate practice in solving problems in a domain (Ericsson, 2004). As new knowledge is acquired and practiced, it gradually becomes automated and nonconscious. For example, once we learn how to drive, we can do so without thinking much about the action decisions we make to navigate even difficult traffic and instead are able to talk to fellow passengers or listen to the radio. Many popular accounts of the social and cognitive utility of automated expertise have been published in the past decade (see for example Ericsson, 2004; Ericsson & Charness, 1994; Gladwell, 2005; Wegner, 2002). Automated knowledge helps overcome limits on the amount of conscious information we can hold in "working memory" and free our minds to handle novel problems. Yet it also causes experts to be unable to completely and accurately recall the decision knowledge and analytical skills that are an essential component of their expertise—even though they can solve complex problems using the knowledge they can't describe.

Experts don't know what they don't know. Automated expertise causes significant though unintended omissions when experts attempt to communicate their skills to others. Prior attempts to use standard interview or self-report protocols to extract the decision-making and problem-solving strategies of surgical experts for use in educational settings have been problematical. Cognitive studies suggest that the resulting information often contains significant errors and omissions (Clark & Estes, 1996; Clark, Feldon, van Merrienboer, Yates, & Early, 2008; Clark, Yates, Early, & Moulton, 2010). Glaser et al. (1985), Besnard (2000), and Feldon (2004) provide evidence that when experts teach, they leave out or distort approximately 70 % of the information needed by students to learn and apply healthcare techniques. Healthcare professionals who teach do not often recognize these errors even though they wish to give accurate information to students, presumably because the knowledge they are describing is largely automated and nonconscious (Wheatley & Wegner, 2001). The problem is further complicated by the fact that experienced healthcare professionals mistakenly believe that their reports are complete and accurate and that they solved the problems they are describing in a conscious, willful, deliberate manner (Wegner, 2002). These reporting errors most likely increase in number and severity under time–pressure and anxiety-producing situations (Hunt & Joslyn, 2000) such as those experienced when healthcare professionals teach and monitor students while they practice surgery in teaching hospitals.

During the past 25 years, advances in cognitive science and human performance research have resulted in the development of CTA as a group of knowledge analysis methods that capture the nonconscious knowledge experts use to solve complex problems and perform demanding tasks. By capturing the decisions and other analytical processes experts use in problem solving, instruction can be developed that more completely replicates expert performance. Students who receive more complete information are able to learn more quickly and perform with fewer "trial and error" learning that may put patients at risk (Clark et al., 2010). The evidence for the benefits of CTA is obvious in two recent meta-analyses.

Meta-analysis of CTA studies. Meta-analytic reviews of research on instructional studies where CTA is used as part of the design of instruction provide strong evidence for its benefits. Lee (2004) analyzed 38 comparison studies and reported an overall average post-training learning and performance gain of about 46 % (Cohen's $d=1.72$) for CTA training when compared to more traditional training design using expert-based task analysis. In a more recent and more conservative meta-analysis, Tofel-Grehl & Feldon (2013) analyzed 57 comparison studies and reported an overall learning gain of 31 % (Hedges $g=0.88$) from all studies. She also reported different effect sizes for different CTA methods ranging from a low of 13 % gain ($g=0.33$) for the popular Critical Decision Method (Klein, Calderwood, & Macgregor, 1989) to a high of 45 % gain (Hedges $g=1.598$) for CTA methods based on the Precursor, Action, and Interpretation (PARI)-type methods (Clark, 2006; Hall, Gott, & Pokorny, 1995). This most recent meta-analysis makes it clear that some CTA methods are much more effective when applied to instruction. Clark and Estes (1996) describe some of the more prominent CTA methods in greater depth.

In addition to learning benefits, it has been assumed that CTA-based professional study curriculums in universities would benefit graduates by making them much more attractive to employers.

Employer satisfaction with healthcare graduates. Another source of concern that has contributed to interest in CTA derives from evidence from healthcare employer surveys. In one survey, over 68 % of healthcare employers in areas where occupational certification and licensure are required expect that job applicants will lack essential occupational skills (Workforce Connections, 2011). This is higher than the average expectation of less than 53 % for all occupations. In nursing for example, the inability to handle the intense working environment, advanced medical technology, and patient needs result in new graduate nurse turnover rates of about 35 % in rural areas to 60 % in urban areas during the first year of employment. This results in a loss of approximately $40,000 for employer hiring and orientation expenses for each replacement (Halfer & Graf, 2008). It also contributes to the huge expense of on-the-job training for newly hired healthcare professionals, estimated at 68 % of the training and education budget in healthcare. Discussions about the cause of this situation in nursing and other healthcare professions focus on the failure of university and specialist training organizations to capture the current context, challenges, and expertise required for students to perform adequately after being trained. It is possible that CTA-based professional study programs would help close some of these gaps between the demands placed on new healthcare employees and the adequacy of the training they have received. Studies in a variety of healthcare areas and tasks seem to validate the potential learning and transfer benefits of CTA-based instruction.

Evidence from Applications of CTA to Healthcare Training

A number of studies conducted in the past two decades have provided enticing views of the possible benefits of CTA to various healthcare areas such as the training of nurses and surgeons, the functioning of medical teams, the design of medical simulators, and other technology-based supports for healthcare professionals. Selected and briefly described examples of these studies are presented next.

Nursing. Crandall and Gretchell-Leiter (1993) described a study where a CTA of expert neonatal nurses exposed a strategy for diagnosing life-threatening infections in premature infants that was significantly more effective than the textbook method taught in universities. Registered nurses who averaged 13 years of overall experience and 8 years specializing in neonatal infants were asked to describe critical incidents in which the nurses believed that they had significantly impacted an infant's medical outcome. Nurses were asked to be specific about their assessment strategies, diagnostic cues, and the clinical decisions they made. The CTA analysts utilized semi-structured knowledge elicitation probes developed by CTA pioneer Gary Kline and colleagues (Klein et al., 1989) to identify additional relevant information that was not described during free recall. Analysis of the CTA interviews revealed that the structured questions elicited significantly more indicators of medical distress in infants suffering from sepsis. The nurses' CTA explanations of the cues they used were either not mentioned or described only vaguely during free recall. Comparison of the CTA-elicited cues to those described in the medical and nursing literature provided strong evidence that the nurses' statements were not derived from their textbook knowledge. More than one-third of the individual cues (25 out of 70) used to correctly diagnose infant infections were not listed in any of the existing medical research or training literature. These cues comprised seven previously ignored categories that were subsequently incorporated into textbooks and training for nurses entering neonatal intensive care (Crandall & Gamblian, 1991).

Physicians. Velmahos et al. (2004) studied the expertise of emergency medicine specialists. In a controlled study using the Concepts, Processes, Procedures (CPP) CTA method (Clark, 2006), half of a randomly assigned group of 24 medical students were taught a routine emergency procedure in a traditional modeling and practice strategy by expert emergency physicians. These students' post-training performance was compared with the other half of the medical students who were trained with information gathered from a CTA conducted with the same emergency medicine experts who taught the control group. It was clear from the analysis that the information provided to the traditionally taught students by the experts contained significant omissions and errors, and primarily focused on essential decisions and problem-solving strategies that were never discussed or were incorrectly described by the experts.

After training, whenever the medical students performed the routines with patients in the following year, they were observed and evaluated by judges who were unfamiliar with their experimental status. The experimental group who received training based on CTA outperformed the expert-taught control group on all analytical (diagnostic) and many performance items by over 50 % during the year following training. Velmahos (personal communication) also reported that the traditionally trained doctors caused four serious medical emergencies applying the medical protocol with patients (about average for new physicians) and those with CTA training made no life-threatening mistakes.

Dental Hygienists. Mislevy, Breyer, Almond, and Johnson (1998) applied CTA to capture the assessment, treatment planning, and progress monitoring expertise of dental hygienists in order to develop a licensure test as well as a coached practice computer system where achievement testing could be performed. The resulting computer-based system for assessment and simulation of dental hygiene skills and behaviors has been successfully tested and is in use.

Surgery Residents. Campbell et al. (2011) applied CPP CTA to study the relative effectiveness of CTA-based instruction on performance of an open cricothyrotomy (OC) when compared with instruction provided by the same experts who participated in CTA interviews. In this study 26 second- and third-year surgery residents were separated into two groups. All participants completed a pretest on OC knowledge and their self-efficacy related to the procedure. One group received CTA-based instruction and experts taught the control group. The CTA group significantly outperformed the control group based on a 19-point checklist score (CTA mean score: 17.75, SD = 2.34, control mean score: 15.14, SD = 2.48, $p = 0.006$). The CTA group also reported significantly higher self-efficacy scores based on a 140-point Bandura self-efficacy scale (CTA mean score: 126.10, SD = 16.90, control: 110.67, SD = 16.8, $p = 0.029$). This study provides evidence that CTA-based instruction can not only increase learning but also increase students' confidence that they can perform complex CTA-based procedures.

The learning, self-efficacy, error reduction, and assessment benefits of CTA have been established in a number of healthcare areas. Replicating these studies and extending CTA benefits to additional areas require careful consideration of the way that analysts and experts are selected and the choice of the specific CTA protocol that is used. The discussion turns next to what has been learned about the selection of analysts and experts who participate in CTA interviews.

Selecting Analysts and Experts for Healthcare Cognitive Task Analysis

A trained CTA analyst who is not an expert in the healthcare specialization being studied most often performs CTA. Most CTA researchers have informally observed problems when subject matter experts (SMEs) become CTA analysts and interview other experts. CTA analysts who are also SMEs most often edit what they are told by other experts in CTA interviews so that the information they collect is consistent with their own experience and expectations. CTA analysts should have a general knowledge base to assist them in understanding what they observe and hear but most analysts have found that they should not have performed and/or taught the healthcare tasks they are attempting to identify. This clinical observation, widely accepted in the CTA community, would benefit from being tested in research. Analysts must also be skilled at listening and trained to accurately categorize and format the information they are receiving from SMEs during CTA interviews and the transcripts of interviews.

The 70 Percent Rule

Selecting the best healthcare "experts" is as important as the selection and training of analysts. Experts who engage in a CTA must have a record of consistent success and no serious errors while performing the tasks being captured for at least the 3–5 (or more) years required to become fluid and automatic. When possible experts should not have served as instructors on the tasks being analyzed. The reason for this requirement is evidence that experts who teach can't recall about 70 % of their own automated decisions and analytical strategies but must describe an approach to students and so tend to fill in their memory gaps with assumptions that are often wrong or irrelevant. Most experts have served as occasional mentors but those who have worked primarily as instructors for a year or more should be avoided if possible.

Clark et al. (2008) describe a number of studies in healthcare and other areas that have reported this 70 % gap phenomenon. All studies that have examined the issue of percent recall of decisions by experts have reported data within the 70 % range, with one interesting exception. Yates, Sullivan, and Clark (2012) hypothesized that healthcare experts' ability to consciously remember decisions they make during procedures was based on the amount of discussion surrounding the procedure. In an interesting study they focused on two common trauma procedures, one of which was controversial (central venous catheter insertion) and being discussed openly and the other (open cricothyrotomy) was common and not controversial. They started the interviews with a free recall interview (e.g., "Describe all of the steps a physician would need to take in order to successfully implement cricothyrotomy or a central line"). After capturing free recall descriptions from each expert, they implemented structured CTA interviews and repeated the process. All transcripts from both segments of the interviews were coded and compared favorably for inter-rater reliability. Individual CTA transcripts were combined into a CTA "gold standard" summary of the action and decision steps reported by all of the SMEs. As they captured the action and decision steps for both procedures, the analysts noted the amount of new information captured from each new SME as they continued to conduct interviews. What they found was that experts' free recall version of the OC procedure omitted 72 % of decision steps but only 35 % of the decision steps for the controversial central line procedure. What is most interesting is that 7 years before this study was performed, another CTA study of the central line procedure conducted before it became controversial had found that experts omitted 70 % of the

Table 42.1 Percent of OC steps described by trauma experts during CTA compared to the total steps in the procedure (based on Yates et al. (2012))

	Clinical knowledge (%)	Action steps (%)	Decision steps (%)	Total steps (%)
Surgeon A	29	69	30	50
Surgeon B	21	42	30	34
Surgeon C	28	42	30	34

Table 42.2 Percent of knowledge extracted during individual CTA interviews compared to the total steps in the procedure (based on Yates et al. (2012))

	Clinical knowledge (%)	Action steps (%)	Decision steps (%)	Total steps (%)
Surgeon A	71	88	60	76
Surgeon B	64	65	60	66
Surgeon C	64	76	70	72

decisions (Maupin, 2004). The informal comparison of the original Maupin CTA of the central line procedure and the more recent Yates, Sullivan, and Clark CTA after it became controversial provides evidence for the hypothesis that controversial healthcare procedures may be significantly less automated and nonconscious than noncontroversial procedures.

It is also interesting that experts in this and other studies are able to recall many more action steps (physical actions) than decision steps. It is assumed that the high recall of action steps may result from experts forming a mental image of their actions and describing the image. Since our decisions are not directly observable, even when they are conscious they may not lend themselves to images that represent thought processes. Table 42.1 describes the number of steps in the OC procedure that experts described when teaching the procedure. Table 42.2 describes the number of steps the same experts revealed during CTA interviews. Clinical knowledge refers to the amount of relevant conscious conceptual knowledge about the procedure (facts, concepts, processes, scientific principles) the surgeons could recall.

Yates et al. (2012) replicated previous studies by Chao and Salvende (1994) and Wei and Salvendy (2004) that found that most of the required cognitive decisions can be captured from three to four experts. After three to four experts, diminishing returns reduce the utility of the time and effort invested in CTA interviews. Future research might examine the reasons why three to four experts have been found to be optimal for capturing most noncontroversial decisions in all fields studied. It is likely that different experts focus consciously on different decisions but why should they each contribute about 1/3 of the reported decisions needed to perform a complex procedure?

It is also important to note that no one has found evidence to support the common assumption that recently trained practitioners in every field are more able to remember the decisions that must be made because they have not yet automated them. The available evidence more reliably supports the view that new practitioners are filling in gaps in their learning through trial and error though they may not always recognize error (Clark et al., 2008). Experts are interviewed individually to prevent arguments and negotiation over disputed points. Finally, healthcare educators must be cautious about the CTA method they select. Many methods are available but only a small number are evidence based.

100 Versions of CTA But Only 6 Are Evidence Based

Yates (2007) analyzed all published descriptions of different methods of CTA and identified approximately 100. Of the 100, Yates and Feldon (2008) concluded, "… only six … are formal methods supported by empirical evidence and standardized procedures that, if followed, predict knowledge outcomes." (p. 16). Clark et al. (2008, 2010) suggest that of the six evidence-based CTA methods that are most compatible with instruction, most are implemented in five stages:

1. The CTA analyst identifies the target performance goals and reviews general knowledge about the task domain to become familiar with terms and processes.
2. Experts are asked to describe the sequence of tasks that must be performed in order for the performance goals to be achieved.
3. Multiple experts are asked to describe the step-by-step knowledge required to perform each of the tasks as well as the conceptual knowledge related to the steps.
4. The CTA analyst categorizes and formats the elicited knowledge and verifies it for accuracy and completeness by reviewing transcripts and cross-checking with multiple SMEs. In some CTA approaches, the analysts test the elicited knowledge by providing it to novices and testing their performance.
5. The CTA analyst formats the edited knowledge for trainees by selecting one viable approach to teach that includes, for example, procedures that include action and decision steps, conceptual knowledge, and job aids.

The result of this process is at least three different versions of the tasks and steps needed to achieve a performance goal (versions depend on the number of SMEs interviewed). After the separate lists are edited and corrected by all SMEs, the separate lists are condensed into one master list of steps (often called a "gold standard" CTA). This gold standard list consists of the sequence of tasks or subtasks that must be performed in order to achieve a performance goal and the action and decision steps necessary to achieve each task (see Fig. 42.1 for an example of a CTA-based task outline and Fig. 42.3 for an example of a decision step for a central venous catheter insertion).

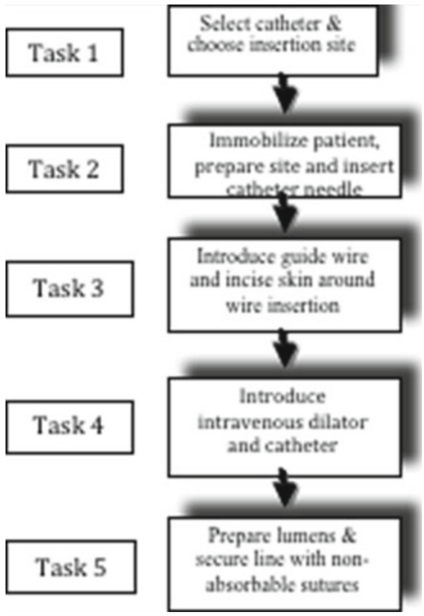

Fig. 42.1 Example of a CTA-based outline of tasks for the insertion of a central line (based on Maupin, 2004)

Example of an Evidence-Based CTA Method: The Concepts, Processes, and Procedures Method

Clark et al. (2008; Clark, 2006) have described one of the six evidence-based CTA methods that have most often been used in research on healthcare instruction (other methods are briefly described in Clark et al. (2008)). The CPP CTA method is based on the PARI method (Hall et al., 1995) but modified to include the instructional design recommendations of Merrill (2002a, 2002b, 2006). The CPP approach implements the stages described above in a multistage process where a CPP trained analyst interviews at least three healthcare experts separately and asks them to describe the same procedure, followed by cycles of expert self- and peer-review. Clark and colleagues (Clark et al., 2008) have found that while experts tend to report similar cognitive strategies, each expert is also able to report new decisions and analytical strategies that the others have missed due to their automated knowledge.

Yates and Feldon (2007) have described the research that has led proponents of many of the evidence-based CTA methods to interview three to four experts. Yates and Feldon (2007) report evidence from multiple studies in many fields that indicate diminishing returns when interviewing more than four experts. Descriptions of the experiments where the CPP method was used are available in reports by Velmahos et al. (2004) and Campbell et al. (2011). Other evidence-based methods are described in Clark et al. (2008).

Interview

The initial, semi-structured CPP CTA interview begins with the CTA analyst describing the interview process for the SMEs so that they know what to expect. Many CTA analysts have informally reported the need to prepare all SMEs for interviews because the process can be frustrating for them due to the emphasis on very small segments of performance and the breaking down of their expertise into small steps. SMEs who were not adequately prepared have refused to cooperate with CTA interviews when they saw the first results of the time they have invested.

After the preparation, SMEs are first asked to quickly list or outline the performance sequence of all key subtasks necessary to perform the larger task being examined. The analyst attempts to outline the subtasks that must be performed and the sequence in which the SME performs them to outline the entire task being captured. Analysts have to urge SMEs to be brief and provide only an outline and avoid going into detail about any of the tasks.

Knowledge captured in interview. Once an outline has been captured, SMEs are asked to describe (or help the interviewer locate) at least five authentic problems that an expert should be able to solve if they have mastered the task. Problems should range from routine to highly complex whenever possible. These problems are used during training to demonstrate the application of the procedure collected as well as practice exercises and performance testing. Both the outline and the problems are continually developed and updated during and after the CTA interviews. Once the outline and problems have been drafted, the analyst begins the CTA interview by focusing on the first subtask in the outline:

1. Action and Decision Steps for all Tasks: The expert is asked to describe the exact sequence of actions and decision steps necessary to complete each subtask described in the outline captured before the CTA begins. To help them, the analyst might ask them to remember and describe one or more memorable events where they used the procedure. Only when all action and decision steps have been captured, corrected by the SME, and summarized does the analyst go to step 2.
2. Benefits and Risks: The expert is then asked to review the steps and describe the reasons for each procedure (benefits of performing, why it works, risks of not performing) for each task and also to indicate the steps that novices seem to have problems learning and/or performing. This information is used to create value for the procedure and to form a basis for the conceptual knowledge about the procedure that students need to learn so that they understand why it should be expected to succeed.
3. Conceptual Knowledge Related to the Steps: Experts are then asked to describe all concepts, processes, and

Fig. 42.2 Crosswalk between the elements of a CPP CTA and the information required for a GEL Training Design

CTA Report	GEL Design
Task Objective	Learning objective
Benefits & Risks (Reasons)	Reason (benefits & risks)
Main Tasks & Procedures	Overview of course or lesson
Prerequisite Skills/Knowledge	Connections to prior knowledge
Concepts, Processes, Principles (CPP)	CPP required for performance
Action & Decision Steps	Demonstration of skill
Problems from SMEs	Practice on authentic problems
Checklist based on Steps	Feedback on practice
Checklist based on Steps + CPP	Whole Task Assessment

principles that are the conceptual basis for the experts' approach to each subtask. This information will be used to introduce and define new terms related to the procedure as well as describe the process where it takes place and the scientific principle(s) it implements.

4. Indicators and Contra-indicators: The conditions or initiating events that must occur to start the correct procedure. This information permits the description of the most important "indicators and contra-indicators" for each procedure.
5. Tools: The equipment and materials required for each subtask. The analyst asks the SME for picture and examples that can be used during the training.
6. Sensory Requirements: The sensory experiences required (e.g., the analyst asks if the expert must smell, taste, or touch something in addition to seeing or hearing cues in order to perform each subtask). This information helps instructional designers determine what part of the training can be presented via media that only present visual and aural information versus parts that must be practiced "live" in order to appreciate the smell, taste, or motor learning needed.
7. Quality Standards: The performance standards required, such as speed, accuracy, or quality indicators to support the development of practice, feedback, and testing.

Guided training design. This information is then formatted to identify the requirements of current "guided" instructional design based on Merrill's (2002a) specifications and Clark's (2004) Guided Experiential Learning (GEL) design. Each element of the CTA information captured is pulled into the design of a course and each lesson in the course (see Fig. 42.2 for a crosswalk between the element of a CTA and the elements of a lesson design).

The design of CTA-based training depends in part on the media selected for delivery (e.g., computer, live instruction). Table 42.3 describes two of the decision steps that start the demonstration of the central line CTA described above.

Instructional demonstrations are often combined with video that illustrates each of the action steps and many of the decisions. Figure 42.3 provides an example of part of a demonstration segment for the CTA-based central line training. The pictures illustrating the steps are icons that when clicked during training play a video of the performance of each step.

Assessment. Finally, Table 42.3 provides an example of a checklist created from the CTA task outline in order to assess the implementation of the procedure. Additional assessments must be developed to assess the learning of conceptual knowledge related to a procedure.

Table 42.3 Example of two decision steps for task 1, taken from the CTA on central line insertion (based on Maupin, 2004)

Step 1: Decide between two types of catheters	
When:	Use this catheter
IF it is necessary (or likely) to infuse two or more types of fluids or the patient will be on long-term fluid administration or TPN	THEN select Triple Lumen
IF Fluids need to be infused rapidly, or if a pulmonary artery catheter will be inserted	THEN elect Cordis
Step 2: Decide among three sites for catheter placement	
When:	Choose this site:
IF the neck is accessible and can be moved, and the head and neck are free of excessive equipment	THEN Jugular Vein
IF the neck is inaccessible or cannot be moved	THEN Subclavian Vein
IF the neck is inaccessible, the subclavian veins are thrombosed and there is no injury to the IVC	THEN Femoral Vein

Table 42.4 Example of a checklist created from the CTA task outline in order to assess the implementation of the procedure based on Maupin (2004)

ITEM	Checklist for CVC placement performance review	Step #	Score
1	Select appropriate catheter for condition	1	
2	Select appropriate site for insertion	2	
3	Place patient in appropriate position	3	
4	Sterilize the site using appropriate technique	4	
5	Glove and gown	5	
6	Inject 1 % Lidocaine	6	
7	Locate correct point for needle insertion	AP A–C	
8	Start insertion with 2-hand technique	7	
9	Create anatomical position with nondominant hand	7	
10	Stabilize syringe when reaching for wire	8	
11	Use correct technique for advancing wire into needle	9–10A and B	
12	Advance wire to correct depth	10A and B	
13	Withdraw needle	11	
14	Use appropriate scalpel technique to incise skin (0.5 cm)	12	
15	Introduce dilator appropriately into the incision	13A and B	
16	Advance the catheter correctly into the incision	15A–16A	
17	Maintain guide wire positioning w/ nondominant hand	16A and B	
18	Position catheter at the correct depth	Append A–C	
19	Withdraw the guide wire	17A and 17B	
20	Prepare the lumen(s) correctly	18A–20AB	
21	Attach fluids to the catheter correctly	21	
22	Attach the line using nonabsorbable sutures	22	

Future Research on Cognitive Task Analysis

CTA research suffers from many of the same problems as instructional design research. Despite a long history of development resulting in over 100 different application methods and many practitioners, CTA has not attracted the research interest it deserves. Part of the reason is that a number of practitioners have based business ventures on their own proprietary version of CTA and most are either not conducting research or not sharing the results of their studies. In addition, nearly all CTA methods require a significant number of human judgments throughout the process of identifying experts and then capturing and formatting their knowledge. These judgments introduce variability that makes analysis, generalization, and replication difficult if not impossible. Research progress in this area first requires some agreement to focus studies on one or more of the six CTA approaches whose methods have been described and whose advocates have conducted and published research in peer-refereed journals (Yates & Feldon, 2008; 2011). Yet since none of the six evidence-based approaches have been unambiguously described, a first step in a systematic research program might be to conduct a CTA on expert practitioners of CTA using the same set of tasks and experts. The results of these CTAs would be carefully documented and then be incorporated into the same instructional design and development model and the resulting instruction presented to randomly selected groups of students representing the same population. A more conservative approach would present different versions of each element of a CTA method to assess its impact on learning and performance. An attractive test bed for these kinds of studies can be found in the large online academic programs offered my many universities and some businesses. When the same course is offered online multiple times in a week to thousands of students at once, it is possible to make many micro changes to a lesson and assess the impact quickly. The goal of this research would be to more clearly articulate the operational steps in different versions of CTA and provide evidence about the learning benefits of each version and/or its components.

Computational data mining research. It may also be possible to avoid some of the more challenging reliability problems associated with analyst interviews of experts by using computer data mining procedures (Cen, Koedinger, & Junker, 2007). In these studies, computer-based healthcare problems would be provided to both experts and novices who vary in prior knowledge of the problems while their solution strategies and errors are captured and summarized automatically. It is likely that participants would have to be asked to explain the rationale for some of their problem-solving steps but keystroke analysis would increase the reliability of observations

Needle insertion technique

Begin insertion of the needle by using both hands.

Hold the plunger in the dominant hand and guide the needle (at correct angle and direction) with the non-dominant hand.

Once the needle is subcutaneous, place the thumb of your non-dominant hand at the point of insertion and the index finger in the direction of the target point.

Create constant suction by using the dominant hand to gently draw back on plunger of syringe while slowly advancing the needle into the vein.

Stop when venous blood enters the syringe barrel.

Fig. 42.3 GEL instructional demonstration based on a central line CTA (following Maupin, 2004)

and the patterns identified would give a unique insight into expert and novice strategies.

Conclusions

The goal of all CTA methods is the identification of cognitive operations experts use to accomplish healthcare tasks. Current evidence suggests that when one of the six evidence-based CTA methods are applied to training or simulations, students learn about 30 % more overall than with existing front-end analysis or task analysis techniques. When PARI-type CTA methods are used, average learning gains increase to 45 % based on the most conservative meta-analysis techniques. There are also indications that CTA trained healthcare professionals would be more attractive to employers and perhaps also to those who insure healthcare organizations. These gains and benefits may derive from evidence that CTA captures more of the automated, nonconscious knowledge that experts use effectively but can't recall or describe consciously. A growing evidence base suggests that experts are only aware of approximately 30 % of the critical decisions and cognitive strategies they employ to solve problems due to limitations on working memory. Since experts design instruction and teach, about 70 % of the information students or simulators need to perform or simulate healthcare tasks may be unintentionally omitted from current instructional materials and presentations. When evidence-based CTA is introduced at the front end of instructional design, learning increases and it is also likely that the errors committed by students and recent graduates of healthcare programs decrease.

At the present time, our healthcare educational system may not be taking advantage of the considerable problem-solving expertise developed by the top practitioners in every field. We seem to expect students to rediscover ways to solve about 70 % of each healthcare problem when experts have already achieved a solution they could learn and apply. While CTA adds to the front-end cost of healthcare instruction, what is the cost of implicitly requiring students to "fill in the blanks" and find their own solutions to problems through trial and error because their instruction is incomplete? What is the benefit of capturing more accurate and complete solutions to critical healthcare problems and transmitting them more completely to students who will become practitioners?

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Mathematics Education

43

Lieven Verschaffel and Brian Greer

Abstract

The chapter documents the emergence of mathematics education as a field in its own right, with its own distinctive theories, methodologies, and preoccupations. We present four widely differing examples of theoretical/practical programs of work that illustrate the rich diversity that now characterizes the field. These examples reflect a considerable maturation of the field, in terms of disciplinary influences, methodologies, philosophical and epistemological analyses, and broader considerations of the roles and purposes of mathematics education as embedded in historical, cultural, and societal contexts.

Keywords

Mathematics education • Design science • Social constructivism • Realistic mathematics education • Critical mathematics education

Introduction: Declarations of Independence

The emergence of mathematics education as a field of study in its own right has been charted in De Corte, Greer, and Verschaffel (1996).

Around 1970, which is about when research in mathematics education began to emerge as an independent field of study, Bishop (1992) proposed that there were three identifiable traditions. He termed these the empirical-scientist, the pedagogue, and the scholastic-philosopher tradition. To a considerable extent, research in mathematics education at that time was conducted within the empirical-scientific tradition, relying heavily on psychological and instructional theories and methods. However, the limited perspective of such research has always been open to serious criticism from the perspectives of the other two traditions. Relying on a deep knowledge of mathematics and/or a rich experience with how to teach it, scholars from these two other traditions reacted especially against the assumption that a theory of mathematics education could be derived from domain-independent theories of cognition, learning and/or education, and their accompanying methodologies.

Increasing interactions between researchers and scholars working within these different traditions led to the first intimations of the idea that mathematics education could be delineated as a field of study on its own right, while retaining strong links with other disciplines. As that field developed, it both reflected and contributed to a general move within instructional/psychological theory towards domain-specificity and situationism. With the emergence of organizations such as the International Group for the Psychology of Mathematics Education (which first met, in Utrecht, in 1977), the establishment of centers such as the Freudenthal Institute in Utrecht, the Institut für Didaktik der Mathematik at Bielefeld, and the Shell Centre in England, the proliferation of journals devoted specifically to mathematics education, and an increasingly rich literature, various "declarations of independence" were made on behalf of the emerging field.

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For example, Freudenthal (1991, p. 149) was highly critical of educational psychology research relating to mathematics "as long as, for the researcher, mathematics is no more than an easily available and easily handled subject matter, chosen to test and apply general ideas and methods, with no regard for the specific nature of mathematics and mathematics instruction". Fischbein (1990, p. 10) stated that "(m)athematics education raises its own problems, which a professional psychologist would never encounter in his own area and that the methodology should also be adapted to the specificity of the domain".

Wittmann (1995, p. 356) also strongly pleaded for mathematics education to be validated as a scientific field in its own right, one that cannot be developed by simply *combining* the insights from other fields like mathematics, general didactics, pedagogy, and psychology; "rather, it presupposes a *specific* didactic approach that *integrates* different aspects into a coherent and comprehensive picture of mathematics teaching and learning, and then transposing it to practical use in a constructive way".

We may further remark that mathematics includes a diversity of subdomains, such as algebra, geometry, and probability, that have their own specific forms of representation, patterns of proof, manifestations of intuition, and so on (see De Corte et al., 1996, p. 499).

Expanding Views of Mathematics Teaching/Learning as a Field

During the 30 or so years in which we have been working in the field, its scope has expanded greatly—some might say exploded. Major developments, that collectively reflect Freudenthal's characterization of mathematics as a human activity, include:

- Diversification of influential disciplines and related methodologies—broadly speaking, the balancing of technical disciplines by human disciplines, and of formal statistical methods by interpretative methods of research and analysis.
- Realization of the ubiquity and importance of "mathematics in action" (Skovsmose, 2005, Part 2) and the implications for mathematics education, including more curricular space for probability, data handling, modeling and applications (see, e.g., Blum, Galbraith, Henn, & Niss, 2007).
- Heightened awareness of the pancultural nature of mathematical practices (Powell & Frankenstein, 1997) and heightened awareness about the relationships between knowledge, education, and power in relation to mathematics and mathematics education (Apple, 2000).

Concurrently, important developments in psychology, philosophy of mathematics, and critical educational theory, which have both influenced, and been impacted by, work in mathematics education, include:

- Situated cognition (Lave, 1988), cultural cognition (Cole, 1998), the "second wave" of the cognitive revolution (De Corte et al., 1996, p. 497).
- Post-modern questionings of the assumptions of progress, objectivity, theories of language use, etc.
- New philosophy of mathematics (e.g., Ernest, 1991; Hersh, 2006) reflecting historical changes in views of the ontology of mathematics.
- Critical education and related movements.

In the course of these developments, tensions and perspectival differences between mathematic educators and both experimental psychologists and mathematicians—already commented upon by Bishop (1992)—have continued. The book edited by Sierpinska and Kilpatrick (1999) makes clear that the field has far from settled into a phase of normal science (in the Kuhnian sense) but rather has entered a period of considerable complexity and diversity in theoretical perspectives, experimental methodologies, and, indeed, reflections on the fundamental question of "What is mathematics education *for*?", that is exhilaratingly liberatory or bewilderingly anarchic, depending on one's point of view (see, for example, the review by Steen (1999) of Sierpinska and Kilpatrick (1999)).

Enrichment of Methodologies

The handbook edited by Kelly and Lesh (2000) amply shows the diversity of the methodological repertoire now exploited by researchers in the field—often with triangulation through the combination of several methodologies—including methods from well beyond the narrow range of the empirical-scientific approach, showing the influence of such fields as anthropology, sociology, and linguistics. As mathematics educators have pursued research that answers to their perspectives, a strong trend has been towards the classroom rather than the laboratory as the main site for research (as exemplified in examples discussed below). It is repeatedly pointed out by many scholars that research in mathematics education inevitably focuses on behavior arising in complex, dynamic, and adaptive systems that is problematic to study in laboratories with techniques that require the full control of variables (De Corte et al., 1996; Lesh & Sriraman, 2010). The range of methods that have been added to the repertoire include clinical interviews and analyses of (verbal) protocols, ethnomethodology, microgenetic analyses of mathematical development in a single student or a small group of students over a considerable period of time, introspections, and intervention studies, particularly "design experiments". The last approach has been implicit in many earlier developments, and is closely related to "developmental research" as pioneered and elaborated in the Freudenthal Institute in the Netherlands (Gravemeijer, 1994), but more recently has been made explicit and elaborated.

According to Cobb, Confrey, diSessa, Lehrer, and Schauble (2003):

> … design experiments entail both 'engineering' particular forms of learning and systematically studying those forms of learning within the context defined by the means of supporting them. This designed context is subject to test and revision, and the successive iterations that result play a role similar to that of systematic variation in experiments. (p. 9).

Design experiments typically involve a kind of interdisciplinary teamwork that evolves among practitioners, researchers, teacher educators, and community partners around the design, implementation, and analysis of changes in practice. Results provide case studies that can serve as instructive models about conditions that need to be satisfied for reforms of the same kind to be successful, and about conditions that impede success.

Among the mathematics educators who have pleaded strongly for design experiments as the main type of research in the field are Freudenthal (1991), Wittmann (1995), and, more recently, Lesh and Sriraman (2010). In his seminal article entitled Mathematics education as a design science, Wittmann (1995, p. 363) describes the core of research in mathematics education as "(…) the construction of 'artificial objects', namely teaching units, sets of coherent teaching units and curricula as well as the investigation of their possible effects in different educational 'ecologies'". And, he continues: " … the quality of these constructions depends on the theory-based constructive fantasy, the 'ingenium', of the designers, and on systematic evaluation, both typical activities for design sciences." According to Wittmann (1995), the so-called developmental research projects of the Freudenthal Institute and his own team's work on the Mathe 2000 project are typical examples of this approach (see below).

Design research basically encompasses three phases which are typically iterated through many cycles, namely, developing a preliminary design, conducting a teaching experiment, and carrying out a retrospective analysis. The first phase starts with the formulation of a "conjectured local instruction theory" (Gravemeijer, 2004, p. 109) that involves conjectures about (a) the learning goals, (b) the instructional tasks and activities and possible tools that will be used, and (c) the thinking and learning processes in which the students might engage in this instructional environment. These conjectures are based on the historical development of mathematics and/or research-based knowledge about children's informal strategies, misconceptions, developmental processes, etc. In the second phase, the teaching experiment, those conjectures are put to the test. In the course of the design experiment, the hypothetical teaching/learning trajectory is gradually and cyclicly adapted, corrected, and refined on the basis of the input of the students and assessments of their actual understandings, as well as of the input of the participating teachers. The retrospective analysis both summarizes what has been learnt and provides the foundation for the next iteration. However, the nascency and complex nature of design experiments has led to a variety of interpretations and applications, both about the methodological requirements of this approach to research and about the constituents of the learning trajectories (for thorough discussions, see Gravemeijer, 2004; Nickerson & Whitacre, 2010).

Although in cognitive and learning sciences the term "design research" is widely considered to have been introduced in the mid-nineties by scholars like Brown (1992), it is important to note that the essential features of design research were actually pioneered much earlier by mathematics educators (De Corte et al., 1996; Lesh & Sriraman, 2010).

It is commonly accepted that design research has two goals, namely, contributing to the innovation and improvement of classroom practices and to the advancement of theory building about learning from instruction (Cobb et al., 2003; De Corte, Verschaffel, & Masui, 2004)—which must proceed in a mutually supportive fashion.

Examples of "Homegrown" Theories of Mathematics Education

The mathematics education community has witnessed the emergence of many instructional models and theories, which typically are at odds with a teaching practice characterized by the transmission of mathematical results, definitions, and concepts by repetition and memorization, with scant emphasis on meaning or mathematical reasoning. The overwhelming majority of these models and theories aim at the integrated mastery of mathematical proficiency that has been defined as five interwoven strands, namely, conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and a productive disposition to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's efficacy (Kilpatrick, Swafford, & Findell, 2001, p. 5). Further, they are typically characterized by more meaning-oriented, process-oriented, and/or problem-oriented forms of teaching and learning (De Corte et al., 1996; Verschaffel, Greer, & De Corte, 2007).

Evidently, it is impossible to provide an overview of all the prevailing instructional models and theories within the field of mathematics education. Therefore, we restrict ourselves to four examples, following some preliminary comments. First, we have deliberately chosen examples of "homegrown" models or theories in mathematics education, rather than theoretical frameworks that were largely developed in and borrowed from other disciplines, although, as previously stated, these homegrown theories also draw upon pertinent components of other disciplines. Second, these models or theories can be distinguished in terms of generality. Whereas some authors aim for a "grand theory of mathematics education", others consider such a grand theory as impossible, either because of the great diversity in the subdomains of mathematics and/or in the aspects of mathematical thinking and learning, or because its claimed generality would require extracting mathematics teaching and learning from the social and cultural contexts that render them intelligible. Third, while some authors use the term "theory", Kilpatrick (2010, p. 4) commented that "to say that something is a theory of mathematics education—rather than, say, an approach, theoretical framework, theoretical perspective, or model—is to make an exceedingly strong claim" and that he would not award "theory-of-mathematics-education status" to any of the candidates he knows.

Mathe 2000

Our first example of a homegrown instructional theory is that of the German mathematics educator, Erich Wittmann. It has been elaborated and implemented in the *Mathe 2000* project that created the elementary school textbook series *Das Zahlenbuch* (Wittmann & Müller, 2004). The work on *Mathe 2000* began in the mid-eighties, when the mechanistic, drill-and-practice approach to mathematics education was quite popular in Germany.

Relying heavily on Freudenthal's maxim that learners need to experience mathematics as a human sense-making activity, and on Piaget's basic principle that "to think is to operate", but also on Wittmann's personal experiences of nearly 40 years in the theory and practice of mathematics learning from kindergarten through high school, the following five instructional design principles of the *Mathe 2000* project have been developed:

1. *Less is more:* Understanding is crucial in mathematics learning. Therefore, it is useful to focus on a few "big mathematical ideas" and to gradually, systematically, and cyclicly develop them from kindergarten on. Instruction also should use only a few well-chosen visual aids that meet the mathematical core.
2. *Trying out yourself, instead of absorbing*: Mathematics is best learned through one's own actions and social interactions. Learning situations should be designed so that the learners receive as many opportunities to be physically active and socially interactive. This aim requires mathematically rich tasks that encourage trial and error combined with discussions about, and reflections on, these explorations, in an open, positive classroom climate.
3. *Practice makes perfect*: The long-term success of a mathematical learning process stands or falls with practice, but not the mechanical practice of specific skills, which is not effective and can even be counterproductive. Needed are forms of exercise and practice in which mathematical relationships and patterns are established and which, therefore, enhance the simultaneous and connected acquisition of expertise in the to-be-practiced skills with the promotion of general mathematical skills.
4. *To everyone his own*: Support is needed for learners with different learning capacities and needs in shared learning environments. Because the learning capacities and needs of learners are different, the learning opportunities should be designed primarily so that the input threshold is low and each learner on his/her level can do something with it. The necessary conditions should be created so that each learner is given the opportunity to decide how (s)he wants to use the instructional input for her/his own individual progress.
5. *Who helps instantly, gives double help*: The direct and daily contact between teachers and learners provides the best conditions to assess levels of development, identify learning problems, and give on-the-spot feedback and help. The most effective form of assessment is the one that is incorporated into the teaching/learning process itself (rather than diagnostic tests coming from outside).

Starting from these basic instructional design principles, and a view of mathematics as "the science of patterns", Wittmann developed, for instance, an alternative perspective on, and approach to, productive practicing in the early years of the elementary school, in which the practice of elementary arithmetic skills is integrated with the realization of important higher-order goals of pattern-finding, reasoning, describing, generalizing, and communicating.

As an example, we give a brief sketch of the activity "arithmetic triangles" (or "arithmagons"), which affords flexible variation in the complexity of the task posed, such that it can be used with first-graders up to secondary school students. The basic situation is simple. The number to be displayed on each side of the triangle represents the sum of the numbers of counters in the two adjacent kite-shaped divisions of the triangle (Fig. 43.1a). This task not only offers practice in counting and simple computation, but also can be expanded in many ways—by leaving out some of the information, by using number symbols instead of counters, larger integers, fractions, and even algebraic expressions (Fig. 43.1b–e). It is an interesting puzzle when only the numbers on the sides are given (Fig. 43.1b, c). A specific problem can be solved by many methods—from undirected trial and error, to systematic trial and improvement, to systematic arguments based on mathematical principles, to formal algebra (Verschaffel et al., 2007; Wittmann, 1995). Moreover, the problems can involve systematic variations, such as

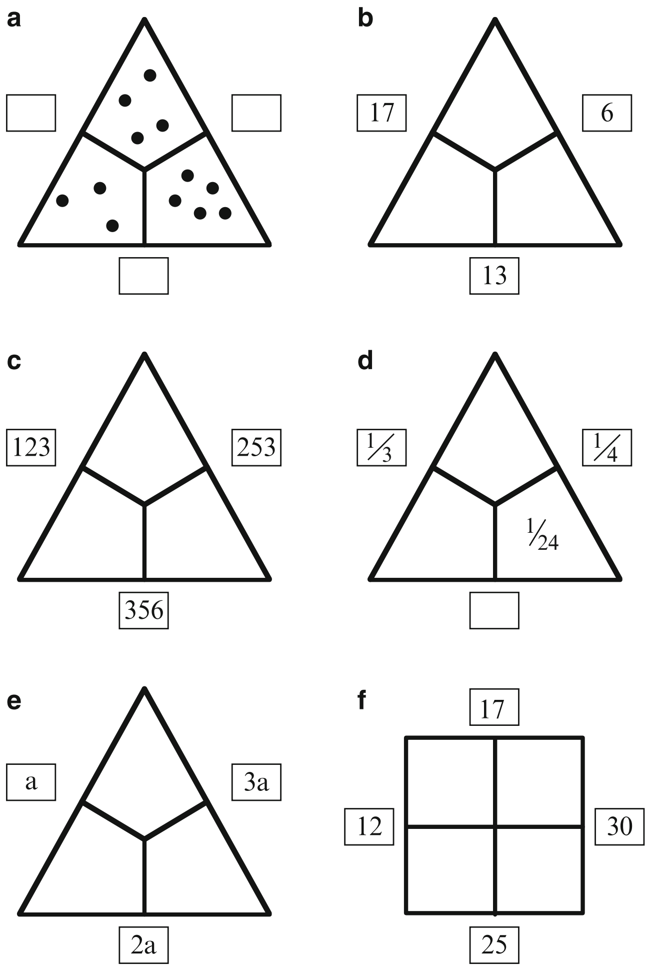

Fig. 43.1 Arithmogons (Wittmann, 1995)

"What happens if one additional counter is placed in each kite?" or "What if a square (or other regular polygon) is used instead of a triangle?" (Fig. 43.1f). Within the variations of this simple task, practice of counting, addition and subtraction of natural and of rational numbers, and algebraic procedures is connected with higher order skills, by providing many opportunities for learners to describe, conjecture, and reason. Even though the problems are not (necessarily) related to real-world problems and experiences, the practicing of skills is meaningful and motivating. For a more extensive description of this teaching/learning unit see Becker and Selter (1996), Verschaffel et al. (2007), Wittmann (1995), and Wittmann and Müller (2010).

For an example of a small-scale design experiment on the *Mathe 2000* approach to mental addition and subtraction in a fourth-grade elementary class, we refer to Selter (1998). There are also a few more systematic comparative studies in which the *Mathe 2000* approach has been endorsed. Hess (2003) and Moser Opitz (2002) compared teaching and learning in classes in which a traditional textbook was used with classes working with (the Swiss adaptation of) *Das Zahlenbuch*, and their results strongly supported the *Mathe 2000* approach, especially among mathematically weaker children.

In Verschaffel et al. (2007, p. 589), we suggested that an emphasis on structure within mathematics, specifically within the arithmetical field, is ripe for renewed attention from the perspective of the learner, avoiding the error of the New Math period in which, as Freudenthal (1991, p. 112) put it, the misjudgment made was "replacing the learner's insight with the adult mathematician's".

Realistic Mathematics Education

Our second example of a homegrown instructional theory is the Dutch answer to the internationally felt need, in the late sixties and early seventies, to reform mathematics education. It was a reaction to both the then prevailing approach to mathematics education (often labelled "mechanistic" or "drill and kill"), and the structuralistic "New Math" movement that was expected to dominate the (Western) mathematics educational world in those days (De Corte et al., 1996; Treffers, 1987).

The foundations of RME were laid by Freudenthal (1983, 1991). Instead of seeing mathematics as a formal subject to be transmitted directly to the students, he stressed the idea of "mathematics as a human activity", and of mathematics education as putting pupils in touch with phenomena for which the mathematical structure is the organizing tool, in order to let them shape these tools themselves in a process of guided reinvention. So, in mathematics education, the focal point should not be on mathematics as a fixed and closed system but on the learner's own activity, on his/her process of "mathematization". Later, Treffers (1987) distinguished two types of mathematization: horizontal mathematization (= the students come up with mathematical tools which can help to organize and solve a problem located in a real-life situation) and vertical mathematization (= the process of reorganization within the mathematical system itself).

The major principles of RME can be summarized as follows (Treffers, 1987; Van den Heuvel-Panhuizen, 1998; see also De Corte et al., 1996):

- The use of well-chosen realistic contexts, which are used as a source for the learning process, to constitute the mathematical concepts and strategies, and to learn to apply them. (Note that the term "realistic" does not necessarily refer to a connection with the real world, but implies that the situation is imaginable for the student).
- Progressing towards higher levels of abstraction and internalization, exploiting representational tools and models to support the transition from the concrete, intuitive, informal level to the more general, explicit, formal one.
- Instead of being seen as passive receivers of ready-made mathematics, learners are considered as active participants

in the teaching/learning process, in which they construct and develop mathematical tools and insights themselves.

- These constructions do not take place in isolation and without support. Learners should be offered multiple opportunities and be challenged to share their experiences with each other and with the teacher, and to reflect on what they have done.
- Instruction should systematically take into account and contribute to the hierarchical organization and the interconnectedness of mathematical knowledge components and skills.

RME can be considered as a grand theory of mathematics education, which has to be refined and adapted to specific mathematical topics and educational contexts before it becomes operational and can be put to a test. Typical examples of such local theories are the RME approach to the arithmetic algorithms, e.g., the algorithm for long division (Treffers, 1987; see also De Corte et al., 1996), to the learning of fractions (Streefland, 1991), and to basic statistics (Gravemeijer, Doorman, & Drijvers, 2010).

Most of these local RME theories have been developed and tested in the context of design experiments, which predominantly have yielded results that are quite positive for the RME approach. For instance, Streefland (1991) reported promising comparative results in favor of his experimental program for the learning of fractions. However, since in several of these design experiments appropriate pretest and posttest measures and/or an (appropriate) control groups are absent, the validity of the conclusions has been questioned. Furthermore, the results of large-scale assessments in The Netherlands have indicated that pupils in schools that use RME-based textbooks perform better in various areas of the mathematics curriculum than pupils in schools that do not, but more recent findings have revealed that gains in those subdomains are accompanied with losses in other subdomains (Koninklijke Nederlandse Akademie van Wetenschappen, 2009).

In an attempt to further advance the theory of RME, Gravemeijer (1999) (see also Gravemeijer et al., 2010) elaborated a heuristic design principle for bridging the informal and the formal level (see the third above-mentioned RME principle), which he called "emergent modeling". First a model is constituted as a context-specific model of acting in a given situation. Then, gradually, the students are stimulated to shift their attention towards the mathematical relations involved. As a result, the students may start to build a framework of mathematical relations. Then, the model begins to derive its meaning for the students from this emerging framework of mathematical relations, and the model becomes more important for them as a base for reasoning about the mathematical relations involved than as a way to symbolize mathematical activity in a particular setting. In this sense, the role of the model gradually changes as it takes on a life of its own. As a consequence the model can become a referential base for more formal mathematical reasoning.

Although the term "emergent modeling" may suggest differently, these sub-models are—in practice—typically not invented by the students themselves. Rather, the emergent modeling process is organized by an instructional sequence and by the teacher who introduces each new version of the model when he or she thinks the development of the students allows for it.

Paul Cobb's Social Constructivist Framing of Mathematics Classroom Activity

Cobb's career trajectory is charted in Yackel, Gravemeijer, and Sfard (2011). While he began his career working within a framework of radical constructivism, and in recent years his concerns have included equity and access (Nasir & Cobb, 2007) and the situation of teachers' instructional practices within the schools and districts in which they work (Cobb & McClain, 2006), probably his most influential work has been in long-term studies of mathematics classroom interactions within a framework of social constructivism.

A number of significant factors have contributed to the development of Cobb's work. These include:

- Working over extensive periods in school classrooms, reflecting an abiding principle that he characterized (Cobb, 2011, p. 11) as "sustained, first-hand engagement with the phenomena that we seek to understand".
- Openness to a wide spectrum of literature and other research paradigms, as evidenced notably in his collaborations with Bauersfeld and the group at Bielefeld (Cobb & Bauersfeld, 1995) and with Gravemeijer and others in the Freudenthal Institute. In the course of prolonged interaction with the RME program, Cobb was particularly influenced by their concept of "developmental research" which led him towards the methodology of design experiments, paying much more attention to coherent sequences of teaching/learning based on conjectured learning trajectories and, like developmental research, relying on tightly integrated cycles of design and analysis.

The signature work of Cobb and his associates focused on the microculture of the mathematics classroom, which is described in terms of social and sociomathematical classroom norms and practices, on the one hand, and teachers' and students' beliefs, conceptions and activities, on the other. By contrast with social norms such as being obliged to explain and justify their reasoning, sociomathematical norms are normative aspects of students' activities that are specific to mathematics such as what counts as a different, sophisticated, or efficient mathematical solution, or an acceptable mathematical explanation (Cobb, Stephan, McClain, & Gravemeijer, 2001).

These clusters of concepts represent respectively the social and psychological perspectives underlying socio-constructivism. The social perspective refers to ways of acting, reasoning and arguing that are normative in a classroom community, while the psychological perspective is concerned with the nature of individual students' reasoning, or their particular ways of participating in communal activities (Cobb et al., 2001). It is a fundamental methodological tenet in these studies that what happens in the classroom can most productively be studied by taking into account both collective and individual processes and their dialectic interactions.

Another important influence acknowledged by Cobb, stemming from his long-term and prolonged interactions with Gravemeijer and others at the Freudenthal Institute, is the role of conceptual tools, including both informal and conventional notations and representations (a fundamental manifestation of the inherently social nature of mathematical practices) (see Cobb, Yackel, & McClain, 2000).

Using the above interpretive framework, Cobb and his colleagues have over the past 10–15 years undertaken a large series of design experiments, in classrooms varying in duration from just a few weeks to an entire school year, and involving different groups of learners from beginning elementary school children learning simple addition to upper secondary school students learning statistics.

To our knowledge, Cobb has not explicitly discussed the political ramifications of his work, though they have never been far below the surface. For example, (radical) constructivism has been controversial within the field (e.g., see the trenchant comments by Freudenthal (1991, pp. 142–147)) giving rise to often emotional debate, on which Cobb (2011, p. 14) comments "I do not believe that these exchanges were particularly productive, especially since none of the leading participants changed their basic positions". Beyond that, criticism of constructivism, and its embrace in the Curriculum and evaluation standards for school mathematics (National Council of Teachers of Mathematics, 1989) has been at the center of the debate commonly known as the Math Wars (Schoenfeld, 2004). At an early stage in his research career, Cobb and his team had to justify the approach taken in their teaching experiments in the face of criticism from officials and parents (Dillon, 1993). Cobb's recent writing on identity and access to mathematics education (Nasir & Cobb, 2007) is intrinsically political and, in his work on learning statistics, he has more than once commented on the importance of such knowledge for democratic citizenship. And in their critique of the National Mathematics Advisory Panel, Cobb and Jackson (2008) focused on the ideologically based "overly narrow view of what counts as scientific evidence" and the lack of "sustained first-hand engagement with the phenomena that we seek to understand" (as quoted above) that characterizes much of the research done by psychologists on mathematics education. Provocatively, they comment that "researchers and research teams cannot adequately investigate phenomena that they do not understand" (p. 579).

Reading and Writing the World with Mathematics: The Freirean Approach of Eric Gutstein

Among (some) mathematics educators, a major value-driven concern is that mathematics schooling is often unconnected with what mathematics is used for in the world ("mathematics in action" as Skovsmose (2005) puts it). To a degree, this issue has been addressed by increasing emphasis in curricula on applications of mathematics, in particular through mathematical modeling and data analysis. However, this concern with making mathematics relevant to students' lived experience is carried further by an emerging group of critical mathematics educators who propose that students should learn how mathematics can provide tools for the analysis of issues important to the students and their families, their communities, and humankind in general (Mukhopadhyay & Greer, 2001).

The clearest example of such a program is the work of Gutstein, a mathematics educator at the University of Illinois, Chicago, who has, for some 15 years, taught mathematics in two Chicago public schools, one of which he helped found, with a focus on the analysis of social injustice. The Freirean spirit of the work is apparent in the title of Gutstein's (2006) book *Reading and Writing the World With Mathematics: Toward a Pedagogy for Social Justice*. Gutstein is reinventing—not copying—Freire's approach in the context of particular communities in Chicago and with specific reference to mathematics. Here "reading" means interpreting and seeking to understand, whereas "writing" means applying that understanding to change the world, encapsulating Freire's belief in the mutual interdependence of reflection and action.

Gutstein's description of the context within which he works exemplifies growing awareness that much of the literature on mathematics education ignores the reality of the worlds in which the students live (Valero & Zevenberger, 2004), a reality that includes poverty, violence, and social injustice—and resilience and resistance—in many parts of the world, by no means limited to the "undeveloped" world. For example, for the students with whom Gutstein works, death of community members through gun violence is an all too common part of their lives. The establishment of the Greater Lawndale/Little Village School for Social Justice, in which Gutstein was involved, was born out of community struggle, including a 19-day hunger strike when an attempt was made to renege on the promise to create it.

In curriculum construction, Gutstein aims at a balance among three forms of (mathematical) knowledge, that he labels

Classical, Community, and Critical. Classical mathematics is the familiar academic mathematics that, to a great extent, dominates mathematics education in most classrooms. Community mathematics draws on the knowledge of the community. Critical mathematical knowledge refers to the application of mathematics in critiquing, and acting upon, social and political issues. The development of curriculum within these guidelines is complex. A central organizational framework is provided by the Freirean notion of "generative themes" that are chosen after discussion, and often suggested by the students themselves (Gutstein, 2012a). For example, 1 year Gutstein taught a 12th grade class that, through dialogue, agreed on five themes: analysis of election data from the 2008 US presidential election, displacement of population in the course of gentrification within the students' communities, HIV/AIDS, criminalization, and sexism. A leitmotif running through these themes is the importance of interrelations among race, class, and gender.

The theme of displacement relates to population shifts in the students' neighborhoods, due to such factors as gentrification, collapse of the housing market including many foreclosures, and immigration/deportation. In this unit, every student learned to model, graph, and analyze various kinds of mortgage, and also understood negative amortization, the mathematics of borrowing, and more. As an action, the students held symposia on consecutive nights in their two neighborhoods, in which they presented what they had learned. (As an aside, it is legitimate to ask what the general lack of foresight, ignorance, and greed that contributed to the housing and more general financial collapses in the USA says about the efficacy of mathematics education there).

The complexity of what Gutstein is attempting is illustrated by another example of a generative theme, namely, the spread of HIV/AIDS (Gutstein, 2012a). He openly describes how it proved very difficult to mathematically model such phenomena with the students, since the most appropriate methods involving differential equations are beyond the students' range. In this untypical case, the class, for a few days, resembled a social studies class without mathematics. On other rare occasions, the students did mathematics without direct connection to sociopolitical issues. Mostly, however, the work achieved, as expressed by Atweh (2012), a balance in "the use of real world activities that promote students' learning about their social world *while* they are learning mathematics and, at the same time, learn about mathematics *while* they are engaging with real world activities".

It will be clear that Gutstein has an overt political agenda, that contrasts sharply with the commonly held position that mathematics education is apolitical—the "ideology of no ideology". This position implies political solidarity with the students and their community, built up over a considerable amount of time and interaction (Gutstein, 2012b).

Conclusions and Discussion

Of the many models and theories that have been developed over the past decades and are being used within the field, the dominant ones are, rather than the general or interdisciplinary ones, those that have put the specificity and integrity of the domain at the center of their work, with no hesitation, however, to borrow ideas and techniques from other disciplines. In this chapter we have exemplarily reviewed four of these homegrown frameworks, which are at the same time illustrative for mathematics educators' reliance on notions and insights coming from well-established general psychological, educational, philosophical, and sociopolitical theories (e.g., those of Dewey, Piaget, Vygotsky, Von Glasersfeld, Freire).

By way of examples, we have presented just four points in a multidimensional space. Nevertheless, these examples, contrasting as they are, share two fundamental characteristics, the first being direct involvement over a considerable period of time with the actual teaching/learning of mathematics.

The second characteristic we could describe as recognition of the child's right to sense-making. This recognition stands in contrast to the emphasis in some psychological work (less than was previously the case), and in some mathematics education (still too much, in our view) on computational and procedural fluency, a tendency exacerbated, all too often, by primitive forms of assessment and their use as crude levers of educational engineering.

Mathe2000, with its emphasis on patterns, and on higher-order reasoning processes applied to those patterns, acknowledges and exploits the structure inherent in the systems of arithmetic and, by extension, in a smoothly articulated way, algebra as the generalization of arithmetic. This form of sense-making we can term "internal" and it is at the heart of mathematics. RME presents an approach to learning mathematics that recapitulates, but in a way that exploits what has been learned by mankind over millennia, the natural development of mathematics from human activities, through what we might term "external" sense-making. Cobb's socioconstructive framework adds an extra focus on how this sense-making leads to the construction of mathematical cognition in ways that are inextricably, and dialectically, both individual and collective. Finally, Gutstein adds a further dimension of sense-making, by relating mathematics to the social and political realities of the lives of his students.

Length restrictions have prevented us from presenting these homegrown models in such a way that it becomes clear what it means to give the mathematical content a pivotal place and role in the instructional design process. However, for each example, we have included references in which detailed and illustrated elaborations of these models or theories can be found.

Another important issue is that of generalizability. Mathematics educators are typically quite critical even about the possibility and meaningfulness of aiming for a "grand theory of mathematics education", and most focus rather on developing and testing local models and theories for particular mathematical topics and settings (Sriraman & English, 2010). There is a clear shift, in many quarters, against illusions of universality (e.g., Skovsmose, 2012).

All theories and models that were presented in this chapter were developed, tested, and refined mainly, if not exclusively, in the context of design experiments. As stated before, the research field of mathematics education was the first where the methodology of design experiments was developed and embraced, before it became fashionable within educational (psychology) research. The reason why it originated in mathematics education was that, within this emerging research community that comprised scholars from very different traditions, it was very quickly generally accepted that the rigid research designs and analytic methods from the fields of psychology and educational sciences are inappropriate, or at least insufficient, for studying complex phenomena arising and evolving in adapting systems (Sriraman & English, 2010). As a consequence, according to Wittmann (1995), research in mathematics education has difficulty being awarded scientific status as a human science because it works on the borderlines of disciplines such as psychology, and not at their core.

Over the years, mathematics education research, with its preference for homegrown theories and accompanying methodologies, such as the design experiment, has endured many attacks from outside, from both other scientific disciplines and policy-makers. These attacks have been most obvious in the USA, under the (unfortunate) metaphor of Math Wars (Schoenfeld, 2004), but show recent signs of export (Van den Heuvel-Panhuizen, 2010). As a dramatic recent example, we refer to the National Mathematics Advisory Panel Report (US Department of Education, 2008) set up by President Bush, which almost completely eliminated mathematics education research from its consideration by adopting rigid methodological criteria that largely ruled out studies other than large-scale randomized controlled trials—to paraphrase early Wittgenstein, "whereof one cannot do randomized experiments, thereof one must be silent". In various sharp reactions (see, e.g., Greer, 2012), the community of mathematics educators, in a special issue of *Educational Research* (e.g., Cobb & Jackson, 2008) objected to this attempt to conform mathematics educators "to perverse psychometric notions of 'scientific research' such as pretest/posttest design with 'control groups' in situations where nothing significant is being controlled, where the most significant achievements are not being tested, and where the teaching to the test itself is the most powerful untested component of the 'treatment' " (Sriraman & English, 2010, p. 18). However, whereas most mathematics educators see their discipline essentially as a design science, they by no means reject experimental and quantitatively oriented methodologies, as long as they are combined and balanced with other methods that do respect the complex and multidimensional nature of mathematical thinking and learning and of the educational and broader cultural environments in which it occurs (Cobb & Jackson, 2008).

In this respect, it should be clear that in the debate about what counts as solid evidence in favor of a certain educational theory or approach, it would be naïve to expect that empirical research alone—of whatever type—will yield a clear and conclusive answer as to what kind of instructional approach is most valuable for teaching mathematics, not only because of the complexity of the field or the diversity of its subdomains, but also because of the profound differences in beliefs about and valuations of the purposes of mathematics education and why it is important for learners and for people and society in general.

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Innovation and Research on Engineering Education

44

Erik de Graaff and Anette Kolmos

Abstract

Our Western society depends strongly on continuous technological innovation. Engineers, the designers of the future technology need extensive competencies to face the challenge of dealing with ever increasing complexity. In some areas more than half the knowledge they learn in University is obsolete by the time the enter practice. Recognition of these issues has recently resulted in worldwide increase of attention for innovation of engineering education. This chapter presents a brief outline of the traditions in higher engineering education culminating in the stage of research and development in the last century. Next, the recent revival of engineering education research is described, contrasting the developments in the USA with Europe and the rest of the world. The efforts in the USA appear to follow Boyer's concept *scholarship of teaching*, and aim for the establishment of engineering education research as a discipline in its own right. The trend in Europe is to build on the experiences with social sciences research in higher education, aiming to involve practitioners in research in their own fields. At the end of the chapter, a taxonomy of engineering education research questions is proposed, based on efforts by the SEFI (European Society for Engineering Education) working group Engineering Education Research (EER) and the European project EUGENE.

Keywords

Engineering education • Educational innovation • Applied research

Introduction

Engineering is rooted in practice. Engineers design and construct the tools that allow us to build pyramids and reach the moon. Modern society depends strongly on continuous technological innovation to increase production. It seems like innovations are succeeding each other with increasing speed. Hargroves and Smith (2005) depict a series of overlapping innovation waves, starting with a first wave at the onset of the industrial revolution characterized by use of waterpower and mechanical constructions lasting from 1785 until the middle of the nineteenth century. The second wave with steam power and steel lasted until the end of that century and the third wave with the combustion engine and electricity till about 1945. After the Second World War, the fourth wave brought us electronics, computers, and space travel, followed in the 1980s by the fifth wave of information technology, digital networks, and biotechnology. The sixth wave, which is where we are right now started somewhere at the change of the millennium, bringing us nanotechnology and sustainability issues. With each of these changes in technology the engineering curriculum had to be adapted. Hence, we see increasing activity in terms of curriculum transformations following in the wake of the innovation waves. See Fig. 44.1 from Desha and Hargroves (2011).

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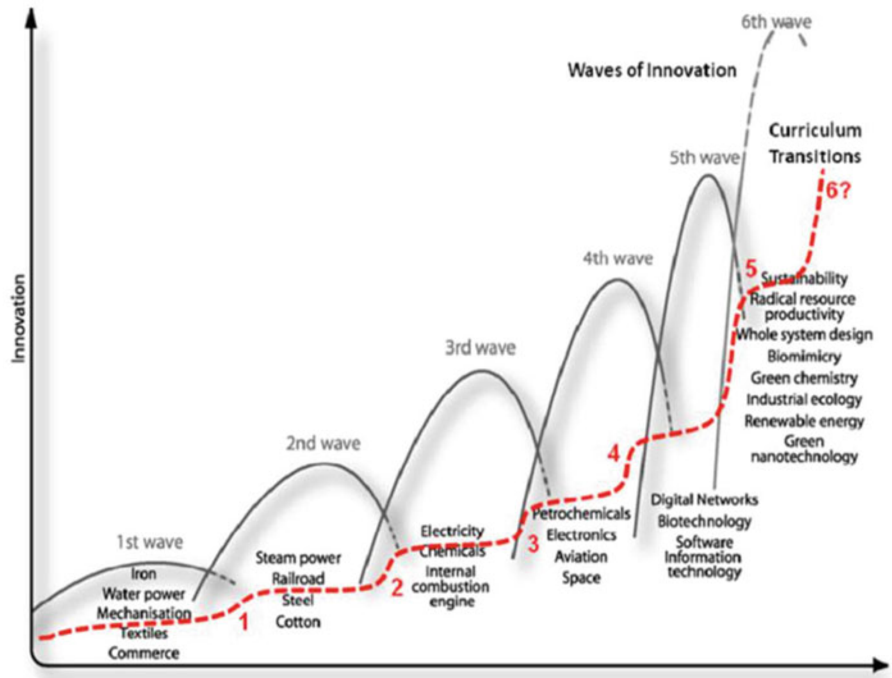

Fig. 44.1 A curriculum with renewal transitions and significant waves of innovation (adapted from Hargroves & Smith, 2005)

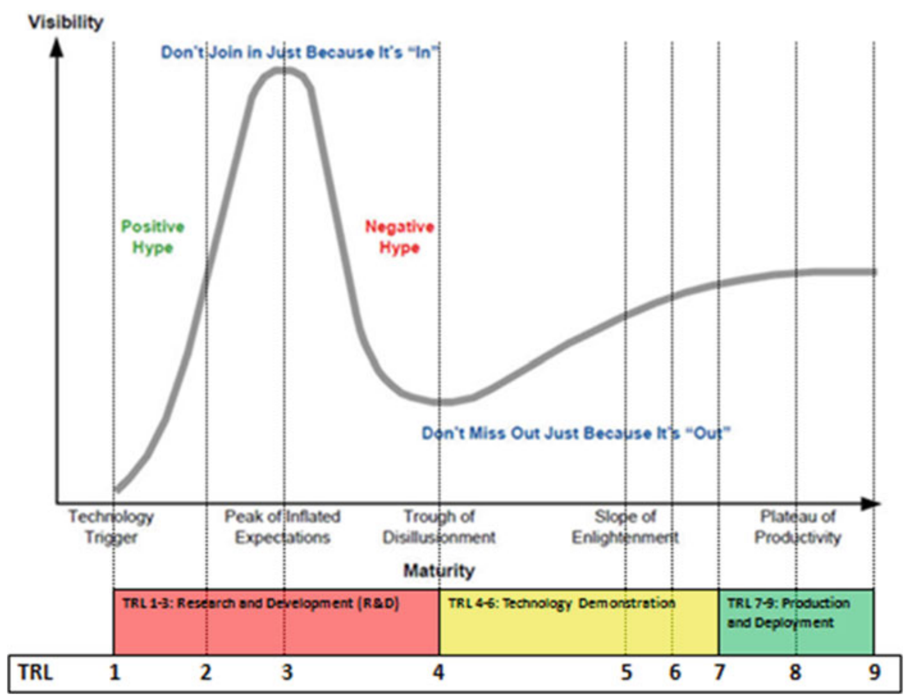

Fig. 44.2 The Gartner hype cycle and technology readiness assessment

Innovations take time before they become common practice a process that is described by the Gartner hype cycle (Linden & Fenn, 2003). In conjunction with the method of Technology Readiness Assessment (TRA), applied by the USA Ministry of Defense (2009), the hype cycle can be used to estimate at what point of time expertise will be needed at a larger scale. Figure 44.2, taken from the research of Dang (in press) displays both approaches in one graph.

At the early stages of the hype cycle most technologies are in the R&D stage corresponding with the stages 1–4 of TRA. The picture confirms the importance of the connection between research and teaching in higher engineering education. Through this link engineers can be trained in working with technology that still needs to be established in production.

Engineering education needs to adapt continuously to meet the changing needs of society. Recognition of this need resulted in worldwide increase of attention for innovation of engineering education. This chapter presents a brief outline of the traditions in higher engineering education culminating in the stage of research and development in the last century.

A Historic Perspective on the Academic Status of Engineering Education

In ancient times the way to learn a craft was to start working as apprentice to an established craftsman. During the Middle Ages the Master–apprentice system was formalized. A student had to stay for a fixed period in the service of the master before he could prove his skills with a master test and become a full member of the guild. This way the guild protected the quality of their profession.

Institutionalized engineering education in Europe dates back to the establishment of the first grand école in the eighteenth century in France, which were founded as a reaction to the more general universities with roots back to the thirteenth century in Italy, and France. The next important phase was the Humboldt University in Germany, based on the idea that research and teaching belong together. Research and Science were closely connected in the formation of technology and the basis in engineering education. In the nineteenth century where the most engineering schools were established, there was a clear pedagogical idea: to teach science and to present research.

For a long time most practical engineering was carried out in a military setting. For instance the Roman army employed many engineers to construct roads, bridges, fortified campsites and war machines. Of course in times of peace the engineers who build these military tools and construction works were set to work for civil purposes. In many western countries today, engineering education also has a background in the military. For instance, the third president of the USA Thomas Jefferson established the first engineering program in America at the military academy West Point in 1802. And the French engineer and mathematician Poincarė analyzed the functionality of the French system of engineering education in order to explain the loss of the French in the war against Germany (Galison, 2003).

The transfer to the civil environment and the establishment of an academic status took quite some time. The development of Delft University of Technology in the Netherlands can serve as an example. On January 8, 1842, King Willem II founded the “Royal Academy for the education of civilian engineers, for serving both nation and industry, and of apprentices for trade.” The Academy also educated civil servants for the colonies and revenue officers of the Dutch East Indies. Just over 20 years later the Royal Academy was transformed in to a Polytechnic school, bringing the school under the influence of the rules applying to secondary education. This School went on to educate architects, and engineers in the fields of civil works, shipbuilding, mechanical engineering and mining during the rest of the nineteenth century. It was not before May 22, 1905, that an Act was passed, acknowledging the academic level of the School’s technical education—it became a Technische Hogeschool, or an Institute of Technology. The Institute was granted corporate rights by an Act passed on June 7, 1956. Recognition of the Institute as University of Technology had to wait until 1986.

Pedagogical Research and Development Centers

During the 1960s there was a rapid increase in the number of students entering higher education in Europe, including the domain of engineering. A good many new engineering institutions were established in order to deal with the need for more engineers. At the same time there was a awareness of development of didactics—defined as the art of teaching—not only in engineering education—but in all HE in north part of Europe.

Universities needed to adjust their teaching methods in order to deal with mass higher education (Wiegersma, 1989). Innovation and improvement soon became keywords in dealing with this issue. In a scientific environment it seems natural that research plays a major part in order to establish a solid foundation for quality improvement. As a reporter argued at the end of the first national convention on Research of Higher Education in the Netherlands Eindhoven 27–28 April 1966 (Vroeiijenstijn, 1981): what is really needed is to establish contact between the people concerned with the teaching of science and those engaged with the science of teaching.

At the beginning of the increase in interest for research on higher education, the Dutch schools of Technology played a central part. The third national convention on Research of Higher Education was organized in Delft, January 15–16, 1976. At the opening of this conference the minister of higher education addresses the position of the RWO [Research of Higher Education] centers. The minister points out that the position of the RWO institutes differs markedly from that of other research institutes, because their finances are drawn directly from the university funds. However, the gap between research and application of the outcomes is one of the problems singled out by the minister. Since the average University professor does not have enough time to study educational science next to his own profession, the minister states, it is not surprising that it is hard to implement new educational insights in the practice of higher education.

During the 1970s and 1980s, institutional pedagogical centers were founded in many places, with the aim to train staff and improve engineering education (Kolmos, et al.

2001; Kolmos et al., 2004; Christensen et al., 2006). The developments in Europe were a fragmented due to the European situation with many national laws and languages. The founding of the European Society for Engineering Education (SEFI) in 1973 provided a platform for collaboration and exchange of experiences. SEFI addresses issues of common interest in working groups like Curriculum Development, Ethics, Gender and Diversity and most recently added to the list, Engineering Education Research.

Still, only sparsely the pedagogical centers were involved in true research, with problem formulations and appropriate research methods (de Graaff & Sjoer, 2006). Research in engineering education often does not go beyond case studies and evaluations of local experiments with limited relations to a theoretical framework of higher education. The scientific background of the majority of the educational researchers was in the social sciences. They published their results in their own journals and conferences. The professors that were responsible for educational development in their own field had little or no access to this information. Teaching and consequently educational development was based on their experiences as practitioners in the field and as researchers. So you could say that educational development in higher education was based on trial and error rather than on scientific arguments (van der Vleuten, 1997). The link between the researchers of higher education and the curriculum developers was at best weak and unsystematic. Consequently the impact of educational research on education was limited.

Revival of Engineering Education Research

Since the end of the last century the need to increase the efficiency of higher education became more and more manifest. The development of the knowledge society requires a large body of highly trained professionals. As a consequence the quality of higher education becomes more important. In Europe it was recognized that the diversity in national educational systems was a disadvantage. In many countries higher education acted like a closed system. There was no public accountability for issues like quality of teaching and retention rate. The Bologna declaration started a process of unification of European higher education aiming to increase mobility. In many participating countries the implementation of the Bologna process was used as a lever to enforce changes in higher education. In 2010 the European Council has adopted the so-called EU 2020 strategy for economic growth. This strategy includes a target to increase the share of 30–34 year olds having completed tertiary or equivalent education to at least 40 % of the population. Such a target serves to increase the pressure on the universities to improve their efficiency. It means more people will have to be admitted and the dropout rates will have to be lowered.

In the wake of this policy of efficiency increasing the need for scientific based understanding of the process of higher education was felt. An important boost came from the USA starting with an influential publication by Boyer (1990) with the title *Scholarship Reconsidered*. Boyer promoted a national, cross-disciplinary dialog about how the scholarship of teaching and learning could enhance the quality of higher education in the USA. The logical result of this discussion was to extend the concept of scholarship with scientific research on the process of teaching and learning.

Called for rigorous educational research across the disciplines, including by establishing guiding principles for scientific inquiry and using research-based knowledge to guide educational reforms. The call did not go unnoticed in engineering education. An analysis of the situation identified a series of problems specific to higher engineering education (Wankat, Felder, Smith, & Oreovicz, 2002). The following selection of problems in the education of engineers indicates the general drift:

– Isolation of teaching and learning from professional practice.
– Overloaded curriculum and a focus on lectures as a means of knowledge transfer.
– Lack of integration of and coherence among technical courses with the rest of the curriculum.
– Little attention for the development of practical skills and ethical judgment.
– Declining enrolments in engineering schools.

To solve the problems listed above systematic research is evidently needed. A movement started to reinvent engineering education research. Supported by a grant from the National Science foundation (NSF), in 2007 for the first time a conference was organized explicitly focused on engineering education research. The International Conference on Research in Engineering Education (ICREE) in Hawaii aimed to start building a community of researchers on engineering education. The initiative was followed up by a second conference called REES (Research in Engineering Education Seminar) in 2008 in Davos, a third REES meeting in 2009 in Australia and the fourth REES symposium in Madrid in 2011.

Despite the ambition to start an international network of engineering education researchers, in the beginning the meetings were heavily dominated by US participants. In 2008 there were 51 US participants out of a total of 63 and in 2008, even though the meeting took place in Europe, there were only three European participants. After the meeting in Australia it was decided to change the structure of the movement. Through a process of online voting a governing board was elected with a fixed number of representatives for each continent according to the following distribution: Canada and the USA (2); Australia and New Zealand (2); Europe (2); Asia (1); Africa (1); Latin America (1).

The governing board decided to change the name once more from REES to REEN (Research on Engineering Education Network). The mission states explicitly that REEN aims to be an …*inclusive forum to advance scholarly discourse on research in engineering education*. The network has been growing steadily to over 200 online members. The fourth REES meeting in Madrid in 2011 is evidence that REEN truly has evolved into an international network.

Accomplishments of Engineering Education Research

As a field of applied research Engineering Education Research aims to answer questions relevant for the field of engineering education. In a large literature survey Jesiek, Newswander, and Borrego (2009) analyzed over 2,000 English-language engineering education journal articles and conference papers published between 2005 and 2008. The authors selected 815 empirical research papers for detailed analysis of keywords. They identified four main categories of topics for engineering education research:

- Preparing students.
- Improving engineering education.
- Changing the nature of engineering.
- Impacting society.

Within these broad categories topics feature like attracting and retaining students, curriculum development, assessment of learning outcomes and implementation of new technology. Countless studies report results of studies on each of these topics. However, as most studies to date have been conducted as single shot experiments in the context of engineering classrooms the generalizability of the results is limited. Of course, it is useful to establish the effectiveness of a particular pedagogical method or tool. Yet, demonstrating that a specific method is successful in one classroom does not necessarily mean it will also be successful in another school with different conditions and with different teachers. The aim of a scientific study is to understand the causes of the success or failure, not just to assess it. We may conclude that the status of engineering education research is clearly that of a developing field.

The editors of the *Journal of Engineering Education* and the *European Journal of Engineering Education* started an initiative in 2007, aiming to support the global development of engineering education as a recognized field of research. This project was called Advancing the Global Capacity for Engineering Education Research and consisted of a 1 year and a half period during which workshops were held at ten international engineering education . The goal was to advance the global capacity for engineering education research through moderated interactive sessions offered in a series of international engineering education conferences between July 2007 and December 2008. The sessions involved the participants in addressing fundamental questions regarding the development of a global community of scholars and practitioners in engineering education research (Lohmann & de Graaff, 2008, p. 1). A paper reporting the outcomes of this global debate was jointly published by both journals (Jesiek, Borrego, & Beddoes, 2010a, 2010b). The authors signal that comments about relating research to educational practice surfaced repeatedly across AGCEER sessions. However, little discussion was observed about the implications of adopting different understandings of the research–practice relationship and comments about relating research to policy and industry also occurred seldom.

Differences in research traditions and criteria defining research quality in different parts of the world were not investigated systematically. However, these differences certainly play a role in discussing the advancement of EER as demonstrated by the following analysis of the JEE and the EJEE reported by Borrego and Bernhard (2011). The authors point out that the differences between the research traditions and their related conceptions of quality are evident in the pages of *Journal of Engineering Education* and *European Journal of Engineering Education*:

> The Journal of Engineering Education, which is based in the USA, reflects the country's method-led emphasis on empirical evidence as a condition for "rigorous research". Although the guide for authors states that the journal accepts quantitative, qualitative, and mixed methods research investigations as well as research reviews, the majority of articles are research studies presenting quantitative, empirical evidence. The European Journal of Engineering Education publishes "research papers as well as position papers and review articles that debate and explore strategic, theoretical and methodological issues, methodological approaches (assessed best practice), and substantive topics." Consistent with a problem-led orientation, the "usefulness" of the research is often valued more highly than quantitative evidence. For example, the EJEE publishes case studies and related papers on topics including sustainable development and diversity with philosophical arguments to support their claims.

A part explanation of the limited scope of engineering education research is, that the researchers often are engineering teachers. This is particularly true in the USA. In Europe there is a standing tradition of researchers with backgrounds in social sciences investigating various fields in higher education, including engineering. The emerging methodological discussion follows the same divide. The striving for "rigorous research" in the USA, borrowing criteria from natural sciences research, aims to gain scientific recognition for a developing field. In Europe criteria the problem is recognized but the solutions continue to come primarily from social sciences. The big challenge for the growing engineering education community is to reconcile the different approaches and to establish a scientific identity.

A Research Agenda for EER

Engineering education research in Europe builds on the tradition of collaboration and exchange between teachers in engineering joined in the European Society of Engineering education SEFI. Supported by SEFI a series of European thematic network projects was initiated focussing on methods to improve the collaboration of engineering educator is Europe:

– E4 "Enhancing Engineering Education in Europe".
– TREE "Teaching and Research in Engineering in Europe".
– EUGENE "European and Global Engineering Education".

Educational research becomes more and more an issue in these projects. Bothe E4 and TREE were primarily aiming at providing tools for engineering educators. See for instance the report Teaching and Research in Engineering in Europe (TREE) (Borri & Maffioli, 2008; de Graaff et al., 2007).). In EUGENE, one of the main activities, line B is devoted to EER. Line B collaborates closely with the SEFI working group EER coordinating the research activities and building the network. Together a workshop was organized during the SEFI annual conference 2010 aiming to discuss the concept of taxonomy development for EER research-topics (de Graaff et al., 2010). The participants easily agreed on a series of relevant topics, like: best practices; the evaluation of specific didactic methods; the development and testing of assessment methods; policy-oriented research, cognitive research. Defining relationships and setting priorities proved much more difficult. The process is still on-going. It is supposed to result in publications in the near future.

Discussion

Over the past decade Engineering Education has clearly established a firm position as a field of applied research. Besides the different networks and conferences several universities around the world have instituted research centers focusing on engineering education, appointing professors in engineering education chairs. Numerous PhD studies have been started, investigating various aspects of engineering education. A strong point in this development is that many of the practitioners of engineering education research are originally trained as engineers. In order to research the teaching and learning environment of engineering they learn to apply methods that have been developed in the social sciences (Case & Light, 2011).

There is no doubt that the researchers background in engineering helps to increase the impact of the research on engineering education practice. Still there is a long way to go for engineering education research to reach maturity and full recognition by the scientific community. The problem originates from the two sides of the interdisciplinary research approach. From a social sciences perspective the present level of engineering education research is not very sophisticated. In many cases researchers seem to be unaware of the recent body of educational research and the methods they apply often are rather primitive compared to the standard of contemporary educational research.

On the other hand it is difficult to get scientific recognition for engineering education research from fellow engineers. A good many traditional engineering institutes feels their task is to investigate engineering, not some social sciences related field like education. Also, engineers tend to derive their criteria for quality of research from the natural sciences. Take for instance the emphasis on empirical evidence as a condition for "rigorous research" applied to publications in engineering education in the USA (Borrego, 2007). Applying these criteria to social sciences research sometime results in strange conclusions. (For instance like the rejection of a papers because the study reports a survey with a response rate of less than 70 % (de Graaff, unpublished).

All in all there is still a long way to go for the field of engineering education research to reach maturity. The fact that engineering education research focuses on researching a practice creates challenges for this development and might contribute with new dimensions of pragmatism to research on higher education in general. The development is clearly gaining in strength and we are looking forward to see what the contribution of the new generation of Ph.D. students in engineering education will bring us.

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Educational Technology in Social Studies Education

45

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Abstract

The National Council for the Social Studies, the largest professional organization for social studies educators, indicates that the primary purpose of the social studies is to help youth become responsible citizens who are capable of making informed and reasoned decisions for the good of society. For this purpose to be met, students need to understand a vast domain of knowledge and have the skills to think critically, problem-solve, collaborate, and act conscientiously in addressing complex issues. This means that teachers need to learn how to use innovative approaches to engage students as thinkers and problem solvers so students may be successful global citizens and leaders of the twenty-first century. Designing an environment where students have the opportunity to learn and practice these skills while exploring social studies content can be challenging, but not impossible. A key component is the essential role educational technology and twenty-first century skills have in facilitating teaching and learning in the social studies. This chapter provides an overview of the research on how educational technology has been used to engage and inspire all learners to be creative and critical thinkers, not only for the good of their individual futures, but for the future of our global society. In providing the overview, the focus is on two major areas within social studies education—historical inquiry and civic education.

Keywords

Twenty-first century skills • Historical inquiry • Civic education

Introduction

Before beginning the discussion of the research on student use of technology in social studies, we believe it is important to provide a contextual background of social studies. Social studies developed into a field of study during the early part of the twentieth century. From that time to the present, ongoing discussions have taken place about social studies on “what should be taught to whom, when, and in what order” (Thornton, 2008). Levstik and Tyson (2008) wrote that, “Social studies educators’ long-lasting discussion regarding the scope, sequence, and purpose of social studies means that generalizations about the field can be elusive” (p. xxvi). As a result, providing a single framework that defines and describes social studies can be complicated, if not problematic.

An organization that has tackled this challenge is the National Council for the Social Studies (NCSS). The NCSS is a US based organization—although its membership includes individuals from 70 countries—that has been in existence for 90 years providing support for social studies educators and advocating for social studies in K12. The NCSS has been at the

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forefront of providing direction on social studies education. One of its greatest contributions has been the development of a set of national curriculum standards for social studies. The NCSS in 1994 released its first version of curriculum standards structured around ten themes of social studies for K12. In 2010, the organization published a revised version of these standards. Both versions are based on the primary purpose of social studies as described by the NCSS. According to the NCSS, "The primary purpose of social studies is to help young people make informed and reasoned decisions for the public good as citizens of a culturally diverse, democratic society in and interdependent world" (NCSS, 2008, para. 1). At the core of this purpose, "is the promotion of civic competence—the knowledge, intellectual processes, and democratic dispositions required of students to be active and engaged participants in public life" (NCSS, 2010, para. 2).

How can this purpose be carried out? Thornton (2008) discussed two common approaches in *Continuity and Change in Social Studies*: Social Studies as social science *and* Social Studies as social education. Within the social science approach, the foundation for the curriculum comes from the content and skills deemed to be currently important by the scholars in the various disciplines that comprise social studies deem to be currently important (Thornton, 2008). These core disciplines of the curriculum traditionally have been history, geography, and government/civics. Over the years, other disciplines such as, anthropology, archaeology, economics, psychology, and sociology have been added to the curriculum. Social studies as social science could be considered a highly discipline-based approach. Social studies as social education takes a more integrated approach to the curriculum by pulling from various disciplines. Social education focuses on "identifying the individual and social demands of associated living and then deciding what material from the social sciences (and collateral material) is relevant to those demands" (Thornton, 2008, p. 5).

No matter what approach is taken, if students are to meet the primary purpose of social studies, they need to have exposure to a diverse domain of knowledge and have the skills to think critically, problem-solve, collaborate, and act conscientiously in addressing complex issues. For teachers, this means using innovative approaches to engage students as thinkers and problem solvers so students develop into successful global citizens and leaders of the twenty-first century. Designing an environment where students have the opportunity to learn and practice these skills while exploring social studies content can be challenging, but not impossible. A key component is the role educational technology can have in facilitating teaching and learning in the social studies. This idea is the focus of the chapter.

The remainder of the chapter is organized into four sections. The first is a synopsis of past literature reviews on technology and social studies. Sections two and three are overviews of research focusing on student use of technology in social studies specifically in the areas of civic education and historical thinking. These areas were selected because they cut across all approaches to social studies, and the content and skills associated with each are instrumental in helping students meet the primary purpose of social studies—civic competence—as outlined by the NCSS. The final section is a summation of the literature reviewed and a look at potential directions future research in technology and social studies could take.

Examining the Research: Time to Focus on Student Use

Over the past two decades, a number of comprehensive literature reviews on social studies and technology have been conducted (e.g., Berson, 1996; Ehman & Glenn, 1991; Swan & Hofer, 2008; Whitworth & Berson, 2003). With each review, a similar conclusion has been drawn: "…while pockets of exemplary activity exist, the anticipated widespread diffusion of technology in K-12 social studies has failed to materialize" (Swan & Hofer, 2008, p. 304). In 1997, Martoella described technology as "the sleeping giant" because of this unrealized potential. Despite the unrealized potential, the most recent reviews of the literature point to strides that are being made to wake "the sleeping giant."

The majority of the literature in social studies and technology over the past two decades has primarily been on the availability of social studies technology resources and the use of the Internet to access information (Friedman & Heafner, 2006; Whitworth & Berson, 2002). This is especially true of the literature in the 1990s when advocacy of technology was a primary thrust. In recent years, two growing bodies of literature have emerged: teacher-centered uses of technology (e.g., Bennett, 2003; Doppen, 2004; Friedman & Hicks, 2006; Swan & Hicks, 2007; VanFossen & Berson, 2008; Whitworth & Berson, 2003; Zhao & Hoge, 2004) and the preparation of preservice teachers to use technology in social studies (e.g., Brush & Saye, 2009; Crowe, 2004; Diem, 2002; Mason, Berons, Diem, Lee, & Dralle, 2000; Saye & Brush, 1999). A much smaller body of literature that focuses on student-centered uses of technologies in social studies is beginning to grow. Our review focuses on this area. Although we concentrated on research in K12, literature dealing with higher education was included because we believe it can inform K12. We primarily examined research available from 2000 to the spring of 2011.

Educational Technology in Civic Education and Historical Thinking

Civic Education

Because civic competence is the primary goal of social studies (National Council for the Social Studies, 2010), K12 social studies curricula should help students understand that civic education is not a list of mechanical skills for a test, but knowledge for "creating a public" (Postman, 1995, p. 18). Civic learning should include a variety of teaching and discovery methods that enable students to understand the roles and responsibilities of democratic citizens, as well as promote knowledge, skills, and dispositions that enable citizens to participate in and sustain democracy (Mason & Silva, 2001; Patrick & Vontz, 2001). Civic participation can include activities such as voting, engaging in deliberations, community service, and working with others to influence or inform public policy.

Many scholars argue that technological advances and increased access to technology resources are helping citizens in the twenty-first century explore and conceptualize what it means to be a citizen, engage in thoughtful deliberations, consider multiple perspectives related to civic ideals and practices, and actively participate as global citizens (Bers, 2008; Montgomery, 2008; Sunal, Christensen, Shwery, Lovorn, & Sunal, 2010). While a digital divide still exists for some groups, general access to technology has increased and become more efficient around the world in the last 10 years (Montgomery, 2008). Computers come in many shapes and sizes and are no longer confined to desktops. Cell phones are no longer primarily used for talking. A smart phone can provide Internet access, a high-resolution digital camera, and a video camera all in one device. Internet connections have moved from slow dial-up speeds connected through the phone line to wireless, high-speed broadband connections.

Over the last two decades information on the Web has also evolved from a passive, read only resource into a more interactive and collaborative resource that is user-centered. Interactive Web sites, streaming video sites such as YouTube and Discovery Streaming, wikis, blogs, Skype, and social media sites like Facebook and Twitter are just a few of the resources that can be used to promote the common good, provide multiple perspectives on issues, raise awareness for social justice, and foster responsible civic participation in the twenty-first century.

This section focuses on the literature related to the impact, as well as the shortcomings, of technology on civic knowledge, skills, dispositions, and action over the last decade. We explore topics related to the civic engagement of the Dot Net generation, the influence of the Internet on civic participation, the use of Web sites, simulations, and video games to engage young people in civic activities, and the creation of online communities to facilitate deliberation.

Civic Engagement and Participation in the USA: A Closer Look at the Dot Net Generation. The citizens of every generation are defined by unique characteristics that are shaped by the world in which they live. Young people who were born between 1977 and 1987 are typically referred to as the Dot Net generation (Keeter, 2006). The citizens of this generation have grown up with the Internet and are deeply connected to interactive technologies, digital media, and instant access to information (Keeter, Zukin, Andoline, & Jenkins, 2002). They are often viewed as a liberal generation when it comes to social issues such as gay marriage, interracial dating, and immigration (Keeter, 2006). Until recently, the majority of this generation was also disengaged from government and traditional political activities such as voting and supporting politicians (Bennett, 2003).

Over the last three decades, overall voter turnout at the polls by the younger generation has been low in comparison to older voters. However, according to a Circle Report published by the Pew Research Center on exit poll data from the last three presidential elections, this trend appears to be changing (Godsay & Kirby, 2010). Between the 2000 and 2004 presidential election there was a 9 % increase in voter turnout among young people (ages 18–29). In the 2008 presidential election, there was an additional 2 % increase, raising the total number of young people (ages 18–29) who voted to 51 %. In addition to turning out at the polls, in 2004 young people were also actively involved in publically supporting candidates (e.g., attending rallies, wearing buttons, displaying signs or bumper stickers) at rates that equaled or surpassed citizens from the Baby Boomer generation (Keeter, 2006). Results from a National Civic Engagement Survey (Keeter et al., 2002) additionally indicated that this generation was more engaged in other aspects of civic life such as volunteering, problem-solving in the community, consumer activism (i.e., boycotting a product to punish a company or buying a product to reward a company), and voicing their opinions on the Internet, in the newspaper, or by signing petitions (Keeter et al., 2002). Based on these results we can conclude that young people from the Dot Net generation are not as apathetic and disconnected from their civic duty as they were once perceived. The next section examines whether or not technology had any influence on this increase in civic participation.

Influence of the Internet on Voting in Presidential Elections. The role of the Internet in election activities and civic engagement has continued to develop and grow over the last 10 years. According to the Keeter et al. (2002), only 18 % of

Americans used the Internet for election news in 2000. The main reason cited for Internet use was convenience. The online audience in 2000 showed less of an interest for engaging in civic activities and more of an interest in accessing information. Media sites such as CNN, the Wall Street Journal, C-SPAN, PBS, and MSNBC.com were seen as more useful than campaign sponsored Web sites. Participating in Internet polls was popular, but engaging in conversations with other citizens in political chat rooms was not (Kohut & Rainie, 2000).

In contrast to the 2000 presidential election, the Internet played a pivotal role in the 2004 elections. The Pew Internet and American Life Project published a report—*Internet and the Campaign 2004*—that indicated these increases were attributed to the growing number of broadband versus dial-up Internet users. During this election, 75 million citizens used the Internet to get news and information related to the election, discuss candidates and political issues via email, volunteer for election events, or make donations to campaigns. Twenty-nine percent of the general public reported that they used the Internet for election news in 2004. This was up from 18 % in 2000. Notably, 27 % of these people said that the information they found on the Internet swayed their actual vote, while 23 % said the information they read actually encouraged them to go out and vote. While convenience was still the main reason cited by most Internet users for getting political information online, more than half of these users reported that they liked going online because they could access more information than from traditional news sources on TV that were often filtered and offered only one perspective (Rainie, Horrigan, & Cornfield, 2005).

The 2008 election report, compiled in the spring before the Presidential election by the Pew Internet and American Life Project, showed that online use for election related activities had already increased when compared to online activity during the spring before the 2004 election. In addition to an overall increase, there were also several new online firsts that came along with 2008 election: (1) three of the presidential candidates actually declared their candidacies online (Obama, Clinton, and Edwards), (2) fundraising records were broken through online donations, (3) citizens were able to actively participate in key debates by asking candidates questions live via YouTube, and (4) candidate supporters were recruited through sites such as Facebook and MySpace. Additionally, more users also read candidates' speeches and position papers online and watched live debates and announcements than in the 2004 election. Activities such as this indicate that users were accessing primary source documents and interpreting information beyond what the news sources were filtering and posting. In spring 2008 there was also an increase in citizens actually contributing to the political conversation by posting their own commentary on blogs and message boards, forwarding information about candidates to other people via email, volunteering time for campaign activities, watching online videos and announcements, donating money, signing up for political newsletters, and signing petitions (Rainie & Smith, 2008).

In contrast to the positive results associated with the increased use of the Internet to engage citizens in the political process, a survey of 1,553 Internet users showed that 60 % of online users surveyed believe the Internet is full of misinformation and propaganda that gullible voters might believe without considering or investigating alternative viewpoints (Rainie & Smith, 2008). Thirty-five percent of those surveyed believe that the people with the most extreme views and loudest ideas overshadow the average voter's positions. Internet users age 65 or older were more likely to believe that the Internet is full of extreme views not held by the average citizen (Rainie & Smith, 2008). Based on the literature, it appears that the answer to the question about whether or not the Internet has had a positive influence on civic engagement and participation will depend on whom you ask. What is clear from the research is that access to the Internet has brought about increased civic engagement and participation.

Using Web sites, Simulations, and Video Games to Engage Youth in Civic Duties. In addition to engaging and informing citizens on issues related to the political process, the Internet can also be used to engage youth in a variety of other civic duties. Montgomery (2008) explored the promises and dangers of the Internet as a way to engage youth in civic duties by surveying and analyzing more than 300 Web sites created by and for young people. She discovered that these Web sites included a variety of different goals. Some sites targeted a wide general audience while others were geared toward specific demographics such as underserved youth, youth in urban or rural areas, and groups of youth with different ethnic or racial backgrounds or sexual orientation. Some of the Web sites provided read-only access to information, while others were used to engage young people in the civic and political process. The study concluded that Web sites could be used as a space for youths to express ideas, collaborate, deliberate, build community, enhance their knowledge, and strengthen their own civic identities. Likewise, these sites also provided youth with a platform to get involved and participate in civic activities such as fundraising, volunteering, and connecting with elected officials. The danger of the Internet as a tool was also highlighted in that the Internet could be seen as a tool that could weaken the possibility for active civic participation by our youth. Montgomery (2008) stated that, "the move towards increasingly personalized media and one to one marketing may encourage self-obsession, instant gratification, and impulsive behavior" (p. 42). Potential behaviors such as these draw attention to the importance of key principles to guide democratic communication that include an emphasis on digital citizenship and attention to civility when using the Internet.

In an attempt to reinforce the positive influence of the Internet on civic engagement, Web-based simulations have been developed and used. Bers (2008) conducted a study that described how a well-designed Internet-based simulation could foster online civic engagement. Two different multiyear longitudinal studies involving 39 students from two cohorts of incoming university freshman were conducted using the Active Citizenship through Technology (ACT) educational program. One of the goals of ACT was to promote civic engagement both at the campus and the community level. This program required students to come together for 3 days to use Zora (a technology-based civic education program) to work with other students to create and inhabit a virtual campus of the future, while also discussing relevant civic issues and participating in electoral simulations and deliberations. At the end of the intensive program, the participants made a short digital video about their virtual campus. The results from the surveys, combined with the online activities and conversations derived from Zora, supported students' active civic engagement by encouraging them to exercise their voice and engage in deliberations related to important issues. Students who participated in the ACT program were more likely to express their political views than the control group who did not participate. Overall, these students' attitudes about a variety of civic and political issues were positively influenced after participating in the simulation (Bers & Chau, 2010).

While some experts suggest that video games can lead to aggression and social isolation (Bers, 2010), there is a plethora of literature (Bers, 2008, 2010; Bers & Chau, 2010; Gee & Levine, 2009; Kahne, Middaugh, & Evans, 2008; Lenhart et al., 2008; Squire & Jenkins, 2004) available to support game play as a way to develop civic engagement and participation. Bers (2008) presented excerpts of scenarios from children aged 11–16 who also used Zora technology to develop a virtual city. The excerpts revealed that the children learned new concepts and ways of thinking about identity and civic life and participated in an online forum for discussing civic issues related to their virtual cities. Gaming appears to be one more way to encourage meaningful civic participation beyond the classroom.

Online Communities and Deliberation. True deliberation involves people who are willing to consider and challenge multiple viewpoints, be open and fair-minded, and weigh all alternatives before forming a position (Parker, 2005, 2008). Since deliberation is often referred to as the foundation of democratic citizenship it is important to consider how many sites on the Internet support communication among people who already share the same ideas or viewpoints. On the Internet any anonymous user can write a blog, make a post on a message board, or create a wiki without any consequence for how his or her ideas or thoughts might affect other people. As a result, some scholars argue that online spaces do not support or foster true deliberation (Galston, 2000; VanFossen, 2006; White, 1997; Wilhelm, 1998). Galston (2000) concluded that factors such as voluntary memberships in groups based on common interests, the ease at which participants can leave a discussion when the views discussed are not in alignment with their personal beliefs, and the inability to read nonverbal cues and facial expressions while online are all barriers that prohibit meaningful and voluntary deliberations in online groups. Gutierrez (2010) also called into question the lack of civility among everyday citizens in our society today. Because Web sites and online activities are not always monitored, attention to digital citizenship or "netiquette" in the classroom is critical to the development of thoughtful and civil twenty-first century citizens who are prepared to participate in online communities and deliberations.

In contrast to the claims made by scholars who questioned whether or not the Internet can provide a forum for true deliberation, the results from the Sunal et al. (2010) study indicated that online communication supported 125 teachers from five different nations as they attempted to define citizenship in the context of their own culture. The online discussion groups in this study were structured to help participants reflect on their own beliefs about citizenship, as well as consider the different perspectives about citizenship shared by participants from other cultures. The overall consensus from this study is that big ideas related to culture and citizenship in the twenty-first century are evolving and are influenced by factors such as global communication, economics, politics, education, and societal equality. Sunal et al. (2010) concluded that it is important for teachers to consider and challenge their own perspectives related to culture and citizenship in comparison to others because it impacts how they teach, the materials they use, and how they interact with students who may or may not share the same culture. It is also equally important for teachers to provide their students with open forums, both online and face-to-face, which allow them to question stereotypes, identify similarities and differences, and consider alternative ideas and beliefs so ideas related to democracy and civic participation can continue to develop and evolve. If teachers are going to use online communication to support classroom deliberations, then structured ground rules must be established and teachers must establish an online presence to monitor posts and ensure that multiple viewpoints are shared and respected.

Historical Thinking

History can help K12 students understand people and societies. History can also help students understand that the past causes the present, and the future is determined by the present. Sterns (1998) wrote that, "studying history encourages habits of mind that are vital for responsible public behavior, whether as a national or community leader, an informed voter, a petitioner, or a simple observer" (para. 15). In essence, history helps students develop civic competence.

History in K12 is the study of an amalgamation of names, dates, places, events, and ideas. Although having a solid foundation of knowledge built around these elements is essential for students to understand history, genuine historical understanding involves more. According to the *National Standards for History Basic Edition* (1996) developed by the National Center for History in the Schools at UCLA:

> In addition, true historical understanding requires students to engage in historical thinking: to raise questions and to marshal solid evidence in support of their answers; to go beyond the facts presented in their textbooks and examine the historical record for themselves; to consult documents, journals, diaries, artifacts, historic sites, works of art, quantitative data, and other evidence from the past, and to do so imaginatively—taking into account the historical context in which these records were created and comparing the multiple points of view of those on the scene at the time. (para. 1)

Scholars (Kobrin, 1996; Levstik & Barton, 2001; van Hover & Yeager, 2002; Wineburg, 1991) have promoted activities such as these because they involve students in "doing history". Students who engage in "doing history" are doing more than gaining historical understanding; they are developing historical thinking skills of chronological thinking, historical comprehension, historical analysis and interpretation, historical research capabilities, and historical issues-analysis and decision-making (NCHS, 1996). The following sections examine literature on student-centered uses of technology that help students develop historical knowledge and historical thinking skills. We explore specific areas of technology use—digital primary sources and simulations and games.

Digital primary sources. Understanding and analyzing past events and conditions is derived from exploring a variety of evidence. From an historical perspective, evidence is referred to as the source. The source can be primary, secondary or tertiary. Although each type of source is important, the primary source is the heart and soul of history. The Library of Congress (2011, April 28) indicates that, "Primary sources are the raw materials of history—original documents and objects which were created at the time under study" (para. 1). These documents and objects provide a direct window into the past allowing students to see, hear, and read the events through the lens of those who made history or were there to experience as history unfolded. "Examining primary sources gives students a powerful sense of history and the complexity of the past" (Library of Congress, para. 2). Berson (2004) discussed that primary sources are valued as instructional tools to assist students in learning historical content and in the development of critical thinking skills.

Swan and Locascio (2008) point out that libraries, universities, and government agencies have developed digital archives of historical documents in response to the growing demand for access to primary and secondary sources. These digital archives provide teachers and students with the ability to freely view and download documents for use in the classroom (Swan & Locascio, 2008). Digital archives have drastically changed who is able to conduct historical research and how the research is done (Bolick, 2006). Granting students access to explore the raw materials of history through digital history sites and other digital media has the potential to actively engage students in the analysis and interpretation of history. "Because learning through historical inquiry with primary sources is a radical shift from how social studies content is typically taught, teaching and learning with digital archives holds the potential of transforming the nature of social studies education" (Bolick, 2006, p. 123).

There are several large-scale digital archive projects that have been discussed in the literature such as the Library of Congress' *American Memory* (http://memory.loc.gov/ammem/index.html), the National Archives' *Digital Classroom* (http://www.archives.gov/education/index.html), the National Endowment for the Humanities' *Edsitement* (http://edsitement.neh.gov/), and George Mason University's *History Matters* (http://historymatters.gmu.edu/) to name a few. In *Fostering Historical Thinking with Digitized Primary Sources*, Tally and Goldenberg (2005) discuss four ideas about using primary source documents with students that have become evident as a result of these projects and the literature about them.

> First, using primary documents gives students a sense of the reality and complexity of the past; the archives thus represent an opportunity to go beyond the sterile, seamless quality of most textbook presentations to engage with real people and authentic problems. Second, the fragmentary, idiosyncratic, and often contradictory nature of primary documents can help students understand the problematic nature of historical evidence and the need for critical thinking about sources and bias. Third, the multimedia nature of most digital archives—the way they combine textual, audio and image formats—offers students with diverse learning styles multiple pathways into thinking about historical and cultural problems. Finally, the search engines that accompany most digital archives—for example, full-text searches on oral history archives or subject-based searching on photographic archives—enable students to query materials in novel ways that only experts have been able to do before now. (Tally & Goldenberg, 2005, p. 3)

Tally and Goldberg go on to say that digital archives hold a great deal of promise in making it possible for students and teachers to engage in authentic historical thinking processes (p. 3). Despite the promise primary sources hold for helping students develop historical thinking, using them does not naturally bring about this type of thinking. The development of historical thinking occurs as a result of a teacher "who asks critical thinking questions of a document, or who elicits the bias or perspective of the author of the document" in order for students to practice and develop historical inquiry skills (Swan & Locascio, 2008, p. 176). As with use of all technology, the teacher and pedagogy used are the key elements in determining how effective the use of digital primary resources will be for students.

Simulations and games. There is a long tradition of using simulations and games in social studies. Researchers (e.g., Ehman & Glenn, 1991; Frye & Frager, 1996; Gredler, 1996; Grimes & Wiley, 1990; Penn, 1988; Reigeluth & Schwartz, 1989) over the past 50 years have documented the effects these can have on student learning. Students involved in simulations and games can experience increased intrinsic motivation (Malone & Lepper, 1987), improved engagement (Ketelhut, 2007) enhanced attitudes toward subject matter (Ke, 2008), and a sense of personal control over their learning (Ehman & Glenn, 1991). Simulations and games can provide students with the opportunity to work on higher level thinking skills such as problem solving and decision-making (Leemkuil, de Jong, de Hoog, & Christoph, 2003). Simulations can also expose students to big ideas and concepts (Akıllı, 2007). Berson (1996) wrote that, "past studies have noted improved achievement in the areas of factual recall, applied learning, and problem solving" (p. 489). Despite the positive outcomes researchers have indicated as a result of student participation in simulations and games, research exists showing mixed results of classroom simulation use.

Several recent studies (Charsky, 2004; Gehlbach et al., 2008; Jurica, 2010; Sardone & Devlin-Scherer, 2010; Squire & Jenkins, 2004) have examined the use of computer-based simulations and games in social studies. Charsky (2004) studied the use of *Civilization III*—a commercially developed historical strategy game—in a ninth-grade advanced placement global history class. Although he observed no statistical difference in student performance on essay tests to measure historical understanding, he found that students were able to understand that historical development was "more than a sequential series of cause and effect events" (p. 134). Squire and Jenkins (2004) also conducted a study on the integration of *Civilization III* developed into a world history unit in three different contexts (an after school program for middle school students, summer media camp for high school freshman, and a world history class for high school freshman). Squire and Jenkins indicated that students increased their background knowledge of world history, and for some students they developed a "nascent systemic level understanding of world history" (p. 326). Despite this, he indicated that there was no direct evidence that this knowledge translated into consistent historical understanding and thinking.

The results from Jurica's (2010) study on the use of the simulation *Oregon Trail II* in two classrooms in a rural elementary school in the southwest USA resulted in similar findings to the studies conducted by Charsky (2004) and Squire and Jenkins (2004). Jurica found that students were motivated to use the simulation; however, the simulation did not affect the students' abilities to think historically (p. 1932). Jurica indicated that this could have been as a result of the simulation not being an integral part of the instructional unit. She wrote that, "Research which explores the use of simulations as an integral part of an instructional unit may find an effect of conveying information" (p. 1932).

Gehlbach et al. (2008) examined the use of a Web-based, role-laying simulation called *GlobalEd* in middle school social studies classrooms. "GlobalEd is a five-week web-based simulation in which students negotiate treaties involving current world issues while taking the perspective of the country they are representing" (Gehlbach et al., 2008, p. 898). The research team was interested in examining whether student interested in social studies increased after participating in the *GlobalEd* simulation. The study used a pre-post design to examine 305 middle school participants in the simulation. Pre- and post-assessments for interest in social studies, interest in issue area, importance of social studies, and social prospective taking. Additionally, a multiple-choice test of the content knowledge the students were covering in social studies during the simulation was given as pre- and post-assessments (p. 901). The researchers found that students participating in the simulation had an increased interested in social studies at the conclusion of the simulation. According to Gehbalch et al., "The most important finding that future studies of GlobalEd or comparable simulations could provide would be that students' participation in the simulation caused them to be more motivated, more interested, or to achieve more highly" (p. 908).

Conclusions and Future Directions

Literature reviews conducted over the past two decades on social studies and technology (Berson, 1996; Ehman & Glenn, 1991; Swan & Hofer, 2008; Whitworth & Benson, 2003) have highlighted the potential of technology to enhance teaching and learning in social studies. The literature in social studies and technology over this time focused primarily on the availability of social studies technology resources and the use of the Internet to access information (Friedman & Heafner, 2006; Whitworth & Berson, 2002). The literature primarily advocated for technology use in social studies and context-specific uses of various technologies. In recent years, there have been two growing bodies of literature over the past few years. One area has been teacher-centered uses of technology in social studies (e.g., Doppen, 2004; Friedman & Hicks, 2006; VanFossen & Berson, 2008; Whitworth & Berson, 2003; Zhao & Hoge, 2004) where researchers have described and examine how teachers have integrated specific technology into social studies classrooms. The second area has been the preparation of preservice teachers to use technology in social studies (e.g., Bolick, Berson, Friedman, & Porfeli, 2007; Brush & Saye, 2009; Crowe, 2004; Diem, 2002; Mason et al., 2000).

While we recognize the importance of these areas of the literature, our focus was on a smaller body of literature that is beginning to grow. The literature we reviewed focused on student-centered use of technology in social studies specifically in the areas of civic education and historical thinking. We found research demonstrating effective uses of technology to provide students with opportunities to think critically, problem-solve, and collaborate as they deal with complex issues. The literature also included studies describing and analyzing innovative approaches for using technology to engage students as thinkers and problem solvers in an effort to help students gain civic competence inside and outside the classroom. Additionally, the research demonstrated that student historical understanding is developed through a variety of experiences inside and outside the classroom.

When reflecting on the literature as a whole, we see a great many possibilities that exist for potential future directions of the research in technology and social studies. Although it is difficult to predict with great certainty what lines of research will continue or emerge, we believe the research over the past decade does provide clear indications from which predictions can be made. As advances in technologies are made, literature advocating and describing innovative uses will persist. The research will also carry on in teacher education on how to best prepare future teachers to use technology in social studies. We see a line of research emerging in this area that explores the effects on preservice teachers when they are provided with opportunities to observe the use of technology in authentic classroom settings and implement technology in their own teaching in these environments. Studies like these will allow researchers to examine what impact these opportunities have on how (e.g., student-centered, teacher-centered) future teachers integrate technology into social studies. Additionally, researchers will be able to examine if these opportunities affect the dispositions, believes, and attitudes of preservice teachers toward technology and social studies. Longitudinal studies that follow preservice teachers once they are in the their own classrooms would be useful to determine the effects various models of technology in teacher education programs have on teacher use of technology in social studies. Along a similar line, we see researchers continuing to spend time in the classroom examining why some teachers use technology in social studies and others do not. This line of research builds on the literature about barriers to technology integration but moves beyond the barriers of time, access, and training. Examining teacher beliefs and attitudes about the purpose and usefulness of technology and of social studies could provide useful insights for teacher educators and for those responsible for teacher professional development. Finally, with the increase in student access to personal technology (e.g., smart phones, laptops, tablet devices), a line of research on how students use these tools to engage in social studies content and related activities (in and outside the classroom) would be beneficial. Additionally, understanding how students use social networking and Web-based tools could give insights into how these tools could be exploited to engage students in learning social studies content and skills.

No matter what specific lines of research continue or emerge, As Doolittle wrote in 2001—which we believe still rings true a decade later—"It is time within social studies education to take a long look backwards at the beliefs, assumptions, and theory underlying the domain, so that the look forward to practice and pedagogy is clear, informed, and valid. It is time to stop professing technological and pedagogical integration and to start integrating with purpose and forethought" (para. 7). A sustained and focused line of research is needed to demonstrate that technology can be used to move "social studies instruction away from passive, teacher-dominated approaches emphasizing recall and regurgitation toward active, student-centered forms of learning demanding critical and conceptual thinking from *all* students at *all* levels" (Crocco, 2001, p. 2).

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Visual Arts Education

46

Barbara B. Lockee and Feihong Wang

Abstract

Given the prevalence of the use of the image for communication in modern society, along with the rapid evolution of electronic tools to create such images and communicate through visual channels, it is easy to understand the dramatic changes that have occurred in teaching and learning in the visual arts. Technologies have evolved not only to provide unprecedented access to global resources for art education but also to offer new tools for the creation of art—thus representing both the medium of instruction as well as the resulting visual message produced by the developing artist. The adoption of electronic technology in art making has had a profound influence on approaches to visual arts instruction; other factors also have converged to impact present-day educational trends in this discipline. To understand the origins of these factors, a brief review of the history of visual arts education is provided. Following the historical overview, contemporary instructional design and technology trends are examined in relation to the teaching and learning of visual arts, as well as recent developments in educational research focused within this area of interest.

Keywords

Visual arts • Media arts • Visual arts education

Introduction

Given the prevalence of the use of the image for communication in modern society, along with the rapid evolution of electronic tools to create such images and communicate through visual channels, it is easy to understand the dramatic changes that have occurred in teaching and learning in the visual arts. Technologies have evolved not only to provide unprecedented access to global resources for art education but also to offer new tools for the creation of art—thus representing both the medium of instruction as well as the resulting visual message produced by the developing artist. As Lin (2005) stated, "The development of computer technology in the late twentieth century has had a huge influence at every level of education. Becoming an aggressive user of computer information technologies has become an important qualification for an art teacher" (p. 4).

The purpose of this chapter is to review research and development in instructional design and the use of educational technology related to education and training in the visual arts. Because technological innovations have so greatly impacted the field of visual arts, it is necessary to begin with defining the parameters of the discipline. In addition, while the adoption of electronic technology in art making has had a profound influence on approaches to visual arts instruction, other factors also have converged to impact present-day educational trends in this discipline. To understand the origins of these factors, a brief review of the history of visual arts education is provided. Following the historical overview, contemporary instructional design and technology trends are

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examined in relation to the teaching and learning of visual arts, as well as recent developments in educational research focused within this area of interest.

Defining Visual Arts

One of the challenges associated with examining research and practice related to visual arts education is the very definition of visual arts itself. The National Art Education Association (NAEA) defines the visual arts as

> … traditional fine arts such as drawing, painting, printmaking, sculpture, communication and design arts including film, television, graphics, product design, architecture and environmental arts such as urban, interior, and landscape design, folk arts; and works of arts such as ceramics, fibers, jewelry, works in wood, paper, and other materials (NAEA, 1994a).

While this NAEA definition maintains a broad perspective on the different forms, products, and environments created through the visual arts, other scholars distinguish the visual arts from the media arts (McCarthy, Ondaatje, Brooks, & Szanto, 2005; Peppler, 2010), with the delineating factor being art that is produced through electronic means and mechanisms, for which some would require a differing literacy based on the cultural implications and contexts in which media have come to be known and utilized (Ferneding, 2007). Peppler contends that:

> The professional field of media arts encompasses all forms of creative practice involving or referring to art that makes use of electronic equipment, computation, and new communication technologies. Beyond surface forays with technology (such as typing, word processing, and web surfing), media art encourages designing, creating, and critiquing genres that connect to youth culture and more actively engage youth in the process of learning than what is traditionally offered in schools, particularly those in marginalized communities (2010, p. 2)

For the purpose of this chapter, a broader definition of the visual arts is presumed, including both traditional and electronic forms of artistic endeavor. The purpose behind the more inclusive definition is to provide a comprehensive perspective on all visual arts, especially with regard to the role of technology in teaching them.

The History of Visual Arts Education

Boughton (2000) describes the history of school-based visual arts education as relatively short, in existence for less than 200 years, and distinguishes such educational programs from the training of professional artists, the history of which dates back to the beginnings of art itself. Prior to the early 1900s, European guilds focused on the apprenticeship model of preparing artists. When the movement to educate students about art began, two strands emerged in Europe, the themes of which were targeted at differentiating the fine arts and the applied arts, driven by the class system evident at the time. The upper class was interested in enhancing knowledge and appreciation of aesthetics, with applied arts being of interest to the working class because of the industrial utility of technical drawings and related handiwork. At the turn of the twentieth century, much of the Western world had adopted formalized art education for the masses across grade levels, in higher education, and in specialized trade schools for art and design (Boughton, 2000).

Supported by the philosophy of John Dewey (1934) and his emphasis on educating the whole child (Eisner, 2002), the visual arts maintained a prominent status in American education until the Sputnik era (Walling, 2001). Reviewing the history of visual arts education in the United States, Walling described the "convergence of influences" (p. 626) at the turn of the twenty-first century to prompt a resurgence of the visual arts from the outer fringes of K-12 school curricula back to a core position. These influences include the development of national standards for art by the NAEA, the emergence of discipline-based art education (DBAE) theory (Dobbs, 1992, 2004), an emphasis on constructivist approaches to teaching, and the incorporation of new technologies into the visual arts classroom. Each of these issues is addressed in the following section, as they each connect to related instructional design and technology trends.

More recently, tremendous emphasis has been placed on the teaching of science, technology, engineering, and math (STEM) content and as a result, the teaching of visual arts is being negatively impacted (DePlatchett, 2008). A study on the influence of the No Child Left Behind (NCLB) legislation on visual arts education in the United States reflects diminished time for art instruction, reductions in necessary instructional resources, and in extreme cases, the elimination of visual arts courses altogether (Sabol, 2010). At the time of this writing, the Los Angeles Unified School District has recently proposed to eliminate its visual arts program for elementary schools altogether, as a budget reduction strategy (Arts for LA, 2012). While many feel that the visual arts have been marginalized within the school curriculum in recent years (Dobbs, 2004; Eisner, 2002), some see new hope for the visual arts in that technological advances are finding their way into the classroom (Sabol, 2010) and helping teachers leverage their features to enhance educational opportunities for learners.

Instructional Design and Technology Trends in Visual Arts Education

Curriculum Sea Change: Discipline-Based Art Education

As Walling (2001) stated, the development of DBAE in the 1990s was a driving force in shifting the emphasis of visual arts education from a singular focus on student art making to a more

Table 46.1 National visual arts standards

Number	Content standard
1	Understanding and applying media, techniques, and processes
2	Using knowledge of structures and functions
3	Choosing and evaluating a range of subject matter, symbols, and ideas
4	Understanding the visual arts in relation to histories and cultures
5	Reflecting upon and assessing the characteristics and merits of their work and the work of others
6	Making connections between the visual arts and other disciplines

Note: Adapted from "National Visual Arts Standards," by the National Art Education Association, 1994a, 1994b, Copyright 1994 by the National Art Education Association. Retrieved from http://www.arteducators.org/store/NAEA_Natl_Visual_Standards1.pdf

comprehensive approach that would prepare students to be informed consumers of art and to appreciate the design features of artistic endeavors. The four disciplinary areas that comprised DBAE include art production, art history, art criticism, and aesthetics (Dobbs, 1992). The dissemination and adoption of this broadened curriculum design were advanced through multimillion dollar support from the Getty Center for the Arts. While the financial backing behind this large-scale curriculum reform initiative has since lapsed, the impact of the DBAE movement significantly changed the content and concepts that are addressed in visual arts curricula today (Dobbs, 2004).

Standard-Driven Outcomes

Reflecting the emphasis on accountability in education that also began during the 1990s, arts education advocates collaborated to develop the National Visual Arts Standards (1994b). Table 46.1 delineates the six resulting standards, which have been adopted by 49 states in the United States.

Currently, a group of art organizations and states are working in partnership to update these national standards. This newly formed group, the National Coalition for Core Arts Standards, states that

> In creating the next generation of core arts standards, the primary goal of NCCAS is to help classroom educators better implement and assess standards-based arts instruction in their schools. Toward that goal, the revised arts standards will address 21st-century skills, guide the preparation of next-generation of arts educators, and embrace new technology, pedagogy, and changing modes of learning (NAEA, 2012).

While the professional associations in the arts developed these discipline-specific standards for the visual arts, others have aligned the National Educational Technology Standards for Students (NETS-S), developed by the International Society for Technology in Education (ISTE), to the NAEA visual arts standards (Gura, 2008; McGraw & Lampert, 2010). In his book, "Visual Arts Units for All Levels," Gura (2008) details

Table 46.2 Sample alignment of ISTE standard to National Visual Arts Standards

NETS•S standard	NAEA content standard
1. Creativity and innovation: Students demonstrate creative thinking, construct knowledge, and develop innovative products and processes using technology	CS-1. Understanding and applying media, techniques, and processes
(a) Apply existing knowledge to generate new ideas, products, or processes (b) Create original works as a means of personal or group expression (c) Use models and simulations to explore complex systems and issues (d) Identify trends and forecast possibilities	CS-2. Using knowledge of structures and functions

Note: Adapted from "Visual Arts for All Levels," by M. Gura, *National Educational Technology Students Curriculum Series*. International Society for Technology in Education, Eugene, OR. Copyright 2008, ISTE

20 lessons that address standard visual arts concepts taught through incorporation of digital technologies, all of which are based on a combination of the ISTE and NAEA standards. Table 46.2 presents an example of Gura's alignment of one of the ISTE standards to the NAEA standards.

Theoretical Influences

DePlatchett (2008) summarizes arts education from a theoretical perspective, maintaining that recent trends in visual arts instruction are based on cognitive theoretical trajectories including Vygotsky's constructivist learning theory (1978), to contemporary scholars DePlatchett (2008). DePlatchett states that

> These researchers contend that human beings learn most effectively when they: (1) construct meaning by attaching new knowledge to existing schema, (2) engage in opportunities for self-exploration, self-expression, and non-linear investigations, (3) acquire and adapt the protocols and procedures within disciplines and program areas, moving toward growing proficiency in transfer and independent use and application, following Vygotsky's zone of proximal development (p. 171).

Because many learning experiences in visual arts education involve the art making process, these theoretical stances are instantiated through common instructional strategies such as project-based or problem-based learning. These student-centered teaching methods are also connected to a related theory of constructionism.

Constructionism was conceived by Seymour Papert (1980) who realized that computers provide educators with an opportunity to engage students in active participatory learning (Kafai, 2006). Constructionism views learning as the building of relationships between old and new knowledge and interactions with others while creating artifacts of social relevance. It claims that the learning becomes particularly effective when

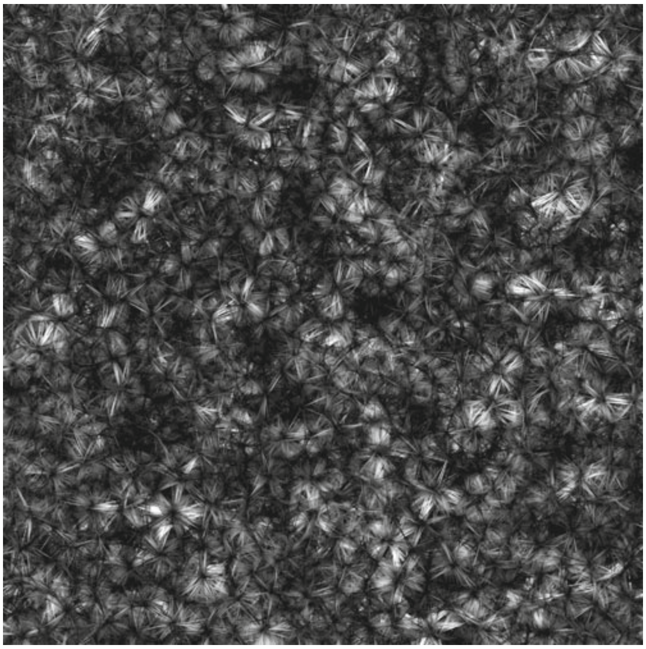

Fig. 46.1 Process Compendium (Introduction), 2004–2010, Digital video (11:06). Courtesy of Bitforms Gallery, New York

it takes place in the context of rich and concrete activates, in which the learner experiences while constructing personally meaningful public artifacts (Harel, 1991; Papert, 1980). Papert believes that when technological constructivist-based activities become accessible and widely used by society, they could be the major leading factors in the child's learning and cognitive development (Harel, 1991). Therefore, constructionists suggest structuring learning around the design process, an ideal fit for the visual arts curriculum (Papert, 1980). Though the constructionist approach to teaching has been in existence for over three decades, its influence is still evident in recent research and development based on Papert's original theory (Kafai, Peppler, & Chapman, 2009; Peppler, 2010, Reas & Fry, 2006). An example of a significant development related to this theory is Reas and Fry's creation of *Processing*, a software language designed "to teach fundamentals of computer programming within a visual context, to serve as a software sketchbook, and to be used as a production tool for specific contexts" (2006, p. 527). Figure 46.1 is an example of artwork created by Reas using the *Processing* software.

The Role of Technology in Visual Arts Education

Perhaps no other factor has so greatly influenced the current state of visual arts education as the incorporation of technologies into the teaching and learning process. For the visual arts, technology provides a new medium of artistic expression (Black & Browning, 2011; Gregory, 2009). As Tillander (2011) suggests, new media production tools that make the creative process more accessible are moving learners from consumers of art to producers of art. From an instructional design perspective, the act of creating visual art is at once an instructional strategy and a learning outcome.

Not all visual arts educators are embracing the adoption of technology for artist expression or instructional mechanism (Black & Browning, 2011; Delacruz, 2009). This resistance reflects a tension that has long existed in the relationship of technology to the visual arts. Bruce (2007) described the conflict as such:

> … at least since Socrates and Phaedrus went for their famous walk beside the Ilissus River, art and technology have also had a close, yet often stormy, relationship. At one time they present a model of wedded bliss, while at another, they fight, as if acceptance of one would spell the end of the other (p. 1355).

Some critics of the utilization of technology (here defined as electronic technologies) for the creation of visual arts contend that such employment detracts from the authenticity of the artistic experience, seeing technology and art as dichotomous entities (Bruce, 2007; Krug, 2004; Lin, 2005). Interestingly, Krug contends that media such as "paper, paint, and clay were new technologies at one point, just as digital media was new when Charles Csuri made his first computer generated artwork back in 1963" (2004, p. 3). Advocates for the use of technology in visual arts education see such tools as holding the potential to transform instruction (Ferneding, 2007, Krug, 2004) and to "permit students to engage in innovative forms of communication, expression, and learning using contemporary media rooted in their everyday lives" (Roland, 2010, p. 22).

Technology-Based Instructional Strategies

Much has been written about the integration of technology into the teaching of the visual arts. Recent technology integration textbooks include specific strategies to utilize technology in visual arts classrooms in support of instructional activities (DePlatchett, 2008; Gura, 2008; McGraw & Lampert, 2010; Roblyer & Doering, 2010). Each of these authors provides guidance for technology-based instruction in the visual arts, with listings of relevant examples and extensive Web-based resources to support the proposed instructional methods and desired outcomes. The following strategies are common themes across these resources, as well as found in other discourse about the use of technology for visual arts.

Art Making

Innovations in technology can support the art making process, the project-based approach serving as an instructional strategy. McGraw and Lampert (2010) indicate, "technology has tremendous potential to expand what constitutes fundamental skills and basic techniques in the art classroom" (p. 463). Technology-based tools provide the means for learners to engage in the creation of their own artwork in a way that was not possible before computing technologies were available. Roblyer and Doering (2010) suggest that technology can be used to "produce and manipulate digital images, support graphic design and 3-D modeling, support desktop publishing with graphics, and create movies as an art form" (p. 377).

Researchers at the University of Southern California's Institute for Creative Technologies produced a groundbreaking virtual reality project, virtual human twins Ada and Grace (named after Ada Lovelace and Grace Hopper). These twins interact with visitors at the Boston Museum of Science and provide suggestions about which exhibits match the visitors' interests (Fig. 46.2).

Often, technology is used as a mechanism to facilitate collaborative activities across disciplines, what Eisner (2002) calls the "integrated arts" (p. 39). In this approach, teachers from varied subject areas work together to develop instructional goals and activities around a specific theme, drawing on aspects of that theme for instructional events and assignments in each of the related courses (Parsons, 2004). For example, Ruble and Lysne (2010) describe such an integrated approach to teaching visual arts. Focused on an analysis of Miyazaki's film, *Spirited Away*, students examine a combination of issues related to social studies, environmental science, language arts, and visual arts. Using a team-based strategy, seventh graders develop a Japanese anime to reflect themes that they identify in the analysis of the film. Productions are featured in a "media festival" in which parents are invited to a viewing of the final animations. Interdisciplinary approaches such as this can engage learners in a variety of subject matter through leveraging interest in the use of new media (Peppler, 2010; Stokrocki, 2007).

Access to Resources and Expertise

In designing instruction for visual arts, teachers are no longer constrained when it comes to access to instructional materials. With Internet connectivity, students can not only access unlimited collections of artwork (Delacruz, 2009; Gura, 2008), but they can also interact with artists around the world (DePlatchett, 2008). The use of technology as an instructional delivery mechanism can provide learners the opportunity for virtual field trips to art museums (Gura, 2008; Proctor, 2011; Roblyer & Doering, 2010). Extensive collections of art have been made available through the Internet, providing instant access to masterpieces, as well as lesser known artwork. For example, the Google Art Project serves as a centralized entry point for dozens of museums around the world, as well as instructional support materials for teachers and the ability for students to create their own collection, virtually assembling works from across museums (Proctor, 2011).

Assessment

One of the challenges associated with visual arts education is the design of assessments that measure student learning and performance. The emphasis on constructivist approaches to instruction, along with the valuing of self-expression inherent in art education, can seem to be at odds with current interest in standard-based learning outcomes (Boughton, 2004; Eisner, 2002). Eisner suggests that there are identifiable outcomes that can be examined in the assessment of student learning in the visual arts: "the technical quality of the work produced, the extent to which it displays an inventive use of an idea or process, and the expressive power or aesthetic quality it displays" (2002, p. 183). The use of authentic assessment methods, such as project-based learning and electronic portfolios, provides relevant assessment mechanisms that align with the types of

Fig. 46.2 ICT Virtual Twins at the Museum of Science, Boston. Courtesy of the USC Institute for Creative Technologies

Fig. 46.3 Sneak On The Lot film review Web site. Courtesy of ISM Films, Inc.

desired learning and performance outcomes from visual arts instruction, as well as the teaching strategies employed to facilitate such outcomes. Gura (2008, p. 53) offers a rubric for the evaluation of student visual arts projects, the grading criteria being based on items including project completion, research and preparation, theme and concept, technical proficiency, technology usage, and creative expression.

Haanstra and Schonau (2007) review international research related to the use of portfolio-based assessment, among other assessment and evaluation strategies. Self-assessment and peer-assessment are also recognized forms of determining student learning in the visual arts (Soep, 2004). An innovative example of peer-assessment is offered by Independent Student Media Films (ISM Films). This organization maintains an online curriculum to support the use of filmmaking as an instructional strategy. Once students have created their productions, they can upload them to the Web site, "Sneak On The Lot" (www.sneakonthelot.com), for review by other student filmmakers, as well as professionals in the film industry (Fig. 46.3).

Research on Technology for Visual Arts Education

In 1994, Zimmerman led the NAEA's Committee on Research in Art Education, the outcome of which was the "Blueprint for Implementing a Visual Arts Education Research Agenda" (Zimmerman, 1994). The recommendations that emerged from this committee revolved around issues such as demographics of visual arts students and teachers, the concepts and curricula that comprise visual arts programs, as well as the kinds of teaching models and strategies commonly employed. Other items include the measurement of learning outcomes, assessment strategies and methods, and the analysis of teacher education programs. The final category of research recommendation relates to technology, but its emphasis was on the creation of an electronic database that would be used to collect information regarding studies related to the teaching of the visual arts (Zimmerman, 1994, p. 11). It stands to reason that recommendations related to a research trajectory in visual arts education would not include examination of the impact of electronic technologies on trends in instructional practice; the Internet was only beginning its deployment in that time frame and desktop programs for artistic production were only in their infancy.

The NAEA later commissioned follow-up reports in 2005 and 2009, the latter of which is entitled, "Creating a visual arts research agenda for the twenty-first century: Encouraging individual and collaborative research" (NAEA, 2009). In this call for research, one new proposed area of inquiry under the heading of "Learning" was an examination of technological and online learning contexts, as these developments in visual arts education have emerged as pressing topics for investigation.

Research Compendia

A variety of substantive published resources exist that represent collections of research related to visual arts education, some of which reflect topics of interest to the instructional design and technology community. Eisner and Day (2004) compiled The Handbook of Research and Policy in Art Education, with sections focusing on research related to learning, teaching, teacher education, and assessment. The *International Handbook of Research in Arts Education* (Bresler, 2007) contains a section focused solely on the use of technology for teaching the arts ("the arts" being all-inclusive to visual arts, dance, music, and literary studies, as also distinguished by Eisner, 2002). In his prelude to this section, Webster (2007) highlights the fact that research about technology in arts education is inherently focused on "fundamentally good teaching" (p. 1294). Stokrocki's chapter (2007) on research regarding technology-enhanced instruction in the visual arts provides a substantial overview of the history of inquiry related to this topic, as well as a variety of case study summaries and exemplars in how emerging technologies have been used to support, deliver, and assess learning in the visual arts.

In addition to the aforementioned publications, special issues of art education journals have been dedicated to inquiry related to the use of technology for teaching visual arts. *Studies in Art Education* (Krug, 2004) and *Visual Arts Research* (Keifer-Boyd, 2005) are both compilations of research and discourse that explore a broad array of topics surrounding technology as an artistic medium, as well as instructional mechanism. While the studies and critiques included in these journals maintain no common theme, one underlying current across these issues is the need for educators to look beyond technology as a tool and be mindful of the social and ethical implications of engaging in technologically mediated instruction in the visual arts.

The Research Index for Art Education is an anthology of studies related to arts education, and is supported by the NAEA. One section of this resource is devoted to "Technology in Art Education" (see http://artedindex.com/technologyinarted.html). *ArtsEdSearch*, a resource provided by the Arts Education Partnership, offers an extensive database of studies related to the teaching of the arts. This database is organized around four topical areas: outcomes of arts education for students and also for teachers, and the context for learning the arts, in-school or out-of-school. Furthermore, studies are delineated by age group: early childhood, elementary school, middle school, high school, postsecondary, and adult and lifelong learning. Summaries of research findings are provided at the intersection of these topics, as well as a listing of relevant studies and areas for further investigation. General topics under this heading include analysis of methodological issues, the examination of the "arts learning" variable (how development of knowledge, skills, and attitudes related to the arts may enhance or transfer to learning benefits in other disciplines), and the exploration of learning through new and emerging art forms.

Conclusion

Technology has established a firm place for itself in the world of visual arts education, as a medium for artistic expression and as a means to support the teaching and learning process. Whether utilizing technological tools or strategies to develop student creativity (Black & Browning, 2011; Tillander, 2011), to enhance sociocultural awareness (Delacruz, 2009; Ferneding, 2007), or to increase learning opportunities for at-risk youth (Kafai et al., 2009; Knight, 2005; Peppler, 2010), inquiry in this discipline has indicated that the benefits of doing so go beyond the conceptual and practical learning of the visual arts. Our challenge in the realm of instructional design and technology is to inform best practices through meaningful research that will contribute to advancing learning and performance in this vibrant discipline.

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Technologies That Support Students' Literacy Development

47

Carol McDonald Connor, Susan R. Goldman, and Barry Fishman

Abstract

This chapter reviews recent research on technology that supports students' developing literacy skills from preschool through high school. We examine technologies for students across three developmental periods of reading: emergent literacy (preschool through kindergarten); learning to read (kindergarten through third and fourth grade) and reading to learn (third grade through high school). In general, when used with students' learning needs in mind, literacy software can effectively support students' acquisition of skills throughout these developmental periods. However, accumulating evidence reveals that good software will not replace good or even adequate teaching unless it is used with attention to optimizing instruction to meet students' individualized learning needs both face-to-face and on computers. We also review the role of technology in assessment of literacy skills and present promising results. In general, technology can provide an environment that supports reliable and valid assessment, especially when automated scoring can assist teachers in the assessment of students' basic skills, writing, summarizing, and synthesizing information across multiple texts. Finally, we review technologies that support teachers' efforts to provide more effective literacy instruction. Overall, current research indicates that technology-based professional development and specific software applications that support teachers' ability to individualize student instruction using assessment are generally effective in improving students' literacy outcomes.

Keywords

Assessment • Professional development

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Technologies That Support Students' Literacy Development

Children with weak literacy skills face serious challenges throughout their school career and beyond. They are more likely to be retained a grade, be referred for special education services, to drop out of school, to enter the juvenile criminal justice system, and to have limited career options (Hernandez, 2011; Reynolds, Temple, Robertson, & Mann, 2002). The most recent NAEP results show that almost one-third of students fail to achieve even basic reading skills by fourth grade (NAEP, 2011). The situation is even less encouraging for students beyond fourth grade: NAEP reading scores for high

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school students are no different from those in 1971 National Assessment of Educational Progress (NAEP, 2009), remaining relatively flat over the past 40 years (Heller & Greenleaf, 2007; Perle et al., 2005). Results of the 2007 NAEP writing assessment, administered to 8th and 12th graders, show equally flat results: 35% of 8th and 25% of 12th grade students scored at the proficient or advanced level, with no increases in these percentages compared to the 2002 administration (National Assessment of Educational Progress (NAEP), 2008). These data reflect the difference between basic reading skills and skills needed to use reading and writing to solve problems, make decisions, find answers, and function well within our information society (Goldman et al., 2011; Shanahan & Shanahan, 2008). These skills are prominent among the literacy demands of the twenty-first century and their importance is reflected in the recently published Common Core State Standards in English Language Arts, History/Social Studies, Science, and Technical Subjects (CCSSO, 2010) and the National Educational Technology Plan (NETP, US Department of Education, 2010). Education professionals, researchers, and policy makers recognize the need to develop methods and interventions designed to improve students' development of reading and writing skills at both basic and complex levels. In this chapter, we review the recent knowledge base on effective uses of technology and promising emerging applications that focus on students' literacy development and on supporting more effective literacy instruction.

The articles and chapters selected for this review met three criteria: First, they had to be published in peer-reviewed journal articles, federal reports, or chapters in books. Second, only recent publications, most published in the past 5 years, were included. Readers are referred to two reviews completed in 2001 and 2002 (Blok, Oostdam, Otter, & Overmaat, 2002; MacArthur, Ferretti, Okolo, & Cavalier, 2001) for older studies. Finally, publications had to be about literacy from preschool through high school. Research with adults, including college students, was not included in this review. We used typical electronic search procedures and concentrated on technology projects with evidence of documented efficacy defined by the IES What Works Clearing House as "interventions [that] produce a net positive impact relative to a counterfactual when they are implemented in authentic education delivery settings (e.g., schools). …" (http://ies.ed.gov/funding/pdf/2012_84324A.pdf, p. 45). We did, however, include highly promising technologies for which there was quasi-experimental evidence.

In this chapter, we consider technologies relevant to three developmental periods of reading: *emergent literacy* (Lonigan, Burgess, & Anthony, 2000), *learning to read*, and *reading to learn* (Chall, 1996) and provide an overview of the skills students are developing in each. Then we review the research on three areas of reading and writing technology: (1) technologies that students use directly in order to improve their reading and writing skills; (2) technologies designed to facilitate assessment of students' reading and writing skills; and (3) technologies designed to support teachers' efforts to provide more effective literacy instruction. We conclude with recommended directions for research and development of technologies for reading and writing.

Research on Language and Literacy Development

Emergent Literacy. For typically developing children, preschool, or roughly ages 2–5 years, is the time frame for emergent literacy, a period of tremendous growth in oral language and awareness of print (Teale & Sulzby, 1986), nascent phonological awareness, and emergent grasp of the alphabetic principle (Lonigan et al., 2000). Phonological awareness is the ability to consciously manipulate the phonemes of the English language (e.g., What are the phonemes in the word "bat"? /b/ /a/ /t/). Phonological awareness appears to facilitate grasp of the alphabetic principle: that phonemes map onto letters in fairly predictable ways (grapheme–phoneme correspondence) and that these graphemes combine to form meaningful words. Preschoolers begin to grasp these concepts and they are mastered in kindergarten and first grade for most children (Ehri, 2002). Weak phonological awareness and failing to grasp the alphabetic principle is a characteristic of many children with reading disabilities or dyslexia (Vellutino, Fletcher, Snowling, & Scanlon, 2004). At the same time, young children are bringing their developing oral language, including vocabulary, to bear in the understanding of text. This link, too, appears to develop in fairly predictable ways (Scarborough, 2001).

Learning to Read. The transition to learning to read begins with the onset of formal schooling—kindergarten and first grade for many children—and continues through third grade, roughly ages 4–8 years. Effective instruction during this phase includes explicit focus on the critical component skills of reading: phonological awareness, phoneme–grapheme correspondence, word recognition, vocabulary development, fluency, and comprehension (NICHD, 2000) as well as writing. As children learn to read and write, their ability to decode and encode words becomes increasingly fluent. Their application of their oral language skills to understanding and writing text becomes increasingly strategic (Scarborough, 2001) until they move beyond learning to read and begin to read to learn (Chall, 1996) There is substantial overlap for the phases and *reading to learn* can be introduced as soon as children have begun to recognize printed words and even before through oral language.

Whereas there is substantial research on how students learn to read, there is much less on how students learn to write and use writing for learning (Harris, Santangelo, & Graham, 2008). Research shows that explicit instruction in planning (Graham, Harris, & Mason, 2005) and revising (Matsumura, Patthey-Chavez, & Valdés, 2002) appears to support students' writing development as do opportunities to write and specific instruction in writing (Moats, Foorman, & Taylor, 2006). Effective writing instruction has been described as a sequence of instructional activities including planning, instruction, writing, and editing and revising, and then writing again (Harris, Graham, & Mason, 2006; Hayes & Flower, 1987).

Reading to Learn. Emerging as early as first and second grade, *reading to learn* becomes the dominant instructional focus by fourth or fifth grade, when students are about 8 or 9 years old. Reading becomes a principal mode for learning, with students expected to acquire new knowledge from written language, including important content area concepts and principles. Doing so draws on morphological and syntactic knowledge, comprehension strategies, and increasingly sophisticated cognitive and metacognitive skills needed to think critically and broadly (Chall & Jacobs, 2003; Connor, 2011). Students learn to employ strategies such as summarizing, finding main ideas, learning vocabulary in context, and making inferences (Guthrie, Anderson, Aloa, & Rinehart, 1999; Snow & Biancarosa, 2003). Key also is learning from discipline-specific texts and tasks that require specialized ways of reading and writing (Goldman & Bisanz, 2002). Discipline-based, reading-to-learn instruction takes into account the way knowledge is created and communicated within the discipline, including the purposes associated with specific genre, language and discourse conventions.

Literacy does not develop spontaneously or in isolation, but rather in the broader contexts where learners interact with others and with materials, especially at home and in the dynamic learning environment of the school classroom (Bronfenbrenner & Morris, 2006; Morrison & Connor, 2009). Thus, the role of technology for promoting literacy is considered here in the context of schools and classrooms and therefore includes not only the technologies designed to be used by students, but tools that support learning, assessment, and teachers' ability to provide effective literacy instruction.

Technology Designed to Be Used by Students

Technology for Supporting Emergent Literacy

We found few preschool studies that met our standards for inclusion in this review and those we did find had conflicting findings. We review what we found here, but clearly more research is needed in this area.

Huffstetter and colleagues (Huffstetter, King, Onwuegbuzie, Schneider, & Powell-Smith, 2011), examined whether *Headsprout Early Reading* supported preschoolers' ($n=62$) oral language and early reading skills. *Headsprout* employs a sequence of animated, interactive lessons to help students learn phonological elements and sight words, in order to build their reading vocabulary. Results of this experiment, in which preschoolers were randomly assigned to condition, revealed that preschoolers who used *Headsprout* daily for 8 weeks made significantly greater gains in early reading and oral language skills compared to preschoolers in the control group.

Preschoolers who attend to text while their parents or teachers read to them tend to learn to read more easily. However, many preschoolers do not attend to printed words during shared book reading, with negative implications for late literacy learning (Justice & Ezell, 2002). Gong and Levy (2009) investigated whether electronic books might enhance preschoolers' attention to print. They found that when children ($n=96$) used e-books that increased their attention to print they made greater gains than when they simply listened to the e-book.

Technology integration does not always enhance instruction. Davidson and colleagues (Davidson, Fields, & Yang, 2009) compared reading gains for prekindergarteners ($n=257$) randomly assigned to classrooms using the HighScope district curriculum with those using the same curriculum but with an integrated technology component, *Ready*, *Set*, *Leap*! They found no significant differences in preschoolers' literacy gains.

Technologies and Learning to Read

Among the most important studies on early elementary reading technology, the study on the *Effectiveness of Reading and Mathematics Software Products*: *Findings from the First* (*and Second*) *Student Cohort*, a national evaluation of education technology, was conducted during the 2004–2005 and 2005–2006 school years at the request of the US Congress (Campuzano, Dynarski, Agodini, & Rall, 2009; Dynarski et al., 2007). In this large-scale study, teachers and their first or fourth grade students, within schools (Cohort 1: 11 districts, 43 schools, 158 teachers and 2,619 students in first grade and 11 districts, 43 schools, 118 teachers, and 2,265 students in fourth grade), were randomly assigned to a business-as-usual control or to use one of several selected reading software packages (see Table 47.1). This study was designed to test the impact of technology that made its way into schools through current district and school decision-making and implementation processes.

The first grade software packages selected for the study tended to focus on code-related skills such as phonological awareness and phonics whereas the fourth grade packages tended to focus on reading comprehension. Packages,

Table 47.1 Products included in the national evaluation of education technology in cohort 1 and cohort 2 (as indicated)

Software package	Grade	Publisher	Web sites
Destination Reading	1	Riverdeep	http://web.riverdeep.net/
The Waterford Early Reading Program	1	Pearson Digital Learning	http://www.waterfordearlylearning.org/
Headsprout	1	Headsprout	http://www.headsprout.com/
Plato Focus	1	Plato	http://www.plato.com/elementary-k-6
Academy of Reading (not in cohort 2)	1	Autoskill	http://eps.schoolspecialty.com/
LeapTrack	4	Leaptrack	http://shop.leapfrog.com
Read 180 (not in cohort 2)	4	Scholastic	http://read180.scholastic.com/reading-intervention-program/about
Academy of Reading	4	Autoskill	http://eps.schoolspecialty.com/
Knowledgebox (not in cohort 2)	4	Pearson Digital Learning	No Web site available

selected from among products that developers and publishers submitted for consideration, met several criteria with the most important being evidence of efficacy, the ability to be implemented in large numbers of classrooms simultaneously, and the availability of teacher training. Schools chose the software package they wanted to use. Teachers in the treatment group received any requested technical assistance and were provided computers and other technology, such as headphones, servers, and printers. This support was not provided to teachers in the control group. Teachers generally received about 1 day of training at the beginning of the school year and ongoing support. They used the products, on average for 48 h/year for first grade and 40 h/year for fourth grade. In general, these procedures would tend to increase the potential impact of the software packages on student outcomes when compared to the control groups.

The five first grade products listed in Table 47.1 had much in common. In general, they all offered tutorial and practice opportunities for students and provided feedback to students and teachers. Three of the 4th grade programs assessed reading skills and then offered students practice in aspects of reading comprehension (e.g., identifying main ideas). Plato Focus provided a large database of resources including text passages, video clips, Internet sites and software modules. The programs were intended to supplement teachers' core curriculum. Thus, the impact of the technology was evaluated in the context of specific, and differing, core literacy curriculums (Crowe, Connor, & Petscher, 2009). The average cost for the technologies was about $100/student. Of note, the cohort 1 study was not designed to evaluate the effectiveness of individual software packages but rather the effect of access to and use of these packages as they might be implemented in schools across the nation. The cohort 2 study did examine programs individually.

The results of the cohort 1 study revealed that there were *no* significant differences between the treatment and control students on the Stanford Achievement Test (SAT-10) or on other measures of reading, including those administered by the schools.

In the second cohort study (Campuzano et al., 2009), the teachers (treatment and control) were followed for a second year using the same software but with a different cohort of students. The aim was to examine whether using the software for a second year would yield stronger reading outcomes and to investigate whether efficacy varied among software products. Six products were included (see Table 47.1); four in first grade and two in fourth. With regard to overall student outcomes, there were no differences in reading outcome effects for students in cohort two for either first or fourth grade compared to the control group. Nor did cohort 2 students achieve stronger reading skills compared to cohort 1 students who received the technology. Although the amount of time students used the software increased from year 1 to 2, the authors concluded that using the technology for a second year did not improve student outcomes. When the investigators examined the effect sizes (treatment vs. control) for the individual software packages for cohort 2, they found that only *LeapTrack* in fourth grade had a significant positive effect (normal curve equivalent difference between treatment and control = 1.97). None of the other technologies promoted students' reading scores compared to the control group students.

These are discouraging results, especially for those who are pro-technology, because it is difficult to find fault with the studies. They were adequately powered. Tested outcomes aligned with the goals of the software packages. Teachers within schools were randomly assigned, which helped to control school effects. The sample included schools in seven states and targeted schools that served children from lower income neighborhoods. Overall, the software programs were used in the way they were intended to be used by the publishers/developers. There were no clear biases. Teachers actually used the software and observations revealed that they made expected changes in their classroom practices.

One plausible reason for the generally null findings is that much of today's reading software does not provide instruction and practice in the areas that research indicates is important for students' mastery of key literacy skills. Santoro and Bishop (2010) reviewed over 20 reading software packages. They found that in general, many of the commercially available reading programs did not incorporate components of reading for which there was research evidence. Instead they focused on providing games and animation of illustrations. This would tend to take students' attention away from the text. Software with more engaging and user-friendly interfaces and that cost more tended to provide less research-based content. Thus popular software programs were likely to be less effective than less "flashy" researcher-developed interventions. Moreover, simpler supports for reading may be just as effective as or even more effective than computer games and other technology supports. For example, based on findings from an experiment they conducted, Smith and colleagues (Smith, Majchrzak, Hayes, & Drobisz, 2011) concluded that reading maps rather than playing computer games better supported 11 year olds comprehension of complex narrative text that required them to mentally model spatial situations.

Another possible reason for the national study findings is that the software might be more effective for some students and less effective for others. For example, Macaruso and colleagues (Macaruso, Hook, & McCabe, 2006) tested the efficacy of computer assisted instruction focused on improving students' ($n=179$) word recognition abilities. Two software packages, *Phonics Based Reading* and *Strategies for Older Students* (*SOS*) by Lexia Learning Systems (highly ranked in the Santoro & Bishop study) were used to supplement the literacy instruction students received in the classroom. Results mirrored the national evaluation study (Dynarski et al., 2007) and revealed that there were no differences in outcomes between students in classrooms that used the software and those in the control classrooms who did not. However, for students who were considered at risk for reading difficulties, using the software significantly increased gains in word decoding compared to students in control classrooms. Such aptitude-, or child-characteristic-by-treatment, interactions (Connor, 2011; Cronbach & Snow, 1977) suggest that extra time on the computer devoted to practicing skills that need to be strengthened might be particularly important for students who arrive in first grade with weaker reading skills but not for students already proficient in the targeted skills.

Despite the general findings of the national evaluation study (Campuzano et al., 2009; Dynarski et al., 2007), other studies of software interventions do find evidence that specific technologies can support students' developing reading skills. For example, Korat (2009) found that kindergarteners and first graders ($n=40$) who used e-books specifically designed using reading research findings demonstrated greater gains in vocabulary and word reading compared to a control group. The effect was larger for kindergarteners than for first graders. Another randomized control study comparing technology-intensive classroom learning activities at 25 rural public schools revealed that students in technology-intensive classrooms made greater gains in word reading (first grade) and comprehension (second grade) compared to students in control districts (Knezek, Christensen, & Knezek, 2008).

The studies examining *for whom* specific technologies are effective and for whom they are not indicate the importance of taking a more highly nuanced orientation to the question of whether technology works. In addition to the results reported above, there is accumulating research that indicates that technology may be particularly helpful for students who face learning challenges. For example, carefully designed e-books also supported improved reading skills for fourth graders who struggled with reading, with greater gains for students in the group that was able to control the animations (Ertern, 2010). Two computer-based interventions designed to improve attention skills, a critical executive function that is associated with reading skill development (McClelland et al., 2007), were effective in improving not only attention problems but reading fluency as well when students ($n=77$) were randomly assigned to either a control condition or one of two computer intervention programs (Rabiner, Murray, Skinner, & Malone, 2010). Notably, to be included in this study, students had to demonstrate attention difficulties.

Students with learning disabilities also face serious difficulties with writing (Graham, Harris, & Larsen, 2001). In a quasi-experiment, Englert and colleagues (Englert, Zhao, Dunsmore, Collins, & Wolberg, 2007) examined whether students using *TELE-web* ($n=35$) might demonstrate stronger writing skills compared to students who did not ($n=20$). All participating students had documented disabilities with the majority with reading disabilities. *TELE-web* is Internet-based software that is designed to provide support as students write expository essays, specifically for improving the structure and organization of essays by focusing on topic sentences, supporting evidence and detail, and concluding statements. Both groups of students accomplished the same writing tasks with the same general instruction except that the control group used paper and pencil. Overall, students using *TELE-web* were significantly more likely to write well-structured essays than were students using paper and pencil supports. However, these results should be interpreted with caution as there were a number of factors that might have contributed to the effects. For example, the researchers' had prior relationships with the *TELE-web* teachers, the overall quality of instruction was not assessed, there may have been unmeasured differences among students in the treatment and control conditions, and the nested structure of the data was not considered in determining treatment effects. Nevertheless, the promising results of the TELE-web technology call for additional research into its effectiveness.

Students who speak a language other than English also face serious difficulties understanding text, particularly with regard to vocabulary. In a quasi-experiment ($n=240$ students), Spanish-speaking fifth grade students learning English (English learners) who worked within a strategic digital reading environment called *ICON*, which stands for Improving Comprehension Online, demonstrated significantly greater vocabulary outcomes compared to students who did not use *ICON* (Proctor et al., 2011). There were, however, no significant differences in reading comprehension skills. Again, as with any quasi-experiment, causal inferences must be limited.

Technologies for Reading to Learn

In our review of the literature, we found three technologies designed to support students' *reading to learn*. The three focus on different but critical skills: Text structure (Meyer et al., 2010), inference making (McNamara, O'Reilly, Best, & Ozuru, 2006), and summarizing (Caccamise, Franzke, Eckhoff, Kintsch, & Kintsch, 2007). All three of these skills are involved in creating a coherent and meaningful mental model of the information presented in text.

Text structure: Intelligent Tutoring Structure Strategy. The importance of text structure for comprehension has been demonstrated in several programs of research, particularly for comprehension (Meyer et al., 2002; Williams et al., 2005). In the Web-based Intelligent Tutoring Structure Strategy (ITSS), Meyer and colleagues (Meyer et al., 2010) have created a technology-based delivery system for teaching students to notice and identify text structure in expository passages. ITSS uses a software agent to teach students to identify the top-level structure of a passage by attending to signaling words and other cues to the organization. Once a structure is learned, students use the structure to write summaries and recalls of passages with which they are presented. ITSS includes an automated analysis system so that feedback on student selections and input is provided during instruction and practice. Meyer & colleagues (2010) examined the pre and post-test performance of fifth and seventh grade students using the ITSS. In this experiment, students within each grade level were randomly assigned to one of two versions of the ITSS: elaborated or simple feedback. They found improvements for both groups on immediate and 4-month delayed posttests on a variety of experimenter-designed measures that tapped the specific skills targeted by the ITSS. Only those in the elaborated feedback condition showed substantial improvement from pre to post test in comprehension as assessed with the Gray Silent Reading Test (GSRT).

Individualizing the ITSS lessons increased the effect on students' comprehension and knowledge of signaling devices in text (Meyer, Wijekumar, & Lin, 2011). Meyer compared a version of ITSS that individualized lesson sequence, difficulty of texts, and practice depending on students' online performance with the standard ITSS. Fifth grade students ($n=131$) were randomly assigned to the standard ITSS or individualized ITSS condition. Comprehension improvements on the GSRT were obtained for both groups but were larger in the individualized ITSS condition. A similar pattern was found on a signaling task that required students to identify cues in the text to its structure. Free recall improved from pre to post for students in both conditions but there was no differential effect of individualization. What is not clear is how using the ITSS might compare to a non-technology business-as-usual condition.

Tutoring inferences: iSTART. iSTART (Interactive Strategy Trainer for Active Reading and Thinking) is an automated intelligent tutoring system that is designed to assist readers in making appropriate inferences as they are reading, particularly those that support deep comprehension as opposed to literal or rote memorization of text. Most widely deployed and tested for science content (McNamara et al., 2006). it was developed to help students improve their ability to read for understanding by constructing self-explanations of text using five strategies for making inferential connections among elements of text and to prior knowledge (McNamara et al., 2006): paraphrasing (to insure accurate comprehension of what the text says); bridging, elaborative, and predictive inferences; and comprehension monitoring. Results of a randomized control trial with 39 seventh and eighth graders revealed that on a post-training text, students in the iSTART condition comprehended more than did the students in the control condition (strategies were defined but no technology was provided). This study also provided evidence that the impact of iSTART differed depending on the pretraining knowledge students in the iSTART condition had of reading strategies. Those with higher knowledge showed greater achievement on inference questions as compared to literal whereas lower strategy knowledge students achieved more on literal than inference questions. As with several other technologies for supporting reading, the impact of iSTART depended on the characteristics of the individual reader. Additionally, the sample was small so it is not clear how iSTART will work with different student populations.

Summarization: Guided practice with feedback. Summary Street is a Web-based system for middle and high-school students that provides guided practice in writing summaries for presented passages. The feedback is provided in the form of suggestions for improving the summary and students then decide what actions to take to improve their summaries. They are free to ignore or act on any of the feedback at their discretion. This "intermediate" level of feedback is consistent with other studies of tutors and tutoring that suggest that the most useful feedback allows the user some agency in determining what to do next (Aleven & Koedinger, 2002; Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001). The feedback utilizes a back-end computational process that relies on latent semantic analysis to determine similarity between the summary generated by the student and the text that the student is summarizing (Wade-Stein & Kintsch, 2004). Sixth through ninth grade students from a variety of socioeconomic backgrounds across the state of Colorado participated in a quasi-experimental study (Caccamise et al., 2007, 2010). Treatment classes ($n=80$ students) used the *Summary Street* software while control classes ($n=60$ students) matched to each treatment classroom did not. At the beginning and end of the semester, students wrote a summary (paper and pencil) whose quality was evaluated by the *Summary Street* system. Results indicated that treatment group students' summaries showed significant improvement in content coverage (more relevant, less redundancy, more parts of the text) whereas those of the control students did not (effect size $d=0.67$). A 2-year evaluation study revealed an effect size (d) of 0.26 when quality of summaries produced by *Summary Street* users was compared to those in the control condition. Study findings for four eighth grade classes indicated that the feedback was strongly associated with improvement in summary writing and gist-level reading comprehension (Franzke, Kintsch, Caccamise, Johnson, & Dooley, 2005). Furthermore, the effects of the feedback on summary writing were greater on more difficult texts and for students who scored lower on a comprehension assessment.

Technology and Assessment

The most recent National Education Technology Plan (NETP, US Department of Education, 2010) focuses on the role of technology for providing better ways to measure what is important for students to learn if they are to successfully navigate information in our global society. This includes diagnosing students' strengths and weaknesses *as* they are learning, using automated scoring to evaluate student writing, providing timely and actionable feedback to teachers and students, and building the capacity of educators to use this technology.

Evaluating Student Writing

Constructed responses. In general, cognitive and educational research findings concur that students learn better and we can make better judgments about their achievement when they are presented with open-ended questions that require constructed responses, including short answer and essays (Bennett & Ward, 1993). Moreover, one likely reason that there is limited research on how children master proficient writing is that the constructed responses and other forms of written products are difficult and time consuming to reliably assess. New automated essay scoring systems offer potentially important solutions to these concerns. These systems use a number of strategies to evaluate the quality of written text. A widely used and validated technology is the e-rater v.2 (Attali & Burstein, 2006). *E-rater* examines "grammar usage, mechanics, style, organization, development, lexical complexity, and prompt-specific vocabulary usage" (p. 7). When e-rater scores were compared with human rater scores for essays generated by 6th through 12th graders, in general, e-rater agreed with the human raters at the same rates as the human raters agreed with each other with kappas ranging from 0.31 to 0.44 for computer–human agreement and from 0.27 to 0.44 for human–human agreement (Attali & Burstein, 2006). Hutchinson (2006) replicated this finding with younger students (11 year olds, $n=600$) in the UK.

In order to take advantage of automatic essay scoring systems, students will likely be expected to complete their essays on computers. A study by Horkay and colleagues (Horkay, Bennett, Allen, Kaplan, & Yan, 2006) examined whether students ($n=1{,}313$) achieved significantly different scores when taking the writing portion of the National Assessment of Educational Progress (NAEP, 2011) online (keyboarding) or with paper and pencil. Results revealed that overall, mode (online or paper) made no significant difference in achieved score. Nor did any of the student or school factors interact with mode with one important exception: Students who had weaker keyboarding skills achieved higher scores when they completed the essays using paper and pencil whereas students with proficient keyboarding skills achieved higher scores when composing their essay online. This offers a cautionary note because not all students have the same access to computers and training in keyboarding.

Formative assessments. Accumulating research strongly indicates that formative assessments, those assessments used to inform the types of instruction and interventions that will better support students' learning, are an integral part of an effective instructional regimen (Deno et al., 2002; Pellegrino, Chudowsky, & Glaser, 2001). Formative assessments differ from summative ones such as the NAEP and state-mandated assessments. The latter are useful in understanding students' achievement relative to a normative group. However, they are less useful when teachers are planning and implementing instruction because of their distance from the actual curriculum and instruction in the classroom. Assessments are considered to be formative insofar as the information gained from these assessments is used to make decisions about what to teach students (i.e., content) and how to teach it (e.g., strategies, directly, implicitly). Technology can facilitate both the administration and scoring of such assessments and thereby make it more likely that teachers will be better able to differentiate instruction appropriately so that individual students' needs are more effectively addressed. For example, Sainsbury and Benton (2011) used latent class analysis to identify four different profiles of learners based on two formative reading assessments. They conjectured that the four different profiles would benefit from different types of reading instruction although this was not tested. In another example of online formative assessment. Connor and colleagues have developed an adaptive vocabulary or word knowledge assessment for kindergarten through fifth grade, *The Word Match Game*, using a semantic matching task (Connor, 2011). Over headphones, students are presented three words (e.g., kitten, cat, tree) and are asked to click the two that go together (e.g., kitten, cat). The task is adaptive, using item difficulty information (Petscher et al., 2012), so the number of items administered is substantially less than might be needed for paper and pencil assessments. Importantly, the results of these formative assessments can be used immediately to help teachers design and implement effective literacy instruction. And they can be administered fairly frequently to monitor whether or not students are improving their skills as expected.

Overall, computer-based assessments have several advantages over paper and pencil. Automatic scoring and use of psychometric information means that the results of the assessments can be presented as grade equivalents, standard scores, and developmental scale scores to monitor gains in skills and knowledge over time. Awkward look-up tables are avoided and data entry and scoring mistakes are minimized. Importantly, scores are available to teachers immediately and can be presented graphically in a number of ways to aid interpretation of the results.

Assessing Multiple Source Comprehension

Technology, specifically the World Wide Web, has expanded the range of available resources for reading to learn, and in multiple formats, including text, audio, and visual. More so than ever before, readers are likely to come across sources that make contradictory claims and offer different evidence, or different interpretations of evidence, in support of those claims. The result is that the skill set for reading to learn has expanded to include reading skills that had previously been purview of subject-matter experts only (Goldman, in press). One tool for assisting teachers in making the transition to reading and writing from multiple sources of information is to create formative assessments that assess the skills required to select and use information from multiple sources. Goldman, Lawless and colleagues (Goldman et al., 2010, 2011, 2012; Lawless, Goldman, Gomez, Manning, & Braasch, in press) have developed Web-based formative assessments of two important skills in learning from multiple sources: selecting sources and synthesis of information across sources. Both assessments are designed to provide teachers with information about middle school students' skills at selecting relevant and reliable sources and integrating across them to address inquiry questions in history or science (e.g., "Why did so many people move to Chicago between 1830 and 1930?", p. 19, Goldman et al., 2012).

The *Selecting Sources Assessment* defines useful sources as those that are relevant and reliable (translated as trustworthy for the 5th-8th grade target population). In this task, students evaluate eight different sources with regard to their *relevance* to answering the question, and for those deemed relevant, the *trustworthiness* of the source. Overall usefulness is determined by rank ordering those sources that survive the relevance and trustworthiness judgments. In the online, computer-based context, judgments are made on a three-point Likert scale for relevance and trustworthiness (1 = highly; 2 = somewhat; 3 = not). For trustworthiness ratings, students rate how helpful to the trustworthy judgment each of four attributes of the source are (author, type, publication date, and publication venue) and make an overall trustworthiness judgment. Usefulness is determined by rank ordering using prize ribbons (first place, second place, and so on) to those sources ranked a 1 or 2 for both relevance and trustworthiness.

Across several studies with 5th through 8th graders, results revealed a wide range of performance. In general, students who performed at higher levels as compared to those performing at lower levels on the usefulness ranking task also performed at higher levels on the relevance judgment task; however, performance on trustworthiness judgments did not differ significantly. Moreover, evidence suggested that these tasks were tapping skills and knowledge not generally captured by more traditional reading comprehension tests.

The assessment tool for *Analysis and Synthesis* across sources asked students to read three texts for purposes of answering an inquiry question. After reading, they were asked to type an answer to the inquiry question using the information from the texts. Specifically they were told, "the answer comes from many sources and you have to fit the reasons you find together like pieces in a jigsaw puzzle to answer the question" (p. 192, Goldman et al., 2012). They clicked on tabs at the bottom of the screen to bring up each text; all three could be accessed in any sequence, any number of times but only one text appeared on the screen at a time. After reading the texts, students typed their responses, and could re-access the texts. The Computer recorded the timing and sequence of which texts were viewed.

The students' essays were scored for inclusion in their essays of information from each of the three texts (analysis) as well as for the degree to which they connected information across the three texts (for details see Goldman et al., 2012). Results across samples of 5th through 8th graders ($n = 247$) revealed that there were three distinct ways in which students completed the task. The *satisficers* (50 % of the students) wrote the shortest essays with the least amount of information, spent the least amount of time writing, and did not relate content across texts. The *selectors* (36 %) wrote the longest essays and spent the most time writing, although they tended to copy sentences directly from the texts. Although 77% of the students included information from all three texts, they did not connect information across texts. The *synthesizers* (13%) connected information across at least 2 texts with the majority, 77%, using all three texts and the information selected tended to be the more important and relevant information from each text.

Technology to Support Teacher Learning and Effective Practice

One of the most promising uses of technology is to support teachers' efforts to provide effective literacy instruction. This includes professional development to increase knowledge about effective practices and how to use assessment results to guide instruction. We discuss recent research in both of these areas.

Technology and Teacher Professional Development

Research on professional development has shown that, in general, a combination of workshops, monthly teacher meetings focused on building communities of practice, and classroom-based coaching are most likely to change teachers' practices (Carlisle, Cortina, & Katz, in press). However, such professional development is costly, especially in more rural districts where travel time is a consideration. Several recent studies indicate that online professional development and other technologies hold promise for providing cost-effective ways to improve teachers' literacy practices. For example, Hemmeter, Snyder and colleagues (Hemmeter et al., 2011) found improvements in preschool teachers' interactions with students and improved student behavior when feedback was provided to teachers via email and using teacher-selected video tapes of their instruction. Amendum, and colleagues (Amendum, Vernon-Feagons, & Ginsberg, 2011) provided *Targeted Reading Intervention* professional development to teachers at randomly assigned schools ($n = 364$ students) using Web conferencing, laptop computers, and webcam technology. Results indicated that the professional development was effective and the reading skills of students who were struggling with reading improved compared to students in the control group. Furthermore, Powell and colleagues conducted a randomized control study revealing that technology-based coaching might be as effective as face-to-face coaching (Powell, Diamond, Burchinal, & Koehler, 2010) for Head Start teachers ($n = 88$). Both treatment groups were more effective than the control group.

In another study, Landry and colleagues (Landry, Antony, Swank, & Monseque-Bailey, 2010) evaluated the effect of four different configurations of professional development compared to a control group. Preschool teachers ($n = 262$) from four different states were randomly assigned to a business as usual control or to one of four PD conditions that provided different combinations of: weekly literacy coach mentoring, paper and pencil assessment, and personal digital device assisted assessment (C-PALLS), and no mentoring. All treatment group teachers participated in a year-long online course called *eCIRCLE*. *C-PALLS* used the same assessments as paper-and-pencil versions but administration was facilitated and scoring and data displays were generated automatically so teacher received immediate feedback. Results showed that teachers in all four treatment conditions improved the quality of their early literacy instruction compared to the control group teachers. Overall, however, teachers who used *C-PALLS* (particularly with mentoring) tended to be rated as highest on the scale and their students made significantly greater gains in early literacy and oral language skills compared to the control and other conditions.

Technology Designed to Help Teachers Use Assessment to Guide Instruction

Accumulating evidence shows that the effect of a particular instructional strategy depends on the vocabulary and reading skill level of the student. This phenomenon has been identified as child characteristic-by-instruction type (child-by-instruction) interactions (Connor, Morrison, & Petrella, 2004), individual response to intervention (Torgesen, 2000) and aptitude-by-treatment interactions (Cronbach & Snow, 1969). Recent randomized control field trials have provided evidence that such child-by-instruction interactions are causally related to the widely varying levels of student achievement observed within and between classrooms and schools from kindergarten through third grade (Connor et al., 2009; Connor, Morrison, Fishman, Schatschneider, & Underwood, 2007). Thus patterns of instruction that are effective for one child may be ineffective for another who shares the classroom but has different oral language and literacy skills. As we discussed, this seems to be the case for computer-based interventions as well (MacArthur et al., 2001). However, differentiating instruction in line with these child-by-instruction interactions is highly complex and demands skills and knowledge that many classroom teachers lack (Roehrig, Duggar, Moats, Glover, & Mincey, 2008).

Assessment-to-Instruction (A2i) online software was designed to help teachers translate assessment results into specific recommendations for literacy instruction. Part of a classroom-based intervention called Individualizing Student Instruction (ISI), which includes professional development, A2i software has four components: (1) assessment and recommended instruction; (2) planning; (3) professional development; and (4) teacher communications. Teachers use the software, which is indexed to their core reading curriculum, to plan daily instruction and monitor students' progress. They have access to online training materials, including videos and discussion boards that provide information about effective instruction, organizing and planning, and classroom management. Importantly, computer algorithms provide specific recommendations for the amount and type of reading instruction that will be optimal for each student, based on the assessment results.

From kindergarten through third grade, students' whose teachers were randomly assigned to the ISI intervention (i.e., differentiated instruction) using A2i made greater gains compared to students whose teachers were in the alternative or delayed treatment control groups (Connor et al., 2007; Connor, Carol McDonald, Morrison, & Frederick et al., 2011; Connor, Morrison, Schatschneider et al., 2011). Focusing only on first grade teachers who used A2i ($n=25$), Connor and colleagues found that the more teachers used A2i, the greater were their students' ($n=396$) reading skill gains (Connor, Morrison, Fishman, & Schatschneider, 2011). This finding was replicated in third grade with 16 teachers and 226 third graders (Connor, Fishman et al., 2011).

In a direct test of A2i, Al Otaiba and colleagues (Al Otaiba et al., in press) compared student outcomes ($n=556$) for kindergarteners whose teachers were randomly assigned to receive professional development (PD) on how to differentiate reading instruction ($n=21$ teachers) but no technology or whose teachers ($n=23$) were assigned to receive professional development on differentiating instruction using A2i (i.e., with technology). They found that teachers were more likely to individualize instruction and their kindergartners made greater gains in reading when they used the A2i technology compared to the PD-only group teachers.

Discussion

Our review of the most current research on reading and writing technology is highly encouraging. Accumulating research shows that carefully designed software can support students' emergent literacy development, improve foundational reading skills as students learn to read, and can offer opportunities to improve their ability to use their developing literacy skills to learn from text, particularly in the content areas. Furthermore, when these technologies individualize the material based on students' skills and abilities, the impact tends to be larger than in the absence of this differentiation. Computer- and Internet-based reading and writing assessments make evaluation of student work easier, faster, and more reliable. They allow us to assess and monitor more complex twenty-first century literacy skills such as evaluating the relevance and trustworthiness of text for the topic at hand. Technology is facilitating professional development efforts and making training more available to teachers in more places. Moreover, technology is helping teachers individualize the literacy instruction they provide to their students by facilitating the use of assessment information to design, plan, and implement effective differentiated instruction.

There are some important caveats, however. Technology is good at some things and not others. For example, accumulating evidence clearly indicates that technology is not going to replace good teaching—or even typical teaching—given the current state of the art. This is exemplified by the national evaluation study (Campuzano et al., 2009) where the overarching albeit implicit research question was: can school districts, particularly those who serve many students from higher poverty families, buy technology and achieve stronger student achievement? In other words, can putting students on computers to replace face-to-face instruction from teachers lead to better student outcomes? The answer was a clear "no." This is good to know and allows us to more honestly evaluate the nuanced role of reading and writing technology. For example, in the national evaluation study, software developers encouraged teachers to become "guides on the side" rather than the "sage on the stage." And classroom observation revealed that, indeed, teachers in the technology groups were more likely to act as guides than were teachers in the control group. However, this begs the question as to whether this is the best use of teachers' classroom time. Although conjecture, might the results have been different if teachers integrated the software into their classroom instruction rather than treating the software as an add-on for the computer lab. What if some of the students had worked with technology-based activities in the classroom while their teacher worked directly with other students, perhaps those who needed small group or one-on-one attention? The key finding from several of the studies we reviewed (e.g., Connor, 2011; Macaruso et al., 2006) was that the impact of the technology or instructional strategy depended on students' incoming reading and language skills *and* whether the instruction specifically targeted those areas in which students' understanding and skills were weaker. For example, technology used to provide students who are struggling to learn to read with extra practice time on the computer with, say an e-book that helps them sound out unfamiliar words and has a dictionary, rather than expecting them to read independently is likely to help them improve their skills. At the same time, for more skilled first graders to spend time on the computer working on basic skills they have already mastered is likely a waste of their instructional time. These students would probably be better served by spending that time reading and writing independently (Connor, Morrison, Schatschneider et al., 2011). The one software package in the national evaluation study (cohort 2, Campuzano et al., 2009) that did appear to promote student learning, *LeapTrack* in fourth grade, described itself as a "personal learning tool" for students (see Table 47.1) and incorporated assessments to place students in e-books that were at the appropriate level for them. It also recorded how well students performed and provided assessment reports. Moreover, *LeapTrack* in fourth grade incorporated research findings on effective decoding and comprehension instruction and was designed to be used in the classroom rather than the computer lab.

Despite accumulating evidence that students are better served when teachers differentiate instruction, individualized instruction is not happening in many schools (Black & Wiliam, 2009; O'Connor, Fulmer, Harry, & Bell, 2005). Technology can assist with this in several ways: first, by providing sensitive, meaningful, and more nuanced formative assessment of skills that truly matter; second, by supporting teachers' efforts to use that assessment information in meaningful ways to plan and implement literacy instruction; third, by freeing up time currently spent on assessment to provide effective instruction particularly on skills that are difficult to teach using technology; and finally, to provide a digital support system or intelligent tutor for students, including students with disabilities, as they work on their own while the teacher works directly with other students. The NETP (US Department of Education, 2010) directly calls for this, stating:

> The model of learning described in this plan calls for engaging and empowering learning experiences for all learners. The model asks that we focus what and how we teach to match what people need to know, how they learn, where and when they will learn, and who needs to learn. It brings state-of-the art technology into learning to enable, motivate, and inspire all students, regardless of background, languages, or disabilities, to achieve. It leverages the power of technology to provide personalized learning and to enable continuous and lifelong learning (p. 8).

For all of this to happen, however, innovative design and rigorous testing of software is required. We were encouraged by the number of well-crafted randomized control and quasi-experimental studies (we carefully reviewed over 80 studies and of these, about 25 met our standards for inclusion in this review; we reviewed over 500 titles and abstracts). At the same time, given budget constraints, funding priorities, and popular support, there is a danger that emerging technologies will go straight into classrooms and schools without strong evidence that using the technology will improve student learning. By understanding how the technology works, in what contexts, and for whom, we can more effectively and efficiently employ school, teacher, and student resources to insure all students receive the instruction they require to succeed.

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Section VI
Design, Planning, and Implementation

J. Michael Spector and M. David Merrill

This sixth section of the *Handbook* is focused on recent research involving instructional design, planning, and implementation. It is most closely related to the section on Design and Development in the previous edition of the *Handbook* (Spector, Merrill, van Merriënboer, & Driscoll, 2008) and to chapters in the soft technologies sections of the first two editions (Jonassen, Harris, & Driscoll, 2001; Jonassen, 2004). As is the case for all chapters in this edition of the *Handbook*, there is no duplication with previous editions, and the research findings and perspectives reported in these chapters are new. The focus is on innovative tools and technologies that support design, development, and deployment of educational and communication technologies.

The section begins with a chapter on instructional design models by Andrew Gibbons, Elizabeth Boling, and Kennon Smith that presents a new look at the nature of design and the notion of an instructional design model. The authors examine traditional instructional design models and note how these have departed from the vast literature on design processes and models in other disciplines. Instructional design researchers are encouraged to take lessons learned from other disciplines and develop a broader and more robust notion of design that is less likely to constrain and limit the potential of new technologies and pedagogical approaches.

The chapter by Michael Savoy and Alison Carr-Chellman on change agency is nicely complementary to the innovative look at instructional design models. Understanding how innovations are adopted within an organization is important for optimizing their impact. The authors review on diffusion of innovation and adoption processes and present recent research in a variety of contexts as a foundation for the implications of a changement management strategy. Findings suggest that leadership is a critical aspect of successful change agency but communication style and message content also play important roles. The notion of a collaborative and distributed approach to change agency is described as one likely approach for many instructional innovations in the future.

The chapter by Phillip Harris and Donovan Walling on policies builds on the previous chapter on change agency as it addresses how policies influence adoption and implementation of new educational technologies. This chapter focuses initially on policies pertaining to technology in the USA, especially as found in the US National Educational Technology Plan of 2010. The discussion then proceeds to a review of policies outside the USA. The emphasis throughout is on how national policies influence educational research priorities, and how those policies are somewhat different in different countries. The authors note that policies can inhibit or enhance educational research and practice. Not surprisingly, policies are not value neutral. In the USA, one can argue that the No Child Left Behind Act of 2001 was aimed primarily at fixing problems with poorly performing schools rather than at transforming how public education occurs. Unlike the fix-it approach of NCLB, the authors argue that the more recent educational technology plan of 2010 takes a forward look at how learning and instruction can be transformed through the use of technology and investments in research and developments. This chapter should serve as a reminder to educational technology researchers that we have a voice that needs to be heard when policies are proposed and framed, and this is true for every country.

The chapter by Michael Hannafin, Janette Hill, Susan Land, and Eunbae Lee on student-centered and open learning environments then describes recent research in an important area of transformative educational practice. Previous *Handbook* chapters have discussed constructivist approaches to learning and instruction so that the topic is not taken up specifically in this *Handbook*. Rather, the editors decided to focus on a specific approach that is consistent with the turn in the last 20 years or so towards constructivism—namely, an emphasis on student-centered learning and instruction. The

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authors review the research literature with regard to self-directed and self-initiated learning in both informal and more structured learning environments. While some of the evidence is critical of student-centered approaches, there is also evidence that in many contexts, providing support for self-directed learning and student-negotiated learning goals can be highly effective, especially with regard to motivation. As with most instructional approaches, there is no magic solution for all learning situations, and there is a need for more research on when and how student-centered learning is effective.

Given the need for continuing research on instructional design and implementation strategies, the chapter by Monica Tracey and Elizabeth Boling on preparing instructional designers is highly relevant. The authors note that since the 1990s a broader conception of design and new approaches to learning, along with many new technologies, have caused instructional design programs to review and rethink how they are preparing instructional designers. A number of recent competencies for instructional designers are reviewed, including the research-based set of instructional design competencies developed by the International Board of Standards for Training, Performance and Instruction (*ibspti*; see http://www.ibstpi.org). The *ibspti* competencies, and those developed by the International Society for Technology in Education (ISTE) and by the IEEE Technical Committee on Learning and Technology, as well as recent textbooks in this area (see, for example, Spector, 2012) all point to the need for changes in how instructional designers are prepared. Developing design expertise is a relatively slow process. Integrating studio-based experiences and actual design work into curricula is important in preparing instructional designers for productive careers. Many programs around the globe are adopting these approaches, and research on their efficacy will be important for the future evolution of professional programs.

The final chapter in this section by Gilbert Paquette is on recently developed tools and technologies to support instructional design practice. While it is of course important to provide instructional design trainees with authentic and realistic learning experiences as argued by Tracey and Boling, it is likewise important to provide instructional designers with state-of-the-art tools and technologies that support and facilitate the development of robust and effective learning environments. The author traces the development of these tools from early authoring tools and instructional advising systems to more recent Web-based repositories, learning objects, and recommendation engines. While the future of instructional engineering is generally rich with regard to resources, it is evermore challenging for designers to craft meaningful and effective learning activities, resources, and environments for specific learners in quite different situations. As always, ongoing research will be required to maintain progress in this area of instructional design, planning, and implementation.

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* An asterisk next to a reference entry throughout this Handbook indicates a reference that the author(s) considers to be central to the topic.

Instructional Design Models

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Andrew S. Gibbons, Elizabeth Boling, and Kennon M. Smith

Abstract

Design has become increasingly important in a number of technology-related fields. Even the business world is now seen as primarily a designed venue, where better design principles often equate to increased revenue (Baldwin and Clark, Design rules, Vol. 1: The power of modularity, Cambridge, MA: The MIT Press, 2000; Clark et al., Brookings Papers on Economic Activity, 3:729–771, 1987; Martin, The design of business: Why design thinking is the next competitive advantage. Boston, MA: Harvard Business Press, 2009). Research on the design process has increased proportionally, and within the field of instructional design (ID) this research has tended to focus almost exclusively on the use of design models. This chapter examines the emergence of the standard design model in ID, its proliferation, its wide dissemination, and a narrowing of focus which has occurred over time. Parallel and divergent developments in design research outside the field are considered in terms of what might be learned from them. The recommendation is that instructional designers should seek more robust and searching descriptions of design with an eye to advancing how we think about it and therefore how we pursue design (Gibbons and Yanchar, Educ Technol 50(4):16–26, 2010).

Keywords

Design • Instruction • Instructional design • Instructional development • Design model • Instructional design model • Instructional systems design • ADDIE • Systems approach

What Is a Model?

A model can be: (a) a simplified representation of something that exists, or (b) a description of something that could exist. In the terms of this chapter, instructional design models are of the latter type; they describe process by which something can be created, but not the thing which is created (Gibbons & Rogers, 2009).

Many kinds of models pertain to the instructional design process. Some models describe decisions to be made. Others describe the order of decision making or activities carried out during design (Dubberly, 2005; Silvern, 1968), the designer's thinking processes (Brooks, 2010), team interactions (Yang, Moore, & Burton, 1995), design architecture (Gibbons & Rogers, 2009), design documentation (Gibbons, 1997), and the decision-making context (Gibbons, 2011; Young, 2008). Models also differ in their intended audiences and purposes; they may speak to the purposes of administration, marketing, budgeting, or cross-function coordination.

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Smith (2008) observes that the term "design" is used to refer to at least three different aspects of design: (a) to the design acts carried out during the second stage of the ISD process, (b) to the more detailed design acts carried out during the third stage of the ISD process, such as the design of screens, graphics, and formats, and (c) to all of the acts carried out during the entirety of the ISD process. That is, the "D" in ISD is taken by some to stand for "design." By far the most numerous models within ID are those that describe the highest-level processes.

History of Models in ID and Design

Contrary to the popular narrative, the instructional design process models we have today are not directly traceable to behaviorism, programmed instruction, or even to the application of the systems approach. Instructional design process models which emerged in the 1950s and 1960s were relative late-comers; core process elements of instructional design models had by that time been described and widely applied long before. The roots of formal design processes go back to the beginning of the twentieth century. The confluence of complex postwar problems and the emergence of the systems approach catalyzed the formalization of a rational approach to design across many fields of design practice, including instructional design, which had been in use long before in the service of very pragmatic ends. The design models that appeared in the 1950s and 1960s had the extra appeal that they *appeared* to provide a scientific basis for design at a time when science was emerging as a trusted source of progress.

The "Plans"

Between 1912 and 1935 a series of controversial "Plans" (Saettler, 1968) were launched in public schools. The Plans were a reaction to efficient, mass-administered, standardized treatments based on the knowledge-reception model of learning. They were local, grassroots attempts to systematize and individualize instruction (see Table 48.1).

The first of these, the Burk Plan (Burk, 1913), was based on specialized texts which implemented several strategic principles: stepwise introduction of task complexity, control of the pace of introducing new ideas, frequent review of previously mastered material, and adaptive branching used for controlling pace and for remediation. These texts were not designed using a formally specified process, but such a process is implied by the highly structured features that the designs included, since no informal procedure could have produced them in the necessary quantity.

The Burk Plan was terminated in 1919 by the California legislature, but Burk's protégé, Carleton Washburne, established

Table 48.1 Comparative features of three major "Plans" between 1915 and 1935

Feature	Burk (1915–1919)	Washburne (1919–1940)	Morrison (1925–1935)
Self-pacing	x	x	–
Self-instructional	x	x	–
Individual practice	x	x	x
Prepared materials	x	x	x
Based on objectives	x	x	x
Diagnostic tests	x	x	x
Self-admin tests	x	x	x
Criterion referencing	x	x	x
Remedial tutoring	x	x	x
Adaptive reteach	–	–	x

the Winnetka Plan in Illinois (Washburne, 1920), which continued in use until the 1940s and was widely influential. It similarly included among its instructional techniques structured core-subject workbooks and rules for using them, again implying a deliberate design process guiding their creation.

The Morrison Plan (Morrison, 1926) employed a "mastery formula … pre-test, teach, test the result, adapt procedure, teach and test again to the point of actual learning" (p. 79). This plan employed a cybernetic feedback principle prior to its formal expression and popularization during World War II.

The legacy of the Plans is that they focused on specially designed materials which had to be created using a deliberate design process, the essential features of which (objectives, aligned instruction, aligned tests, and evaluation) supplied the backbone of formalized instructional design models that emerged some 20 years later.

During this same period several key developments were unfolding outside education that laid groundwork for the later design methods approaches in architecture and product design. Cross (2004) discusses the motion efficiency studies carried out by Gilbert from 1909 to 1917, a forerunner to the idea that design—like other skilled work—could be made efficient. Overlapping this period, the De Stijl and Bauhaus movements began in Europe, both explicitly embodying a movement away from craft-based design and toward principle-based design.

Tyler and the Eight-Year Study

Between 1930 and 1942 Ralph Tyler formed and tested an approach to design as part of the so-called Eight-Year Study (Kridel & Bullough, 2007; Tyler, 1949), which was conceived to prove the superiority of progressive school programs. Tyler believed that teachers should formulate their own paths to reform, and this philosophy transformed the study into an exploration of how instruction is designed and evaluated. Consequently Tyler's team of researchers assisted instructors in constructing instructional goals, aligning them with instruction, and conducting evaluations, which included field tests.

Tyler produced a syllabus to be used by public school instructors as a textbook on instructional design for teachers: his famous *Basic Principles for Curriculum and Instruction* (Tyler, 1949). In it, he addressed in complex terms each aspect of the design process which had come forward from earlier experimenters. For example, he described "behavioral objectives" as capturing a full net of meaning and associations, a much richer concept than that of isolated and fragmented performances which became common later, and which he criticized in later years (Fishbein & Tyler, 1973). The formalized instructional design models of the 1950s, 1960s, and 1970s were arguably less complete and more mechanical than Tyler's much earlier description of design, but his "four questions" even today form the core concerns of instructional design models (Tyler, 1949, p. 1). These questions express the concerns of the earlier Plans equally well:

- What educational purposes should the school seek to attain?
- What educational experiences can be provided that are likely to attain these purposes?
- How can these educational experiences be effectively organized?
- How can we determine whether these purposes are being attained?

Tyler's questions and the process answers he gave to them represent a contribution to the later-emerging models from the public education sector.

The A-V Movement

Contributions were emerging from other sources as well. Following World War I, and again following World War II, media innovations poured out from the military world into the public domain at an accelerated rate, to become popular academically and commercially (Saettler, 1968): silent instructional film (early 1900s); instructional radio (late 1920s); sound film (early 1930s). Post World War II, educational television, programmed instruction and computers ascended in turn, each viewed as *the* "new medium" of its time. Despite constant increases in available media, prior to 1950 it is difficult to find any detailed descriptions of design processes with the exception of those Tyler created during the Eight-Year Study.

After 1953, however, media-related professional organizations began to come together; these facilitated a shift in focus from the technical preparation of media to the educational uses of media, the selection of appropriate media and the enhancement of its instructional value. The discussion of design gradually emerged as a topic independent from media production.

Professionalization and Finn

James Finn, who held prominent positions in Audio-Visual Education during the 1950s, issued a detailed call to professionalize the field. He enumerated six criteria to be met by a profession: an intellectual technique, application of the technique to practical affairs, a long training period to reach expertise, a professional organization, ethical standards, and a constantly expanding, organized body of intellectual theory (Finn, 1953, p. 7), which, he pointed out, the A-V field did not have (pp. 15–16). He foreshadowed the role of the designer as a specialist, separate from the media production specialists already known to the audio-visual community and the attendant implication that these specialists would require specialized tools, concepts and processes. Finn was recommending, as was Heinich, the adoption of "systems concepts" and "instructional development…as a process and a method to operationalize a systems approach to instruction" (Heinich, 1984, p. 74).

Finn set into motion a tendency toward self-examination that continues to influence the whole educational technology field today. By 1960, he clearly considered media devices to be distractions from the abstract questions concerning their use in instruction, setting up what Shrock describes as "…a tension between 'media people' and 'developers' [which] remains in the field today (1995, p. 17). In 1963 Ely edited a special issue of *Audio-Visual Communication Review* (Ely, 1963) which attempted to answer Finn's call with a definition of the field. This was the first of a series of official definitions issued since then (AECT, 1977; Ely, 1972; Januszewski & Molenda, 2007; Seels & Richey, 1994).

Formalized design was coming into its own in other fields during the same period. As early as 1929 Buckminster Fuller was forming his earliest ideas for what he would call design science, but in the USA during the 1930s and 1940s, product designers were termed "stylists," openly committed to aesthetic variation in design intended to drive a post-war consumer economy. At the same time, in the UK, professionalism in product design was well underway. The Society of Industrial Arts was formed in the UK in 1930, establishing exams for credentialing designers. By 1944 this board had undergone a reform, defined three grades of practice and established a Code of Professional Conduct (Buchanan & Margolin, 1995; Read, 1946).

Teaching Machines and Programmed Learning

The period from 1950 to 1970 was marked—and complicated—by the extraordinary success of Skinner's teaching machines (1958), which he expected to address growing needs for schools and teachers. For a brief period teaching machine manufacturers entered the market at the rate of two per week

(Silvern, 1962), although interest waned when it became clear that comparatively expensive programming and not the machines themselves were responsible for the learning effect.

The excitement around teaching machines simultaneously placed mechanisms and design technology front and center, which Finn argued was a negative development. However, designing programs for teaching machines promoted intense engagement with strategic instructional design processes, which was "a factor in the evolution of the instructional design process" (Lockee, Moore, & Burton, 2004, p. 545). While the actual practice of programming was referred to at the time as an "art" (Markle, 1964), and did not result in an explicit design model, programming required a complex design process, precise design vocabulary, and increased attention to detailed instructional goals, content structure, instructional strategies being used, and an intense cycle of design, tryout, and revision. Significantly, Markle remained opposed to formalizing the programming process itself, choosing instead to emphasize the unique requirements of each design problem. Markle did insist, however, on the rigorous cycle of program improvement through trial and revision.

Emerging Models of Design

In contrast to Markle's insistence on "art," in 1963, Leonard Silvern was creating large fold-out diagrams detailing design process models which used a new terminology and symbology to represent what he called models of the educational design process (Silvern, 1968). Silvern emphasized the process formalization requirement that was created by large, complex design projects involving multiple organizations, tough design problems, and large staffs working over extended periods of time: the kinds of problems being worked on at the time by the military and large industrial organizations. He provided box-by-box functional descriptions of the processes represented on these comprehensive foldout diagrams, and also referenced similar work by Ofeish (1963), who was also building models for the military and industry, where such models had been growing steadily for as much as a decade.

The emerging field of formalized instructional design models was on a parallel track with thinking in the wider, international, arena of design at this time. The Council of Industrial Design, in London, published Archer's "Systematic Method for Designers" (Archer, 1965), which included a 14 page "checklist of activities and events" to be checked off on the six-page "arrow diagram… mounted on the wall adjacent to the designer's drawing board [where] the links in the diagram show what must be done next" (p. 16). Archer and Silvern described design in terms of problems and subproblems, and clearly differentiated the roles of the designer who specifies an artifact and the production engineer who manufactures it.

Briggs

It was Briggs, however, who established both the design process model and its definition in the minds of the new class of workers called educational specialists. This group had previously associated themselves largely with the audio-visual movement, but Briggs defined for them a new path forward by refining their design practice. The discovery that it was the program and not the teaching machine that made the difference left open the question what media combinations could or should be used for instruction. This led to a divergence between device-thinking and abstracted thinking about strategic design structure. This was the problem that first caught Briggs attention. In 1967 he published *Instructional Media: A Procedure for the Design of Multi-Media Instruction, A Critical Review of Research, and Suggestions for Future Research* (Briggs, 1967). His publication introduced several ideas that foreshadowed the future of direction of instructional design concepts and practice, and things would never be the same for instructional designers.

Briggs' goal was to establish the instructional requirements of objectives as the basis for media selection, using newly invented taxonomies of instructional objectives (Bloom, 1956; Gagné, 1965). Gagné and Bloom both held to the principle that from the nature of the instructional objective a "best" approach to instruction could be determined. Significantly, Bloom's work was based on that of his mentor Ralph Tyler, as expressed in *Basic Principles of Curriculum and Instruction*.

Briggs followed this by publishing what he specifically called a "design model" in the *Handbook of Procedures for the Design of Instruction* (1970). He described this "set of procedures for the design of instruction" as a model employing the "systems approach" and comprising "(a) the process of instructional design described in an orderly series of steps, (b) based on research findings when possible, psychological theory, or upon common reasoning, and (c) dependent on empirical tryout [validation] to be judged satisfactory"(1970, p. vii).

Briggs' focus was clearly on process. He described a new category of worker called an "educational specialist" who would have access to superior systematic design techniques, and introduced the idea of "multi-media" instruction meaning that teachers (rather than teaching machines) would play a central role in instruction, even if that role was in service to a preset design. He also conceived of the "package of instruction" (1967, p. 9), bringing objectives, media usage and a unit that publishers could produce profitably. He praised

David Markle's design approach (Markle, 1967) describing it as an important methodological innovation that could be "extended to determination of training objectives and to the determination of specific development steps to be taken" (n.p.). A close examination of Briggs' work at this point shows that he was concerned with issues identical to those of the Plans and Tyler before him. The difference at this point was the rising tide of the emerging systems approach and the increased popularity of engineering solutions which created a ready vocabulary for his ideas in the minds of the audience.

Coincident internationally with Briggs' and Silvern's work, the Royal Institute of British Architects (RIBA, 1965) published a 4-Phase model describing "systematic" design processes, and Gregory (1966) published *The Design Method*. These works were frankly aimed at achieving efficiency in design through defining the process of designing, but also made it clear that the complex work of creation and innovation could not be fully depicted in such models (Archer, 1965). This distinction was evidence of a splitting away from the two-dimensional simplicity of engineering models: a trend which would continue in Europe.

Emergence of the Systems Approach

At the beginning of the Cold War a body of accumulated knowledge about how to approach the design complex systems flooded into academic and public domains from scientists and engineers who had spent the early parts of their careers designing technology systems on an unprecedented military scale. The complexity of these systems required large teams from multiple specialties to engage in careful analysis, problem definition, design of solutions, development of equipment and training, and constant evaluation of program and process quality.

In 1965 Robert Gagné edited *Psychological Principles in System Development* (Gagné, 1965b), a volume to which multiple systems approach practitioners contributed, marking the point at which the systems approach merged into the field of audio-visual instruction to begin forming the field that today comprehends instructional technology, educational technology, instructional systems design, instructional systems technology, and other similar academic titles. The book was one work within a larger body of works in many fields on systems development, but to the members of the instructional design community it represented a monolithic statement about the systems design process whose influence even today silently dominates the discourse of instructional design practice, though few designers today could claim to have read it or even know of its existence.

It is worth noting that Gagné presented two major aspects of the systems approach in his book: (1) an orderly, integrated, multidisciplinary, but not structured, problem-solving process which is rational and systematic; and (2) a set of conceptual tools for designing systems which interact properly with neighbor systems, are controllable, and are adapted and adaptable to their environment. There was little mention in this edited work of general systems theory, which emerged in the social sciences years after the systems approach emerged from its more practical application in wartime military laboratories. The systems approach was a problem solving and designing tool, while general systems theory was a descriptive theory for the scientific study of the behavior of both natural and human-made systems.

Origins of the Systems Approach

The systems approach described in *Psychological Principles* can trace its lineage back to systems engineering, which emerged in England early in World War II (Hughes & Hughes, 2000) under conditions of extreme expedience and physical danger. It was a method for solving for complex problems whose solution had to draw on diverse scientific and engineering specialties through multidisciplinary teams. Systems approaches have recently been described as a way of thinking and problem solving, rather than as a specific process. The systems approach uses a constellation of problem solving concepts, tools, and techniques, many of them mathematical or statistical in nature. Ramo describes the systems approach as "… an intellectual discipline for mobilizing science and technology to attack complex, large-scale problems in an objective, logical, complete and thoroughly professional way" (Ramo & St. Claire, R. K 1998, p. 1). The systems approach involves stages of analysis followed by stages of synthesis (Silvern, 1968). Gagné explained that the goals of the approach center on "the desire to achieve maximal efficiency of system development" and that "systematic plans must be made for how the system is to work" (p. 3), including multiple subsystems that describe not only artifacts, but the operations of many interacting component systems.

The systems approach was atheoretic, meaning that it did not entail theories about the inner working mechanisms of the artifacts designed (domain theories). These theories were brought to the problem by the individual problem solver. This meant that a systems approach could be used equally well by any designer regardless of theoretical bias (Richey, 1986).

Models Proliferate

The systems approach was large, complicated, unpredictable, and required multi-specialized teams to solve big, otherwise-intractable problems. This fit neither the skills nor the budgets of instructional design teams, the funds for which were shrinking. But the idea of the systems approach was still rationally compelling. After 1970 the number of instructional design process models claiming to be based in a systems approach multiplied rapidly in the military, the academic, and the corporate-consulting worlds (Gustafson & Branch, 1997b). The literature on these models became so extensive over the ensuing decades that a comprehensive examination of them was deemed impractical. One of the clear trends during this period was the increasing simplification of representations of the instructional design process from both the robust conception of the systems approach and the complex engineering models of Silvern and his associates. Gibbons (2010) identifies a number of dimensions in which descriptions of design started to trivialize.

The best way to capture the magnitude of model explosion after 1970 may be to note the growing number of models available for review during the 1970s and 1980s by Twelker, Urbach, and Buck (1972), Andrews and Goodson (1980), Gustafson (and later Branch, see below) *which could not be reviewed due to their number*. Gordon and Zemke (2000) make particular mention of the mountains of documentation some of them entailed as they became more detailed. Dubberly (2005) has collected examples of diverse design models from many fields, which provides an interesting contrast to the sameness which overtook many of the models described in the instructional design literature at this time.

Model Creation and Application: Still the Systems Approach?

Design model creation is not scientific. Instructional design models begin as process descriptions at a high level of abstraction and grow through the subdivision of individual high-level processes into subprocesses in a manner described by Taylor and Doughty (1988). The purpose of applying a model is to detail the processes which will be applied for a given project, to solve a given design problem. The subdivision of processes is recursive and can be extensive, as shown by Silvern (1968) whose generic model (p. 99) requires a five-foot-long foldout, fully detailed (p. 59).

Instructional design models continue to multiply, which is a source of puzzlement to some, but Smith (2008) posits that as long as a primary goal of models is to specify processes that would otherwise be decided in situ by designers, there is (will be?) no end to the number of detailed models generated (through the decomposition process) to cover all situations. Since models tend to be couched in process terms rather than in terms of principles, the hope that purely process models will lead to breakthroughs in design thinking is slim.

As design models have proliferated, they have tended to claim a grounding in the systems approach, but as time has gone by the identity of the complex problem solving process has become less and less apparent, and models have tended to be rearrangements of each other, shuffling around boxes which have come increasingly to look more like sequences of procedures and less like fresh analytic approaches to attacking unique design problems.

It is helpful to put these developments in context by comparing attitudes towards design models in instructional technology to positions taken in other design fields during this time period. While there does not seem to have been any coordinated, collaborative effort on the part of professionals from instructional design and those from other fields, there are some instructive points of similarity and difference. Between the mid-1960s, when design models emerged in industrial design, and the 1970s, when design models were proliferating in instructional technology, the first generation of design methods were burgeoning in industrial and architectural design (Lawson, 2005). The formation of the Design Methods Group at U.C. Berkeley in 1967 was preceded by Alexander's *Notes on the Synthesis of Form* (1964), and followed closely by publication of Simon's *The Sciences of the Artificial* in 1969 (Simon, 1969), Alexander's *The Timeless Way of Building* in 1969 (Alexander, 1969; Alexander et al., 1977) and Jones's *Design Methods* in 1970 (Jones, 1970; Margolin, 2010). Simon's Sciences, Alexander's pattern language work, which was extended in 1977 (Alexander, et al), and Jones' methods moved well beyond design models, acknowledging a flexible and critical role for the designer, while still being dedicated to a rationalization of the design process at some level. Moreover, design concepts continued to grow; by 1971 Alexander had disassociated himself from design methods as too restrictive. By 1977 Jones had also distanced himself from design methods (Cross, 1984). Neither author, however, regressed to process models.

Reviews of Design Models

The best way to examine trends and developments in instructional design models in the 1960s and 1970s is through the reviews of models that began to appear quickly (Stamas, 1973; Twelker et al., 1972) and continued periodically up to and through the turn of the century (Andrews & Goodson, 1980; Gustafson, 1981; Gustafson & Branch, 1997a, 1997b, 2002; Gustafson & Powell, 1991).

Andrews and Goodson's review of 40 instructional design models (Andrews & Goodson, 1980) provides a glimpse of the land rush mentality which had come to typify the new professional territory of instructional design models. The clear purpose of the review was to untangle the numerous issues relating to models which had become snarled because few were willing to take time away from the headlong rush to define what the basic issues were. The Andrews and Goodson review became a watershed, the scope and clarity of which has not been duplicated. In their review several issues surfaced, many of which remain unaddressed today: the proliferation of models, the absence of validation, the blurring of terms, incomplete model descriptions, and relation to theory. Today, it is clear that another issue that might have been addressed includes the place of models in achieving robust descriptions of design (Gibbons, 2010; Smith & Boling, 2009).

Early reviews by Twelker et al. (1972) and Andrews and Goodson (1980) included models from a wide body of literature and spoke to technical designers working in high-stakes settings. The series of reviews led by Gustafson between 1981 and 2002 was restricted to the literature reported and available in the ERIC Clearinghouse which focusing almost exclusively on education. These reviews were also intended for a nontechnical and mostly novice audience. This limited the scope and depth of the reviews considerably. At around this time, the term "ADDIE" became generally associated with design models. The origins of the ADDIE term are uncertain (Molenda, 2003), which is symptomatic of the disorganized and unsystematic state of the instructional design literature at the time.

Throughout these reviews of design models, several trends may be discerned. The first is that over this period models lost the energy and robustness of the first-generation systems approach to problem solving that was evident in the work of Gagné (1965) and Briggs (1970). Even as the models became more detailed and complex, in extreme cases they lost sight of the systems approach altogether and were presented as mostly procedural and even linear (Braden, 1996). Accompanying this trend was the notion that designers need have only "a half-dozen really different models in his/her tool bag and know how to modify them for each new situation," (Gustafson, 1981; p. 4). This points to a growing and ultimately entrenched set of ideas: that there can/should be distinctly different kinds of models, that models can be selected for projects using known rules or guidelines, and that there is a process for tailoring models to projects. What these kinds, rules, guidelines, and processes may be has not been articulated (Smith & Boling, 2009).

In the second trend, models representing subprocesses, such as objectives analysis and media selection, and specialized processes, such as computer logic design, appeared in greater numbers and became more common during the 1980s and 1990s. Most of the design processes came under more detailed scrutiny to describe their internal subprocesses. This produced models for subprocesses such as objectives analysis and media selection. These subprocess models were left out of most reviews, and though such detailed subprocess models have since fallen out of vogue, they point to an increased interest at the time in design processes at a fine-grained level and a continuing focus on the procedural aspects of designing at every level.

The third trend revealed by these reviews is something of a flat line rather than a trend. The models included in the reviews were similar enough that time after time they could be compared using the same table format emphasizing the steps in each model and their order. In the Gustafson and Branch reviews (1997a, 1997b, 2002) some deeper analysis and additional rigor were introduced. Gustafson lamented the lack of progression across generations of models and the lack of knowledge or design improvements flowing from them, despite their proliferation (1981, p. 1), but there was no sign at this time that any view of design or development outside of process-oriented models was being seriously explored.

Over time, instructional design became invested in fewer models, found mostly in textbooks, and mainly tailored to the needs of a novice audience consisting of public school teachers and beginning graduate students. Meanwhile, in the larger world of design research, architectural and product design was pursuing second-generation design methods (Rith & Dubberly, 2006; Rittel, 1973). Schön (1987) was pioneering empirical studies of designing which led to robust descriptions of a designer's "conversation" with a design problem, and multiple journals focused on research into design were founded (Margolin, 2010). Critiques of design models, like the RIBA model which was still in use (1965), were based in further and rigorous empirical studies of designers (Cross, Christaans, & Dorst, 1997) and soon process models were being repositioned outside of instructional design circles as tools with severely limited utility (Lawson, 1980).

Issues

Models lost the energy and robustness of the first-generation systems approach as they were simplified to include ever-larger populations of novice designers. Some models lost the spirit of the loose-jointed systems approach to problem solving altogether. The growth of design models accomplished by revising and rearranging the same set of basic elements produced a narrow view that ultimately isolated the instructional design practitioner from outside views of design which might have enriched the concept of design and led to an expansion or redirection of design practices (Smith & Boling, 2009). An accompanying focus on the visual representation of design models also led to the impression that the process of designing was rational and sequential because various actions were depicted as bounded, ordered shapes. The depiction of cybernetic iteration, generally shown by arrows or repeated elements in a diagram, appeared in high-level graphic representations masked the cybernetic thinking and judging processes which in actuality take place at the finest level of granularity and all levels in between.

Conclusion

The point of this account of ID model history has been to show that popular misconceptions about the origins and nature of models have obscured our understanding of the design-related problems such models were intended to solve as well as the concepts that were most central to their original development (Gibbons, 2010). Having neglected to focus on the core concepts and the idea that the systems approach was domain-theory-agnostic, we have over time added to the models domain-specific baggage which restricts their application to a narrow range of problems which make certain assumptions (for example, the assumption that task analysis is *the* appropriate form of content analysis), thereby making them applicable to only a stereotyped set of problems for which they tend to produce stereotyped solutions. By focusing on the models themselves, and by associating the narrative of their history with specific philosophical and theoretical positions, especially behaviorism, we have entered a blind alley in which the way forward for many seems to be either: (a) continuing to rearrange and reword existing models, or (b) viewing models with suspicion and advocating their marginalization.

Meanwhile, the design literature from many other design-related fields is reminding us that the problems we face in designing are common to other fields as well and that there are many possibilities yet to consider (Brooks, 2010; Cross, 2007; Goel & Pirolli, 1992; Kruger & Cross, 2006; Lawson, 2005; Lawson & Dorst, 2009; Rowe, 1987).

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Change Agency in Learning, Instruction, and Performance

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Michael Ramon Savoy and Alison A. Carr-Chellman

"Change is not an event, it is an enjoyable and rewarding journey."

(Belasco, 1991, p. 16)

Abstract

The purpose of this chapter is to describe the state of research and theory in the area of Change Agency in instructional and organization systems. The study of the diffusion and adoption of innovations arguably began with a need to understand how external change agents could encourage relatively passive users of an innovation to accept the need for change and implementation of the desired change. The change agents' frustrations with the lack of relevant useful results led to more collaborative efforts to design, develop, implement and benefit from research, processes and products. The last few decades have seen research on change and change agency that is focused more on how to engage users in the change process through change agents who are internal and external to the system.

We begin this chapter with a brief history of research and theory from diffusion and adoption processes to a more inclusive and collaborative look at organization and system change. This is followed by a discussion of the latest research in business/corporate and nonprofit organization change focused on leadership in change management and communication modes and messages. We finally consider what the overall research tells us and what gaps remain to be filled in order to continue a robust agenda for effective change agency research and practice.

Keywords

Change agent • Organizational change • System change • Change management

Introduction

Perhaps more than ever before, we must pay attention to change management and how to lead change efforts in all social systems. With the dramatic changes that surround social systems from schools to corporations to nonprofits, the world is changing around us. We see incredible increases in the uses and imposition of technologies on our daily work, we observe significant shifts around expectations of those we serve as customers and students, we experience significant shifts in the needs of organizations because of restricted resources. From money to time to people, social systems have to respond daily to doing more with less, and this chapter may help us along the journey toward managing these dramatic changes as agents who lead dynamic social systems.

Instructional designers, educators, community members, stakeholders and countless others in the field of learning and instruction develop new and innovative solutions to developing greater human performance. However, all too often these innovations fail to achieve the intended goals without careful consideration of the individual and collective changes necessary

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for the innovation to be implemented (Carr-Chellman, 2007; Poole & Van de Ven, 2004; Rogers, 2003). It is frequently the case that the best designs fail for the lack of proper implementation, which can be dependent on proper change agency. In systems such as business, education, and community organizations, change agency has become an integral and essential part of the process of advancing learning, instruction, and performance. This chapter reviews the research of change agency and attempts at change from the diffusion of innovations and early change models (Ely, 1999; Hall, 1974; Rogers, 2003; Sarason, 1995; Zaltman & Duncan, 1977), through change models in business and industry and k-12 education of the last century (Duffy et al., 2000; Goddard & Bohac-Clarke, 2007; Hammer & Champy, 2001; Havelock & Zlotolow, 1995; Kirkpatrick, 1998; Senge, 1990), to more recent work in systemic change and user design (Banathy, 1992, 2000; Carr-Chellman & Savoy, 2004; Fullan, 2001, 2005; Fullan & Stiegelbauer, 1991; Hargreaves & Fullan, 2000; Hutchins, 1996; Jenlink, Reigeluth, Carr, and Nelson, 1998; Reigeluth and Garfinkle, 1994; Reigeluth & Squire, 2000). The review shares not only information on these theories but also their implementation in practice, and where research findings exist, to give a holistic accounting of the literature at the intersection of change agency, social systems, adoption, implementation, and diffusion of innovations.

History of Change Theories and Research

From Change and Diffusion to Participation

To begin a discussion of change agency, we start with a review of change and diffusion research and theory in general over the last century. Change research has focused on many areas including the diffusion of innovations (Rogers, 2003; Spiering & Erickson, 2006), the obstacles to, the drivers of and the participants in innovation adoption (Nelson, Brice, & Gunby, 2010; Ryan, 1996) and the steps in the process of innovation adoption (Cawsey & Deszca, 2007; Frambach and Schillewaert, 2002). The innovation adoption process is a sequence of stages that a potential adopter moves through in the acceptance (or rejection) of a new product, method, or service (Rogers, 2003). Beginning with its roots in rural sociology the various aspects of change have been studied in order to be more efficient and effective at introducing and sustaining change in organizations (Fliegel & Kivlin, 1962; Ryan & Gross, 1943).

Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system and Everett Rogers may arguably be the foremost and most cited source in basic diffusion theory. Rogers (2003) described eight main types of research projects using a diffusion process that included moving from knowledge of the innovation, through attitude change by persuasion, decision-making, implementation and confirmation (p. 20). He believed that the diffusion of innovation is a somewhat predictable and controllable thing with participants falling in to five adoption categories: innovators, early adopters, early majority, late majority, and late adopters[1]. For Rogers, it is assumed that the innovation is needed and beneficial to those that must change in order for the implementation to be successful (Frambach and Schillewaert, 2002). Some feel this pro-innovation bias does not focus enough on user issues and research focusing only on the diffusion of the innovation (Valente and Davis, 1999; Yapa, 1996), tends to increase inequality as it gives inadequate attention to indigenous knowledge (Carmen, 1990; Carr-Chellman & Savoy, 2004; Evans, 1996; Salvo, 2001).

Many researchers since Rogers have devised their own ideas of how change should progress and components, steps and outcomes of their view of the change process. For example, Hammer and Champy (2001) describe a process they call reengineering or essentially starting over. This process is the fundamental redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance. In reengineering, there seems to be lacking a change agent role or one is not explicitly defined. It is a rather top down approach that gives some credence to the individual within the system but no real power or leadership abilities are outlined. It also may not be possible in truly dynamic social systems that are constantly in states of systemic change. Ely (1999) describes eight conditions necessary in order for any stakeholder to want to and successfully implement change. Participants must be dissatisfied with the status quo, have the knowledge, skills, resources, and time available to them, feel there is some reward for changing, be active participants committed to the change and have an effective leader to guide the change. These and other theories have the potential to help change agents assess the readiness of the organization for change as well as help the change agency process.

Other change research in K-12 educational systems has focused on less prescriptive or top-down approaches and more on authentic participatory change processes. Recent research has focused on "redesign" rather than "change" in these social systems. For example, Jenlink et al. (1998) offer a guidance system for change facilitators to engage broad bases of stakeholders. They advocate that the values and beliefs held within the culture of a given social system are integral to systemic change. They also believe that change agents should work to understand these underlying values and beliefs in order to facilitate system redesigns. This is a

[1] In earlier incarnations of Rogers' work, he called late adopters, "laggards."

more holistic, participatory process than many of the previous organization change models in other industries. Lastly, Bela Banathy (1991) brings forth the idea of comprehensive systems design of education. This idea is the design and redesign of all parts operating at a specific system level of education interactively and simultaneously. It is a process by which visions, ideals, values, and aspirations are shared, collectively agreed upon, and articulated by people who serve the system, who are served by it, and who are affected by it.

One can see over the last century, change research and theories have progressed from understanding how to get people to change as objects of the change process to how to include them as participants in the change process. Theories have moved from more colonial understandings of how to effect change as "light-bringers," to stakeholder-based approaches that engage a variety of users in the creation of their own systems. What this means for who change agents are, how change agents view their work and effect change, and the process and characteristics of change agency in organizations and systems are reviewed through the current research. However, we first look at cross section of definitions and descriptions of change agency over this same time period.

Defining Change Agency

Given the variety in change processes, we can see similar variety in how change agency is defined and what role change agents play in the change processes. "Change has become both pervasive and persistent. It is the norm." (Hammer & Champy, 2001, p. 25) and so change agents have been and continue to be a critical component of organization and systems change. Generally, a change agent is someone or something that causes change, but different fields or industries interestingly, define it differently. For example, according to the Process Excellence Network (2010), a change agent is defined as a person "who leads change within the organization, by championing the change, and managing and planning its implementation. The role can be official or voluntary; must be representative of the user population, understand the reasoning behind the change, and help to communicate the excitement, possibilities, and details of the change to others within the organization." The Mosby's Medical Dictionary (2009) defines change agent as: (1) a role in which communication skills, education, and other resources are applied to help a client adjust to changes caused by illness or disability; (2) a role to help members of an organization adapt to organization change or to create organization change. The Business Dictionary (2010) has a more cynical definition of change agent or "champion," stating the "person who voluntarily takes extraordinary interest in the adoption, implementation, and success of a cause, policy, program, project, or product. He or she will typically try to force the idea through entrenched internal resistance to change, and will evangelize it throughout the organization."

Rogers (1995) defines a change agent, as "an individual who influences clients' innovation-decisions in a direction deemed desirable by a change agency. The change agent usually seeks to obtain the adoption of new ideas, but may also attempt to slow down diffusion and prevent the adoption of undesirable innovations," (p. 27). Rogers goes on to describe change agents as "professionals with a university degree in a technical field," (p. 28). Havelock and Zlotolow (1995) states, "Anyone who intervenes in the problem-solving efforts of a social group or organization can be described as a 'change agent'," (p. 8). "The change agent can and should specialize in helping with that part of the process where he/she as the best chance of making a difference," (p. 8). Havelock and Zlotolow go on to describe four primary ways in which individuals can be change agents: (1) Catalyst, (2) Solution Giver, (3) Process Helper, and (4) Resource Linker. Havelock and Zlotolow recognize that the diffusion process is not only individual but systemic as well; however, in their process, the change agent seems to be the sole determiner of what change is important

Change agents must often be aware of the conditions for change and making sure that the organization or system is ready for change. David Ulrich (1997) describes six competencies required for a change agent to be effective. They have to have the ability to: diagnose problems, build relationships, ensure that the vision is articulated, set a leadership agenda, solve problems, and implement plans to achieve change goals. Zaltman & Duncan (1977) believe it is the change agent's job, "to develop a climate for planned change by overcoming resistances and rallying forces for positive growth," (p. 46). Brown (2010) states a change agent influences change by, "building strong credibility, engaging in meaningful dialogue, seeking to collaborate, educate and network, and capitalizing on all relevant opportunities," (p. 70).

Fullan (1993) defines change agency in k-12 education as "being self-conscious about the nature of change and the change process. Those skilled in change are appreciative of its semi-unpredictable and volatile character, and they are explicitly concerned with the pursuit of ideas and competencies for coping with and influencing more and more aspects of the process towards some desired set of ends," (p. 12). He goes on to say that there are eight basic lessons of the new paradigm of change which includes lesson eight: Every Person is a Change Agent (p. 22). Fullan (2001) believes effective change leaders need to have five characteristics: moral purpose, understanding of change, ability to build relationships, ability to create and share knowledge, and coherence. Williams (1997) describes the change agent as a "carpenter" who "builds consensus among administrators and teachers and among all stakeholders in the school change process. The carpenter honors and considers the hopes and dreams of every participant and guides the group to mold its own purposeful vision. He uses tools and processes to create and support shared decision-making," (p. 19).

Senge (1990) views the leadership of a learning organization as the "designers, stewards, and teachers. They are responsible for building organizations where people continually expand their capabilities to understand complexity, clarify vision, and improve shared mental models – that is, they are responsible for learning," (p. 340). Banathy (1991) doesn't define one change agent but believes all stakeholders in the system are the drivers of change.

The idea of the change agent has developed from being one strong force and sole determiner of what is important within the change process to a more collective group of individuals to an even more inclusive view of every individual involved in the change as an agent of change.

Research on Change Agency

Balagun (2006) states that the key to organization and system change is "to develop comprehensive change plans that take best practice in to account – lots of communication, clear assignment of responsibility, management of stakeholders to overcome resistance, training in new ways of working, and so on," (p. 41). However, the how of how to do all of this is not so clear. The research on change agency is vast, ranging from k-12 educational and corporate entities to large-scale social systems. This section takes a look at change agency through organization change at the corporate and k-12 educational levels. We have chosen to focus the discussion on two widely researched areas: leadership and communication. Leadership for change is first reviewed including a look at research on change involvement at "lower" levels of organizations. We then briefly explore the research on change communication.

Leadership for Change

Many have theorized about what leadership for change should look like (Fullan, 2005; Hamel, 2009; Killon & Harrison, 2006), the characteristics of a good manager of change (Palmer & Dunford, 2008; Senge, 1990; Ulrich, 1997) and the steps a leader should follow in order to effect change in an organization or system (Ackoff, 1981; Fullan et al., 2005). Much of the current research on change management focuses on how those within an organization, specifically middle managers or principals, work as change agents. There are also various studies that focus on how front line workers and teachers view and navigate organization and educational change.

In a comparative case study of the implementation of a change initiative, Stensaker and Langley (2010) examined the choice of change management approaches of several division-level change agents in a multidivisional oil company. The researchers found that the change agents navigated three concerns, "substantive concerns related to goal attainment, political concerns related to conformity to corporate demands, and relational concerns concerning relations with employees," (p. 7). This study focused on the Division level of the company because in most situations, top down initiatives naturally encounter some alterations in the original change or innovation, as they trickle down, by those with either decision-making power, or implementation power. As middle management, who did not start the change project, they often find themselves as intermediaries of process being, "both the object and agency of change," (p. 10). The researchers proposed, "a dynamic 'contingency-balancing' model of change agent choices in a multidivisional context in which divisional- level change agents are seen to balance three key concerns related to (a) goal attainment, (b) employee relations and (c) relations with corporate level," (p. 8). These change agents have to decide how to adopt or tinker with the innovation in order to keep a positive relationship with those they supervise, moving forward with the innovation and not getting in to trouble with upper management about how much the innovation has changed or the pace and extent to which the innovation is implemented. The researchers found that managing change "involves balancing and attending to substantive, relational and political concerns," (p. 23). Substantive concerns include making assessments as to the need for the change being handed to them. Relational concerns involve understanding how pushing for the implementation will affect the work environment positively or negatively and limiting the resistance, when necessary. Political concerns require change agents to determine what they can get away with themselves, without damaging relationships with their superiors, in pursuing the implementation. These change agents were constantly balancing these three concerns weighing their options and which to be more attuned to during different points in the change process. These concerns can often push a change in different directions, so it is hard for a change agent to address all three simultaneously.

In many organizations and systems, change projects and innovations are constantly being introduced. The issues that many face are the continuity between projects and the conservation of external and internal knowledge during the change process. Helping an organization hold on to "organizational identity" through sequential projects can be the work of a change agent. Irgens (2009) took a historical look at several change projects over a 15-year span in a widely changing industrial field, oil and gas, and analyzed the work of the change agents in those projects. They found that successful change agents build bridges between current work in the organization and the new change initiative as they "prepared, introduced, and motivated employees for 'yet another' change project," (p. 162). The study showed that resistance and disruptions of change could be avoided if change agents are able to build bridges between sequential change projects. This helps institutional knowledge to be transferred from the old project to new projects while legitimizing the new project. The change agents attempted to convince stakeholders that the change was not really a change at all but a continued movement forward of their work. Change agents have to find a fine balance between a change being seen as novel and exciting and it being a disruption of current practices. Overall, Irgens (2009) found that "change agents take chances on behalf of their organizations. They leave familiar structures behind, with no guarantee for successful results. At the same time, skilled actors try to reduce this uncertainty by finding an optimal balance between change and continuity," (p. 169).

Nelson, Brice, and Gunby (2010) examined individual and behavioral factors in the innovation adoption process. The researchers investigated the relationship between the personal involvement of a change agent in an organization and the change agent's personal problem solving style, social support patterns, and innovation adoption decisions. In previous research, Nelson and Brice (2008) found that "the innovator problem solving style is positively related to the informational support from within and outside the organization," (p. 74). They believed that through this current research they would find that "managers who seek new ideas and become involved in the innovation as a solution to a problem have an innovative problem solving style," (pg 74). They found that the innovator would naturally seek informational and emotional social support from inside and outside the organization to help with forming an opinion about the innovation and the possible adoption of an innovation. External emotional support helps to moderate both the internal and external informational support for adoption of the innovation. While there is a positive relationship between problem solving style and the internal and external forms of informational and social support, only the external forms of social support seemed to be associated with the eventual adoption of innovations. This study highlights the importance of a change agent having a social network in which to gather support and information as they facilitate the adoption of an innovation.

Chreim et al. (2010) conducted a longitudinal case study that examined change agents' roles, their evolution throughout the adoption process and their ability to exercise influence over the adopters in a healthcare context. This study covered 4 years of a project to develop and implement multidisciplinary primary health teams across different organizations. They found that distributed leadership was important, "in contexts where legitimacy, authority, resources and ability to influence complex change are dispersed across loci," (p. 187). When constituents are varied, distributed or collective leadership is important as the change agent role will likely need to be shared. "The notion of distributed leadership attends to change visioning and implementation as a collective enterprise, involving a variety of actors (individuals and/or groups) sharing in change agency roles (p. 188). This study focused on the actions of leadership not the traits that a leader should have. The researchers' findings "indicated that several strategic activities such as visioning, process facilitation, providing resources, implementing coordination of care and creating early wins were performed to ensure success of the change," and these activities were performed by many different individuals who themselves changed roles as the change progressed. The "sources of influence that the various stakeholders mobilized, the emergence and distributions of leadership roles, the evolution of change agency roles, and the importance of process management" were also key ideas that emerged from this study. With distributed leadership, the researchers found that project managers "played a pivotal role in managing the process, ensuring the agreement on collective goals was reached, and later that action toward achievement of goals was mobilized and sustained," (p. 197). The stakeholders in the implementation, while at times being the key change agent, do not often have the time to devote the necessary daily attention to the change process.

Change agency in the K-12 educational system has come in many forms from strong central leadership to community empowerment and user-design (Banathy, 1991; Carr-Chellman, 2007; Duffy, Rogerson, & Blick, 2000; Freire, 1998; Schlechty, 2001; Wagner, Kegan, Lahey, Lemons, Garnier, et al., 2006), but for the most part has centered around how and who to engage. McLaughlin and Hyle's (2001) case study investigated ways in which a principal takes in to consideration the individual needs of the faculty members when implementing change. Most of the respondents believed the change process was a collaborative team effort and that they were full participants in the process. They saw the principal as the facilitator of dialogue between the teachers. As the key change agent in this system, the principal created a context and positive atmosphere for change. In a 2010 study, Ninni also examined the role of the principal in a school change setting. Through interviews with stakeholders she looked at how the principal, school-based problem solving team, and the teachers perceived the principal's abilities as a change agent, specifically his ability to implement and sustain a response to intervention reform effort. How the perceptions of these stakeholders influenced the change process was also examined. It was found that in this case, the stakeholders felt that the principal displayed many of the characteristics of change agents: knowledge of change, self-efficacy, and the necessary skills to carry out the implementation. Some factors were specifically discussed including providing vision and models appropriate behavior, holding high expectations, fostering commitment to goals, and providing individual support.

In a study of elementary school principals in the Southwestern United States, Kearney and Smith (2010), explored the relationship between a principal's level of influence on his/her staff and three aspects of school change. They believed that the more influence a principal had on the staff the more open to change the staff would be. The "receptivity of the campus principal to change provides an important example for teachers and serves as a critical resource for any successful school reform," (p. 5). The researchers found that this openness to change led to increased levels of change receptivity of the staff and community and the principal's influence on the community and staff is a predictor of the principal's openness to change.. It can be said that building a relationship between the principal and teachers where the staff trusts and follows the principal's lead, that changes being asked of them and of the community will be more readily accepted and implemented. It is therefore important for principals, as change agents, to nurture the kind of environment that increases the staff's belief in their administrators and subsequently their acceptance of change.

A growing realization in school reform is that school improvement efforts that do not include teacher participation if not also teacher leadership are destined to fail. Teachers as change agents often requires professional development in order for teachers to have the necessary knowledge to make changes (Nelson & Reigeluth, 1995) The teaching profession attracts many different types of people. Some choose to affect the lives of children in their classrooms alone while others choose to enact changes in the school or system as a whole. Lane, Lacefield-Parachini, and Isken (2003), explored whether teachers can be developed into change agents inside and outside of their classrooms in their study of preservice teachers. They believe that little has been done to staff urban schools with teachers who have the desire to stay and implement changes in those schools and this can begin to shift with preservice teacher training. The researchers cite four current issues with developing teachers as change agents: shortage of model teachers in urban schools, these model teachers not seeing themselves as change agents, a disconnect between some model teachers' and university's "conceptual orientation," and a seemingly one dimensional relationship between the guiding teacher and the preservice teacher. In the course of this study, the researchers contend "novice teachers need to develop feelings of "ownership" so they feel empowered to transform the urban educational setting rather than feel defeated by it," (p. 56). The idea that empowerment is important for being a change agent is clear but whether it is something that can be developed so early on in a teaching career was in question. As part of the study, preservice teachers were encouraged to challenge their guiding teachers' teaching practice and push for changes. The preservice teachers engaged "their guiding teachers in dialogue about how students learn and how best to facilitate their learning," (p. 66). The researchers found that after the first year the novice teachers became change agents for their guiding teachers, thinking about and implementing new practices that over time were continued by the guiding teachers even after the novice teacher's time at the school was completed. The novice teachers also showed continued drive to be change agents as they went on in their careers. This study shows promise in developing teacher change agents when this is carefully thought about in the learning process.

Lukacs, Horak, and Galluzzo (2011), also examined the training of teachers to be change agents. Teachers taking a course exploring the role of the teacher in educational change were studied to see if this course affected their willingness to be change agents are reported on a Teachers Change Agent Scale (TCAS). The TCAS is a 15-item instrument developed by a panel of experts and administered to teachers to determine which of eight factors correlated with teacher willingness to be a change agent (Lukacs, 2009). Of the factors (content/pedagogical knowledge, ownership, self-efficacy, empowerment, motivation, risk-taking, micropolitical expertise, and community membership) three emerged as the most highly correlated: content/pedagogical knowledge, professional community membership and collaborative expertise. It was found that participation in the study courses significantly increased the participants' willingness and confidence in making changes in their schools. The teachers were more willing to express their ideas and realized a greater ability to influence their fellow teachers; however, the findings also revealed that these teachers were still hesitant to do so. A general feeling that teachers do have more power to affect change was not accompanied by the desire to get their colleagues to exercise that power.

Finally, we see that leadership for change may also come from a whole department of people in an organization. Alfes, Truss, and Gill (2010), describe the role that human resources departments can play in being agents for change. Their research focuses on many areas including how to manage change, describing the change process itself and individual experiences, and roles in the change process. From making sure the right people are in the right place at the right time to make the change happen, to motivating employees, to presenting and discussing the change to building capability and capacity to make changes, HR can have a hand in the change process and success of overall implementation.

Whether the agent of change is the head of an organization, a principal, a middle manager, a teacher, or a department or division of an organization, one important factor in the success of implementation is the message that is brought to or developed by the stakeholders. Communication is another key aspect of change that has been researched extensively over the last half century. In the next section, we explore how change agents shape and interact with various levels of communication and discourse.

Communication in Change Agency

> "Communication is a lot like breathing. When it's going well, you don't even think about it. But, when it's broken, you're sucking wind and everything comes to a standstill," (Sande, 2009, p. 29).

From the beginning of diffusion and change research, the communication of innovations has been at the forefront. Change is often seen by many researchers as more of a problem of communication than anything else. It's not just about how the change idea is delivered but the description of the change, the why of the change (Croft & Cochrane, 2005), understanding the communication of the change process (LeTourneau, 2004), and internal organization conversation and sense-making of the stakeholders that plays a key role in the adoption and implementation of the change. Change communication has many purposes including information sharing, fostering participation, vision creation, providing social support during the change process and evaluating the change implementation (Lewis & Seibold, 1998). Change communication processes "are rarely neat and orderly; rather, change processes are riddled with tensions, paradoxes, and contradictions that must be addressed," (Barge, Lee, Maddux, Nabring, & Townsend, 2008, p. 365). Because of the nature of change, communication is key to success no matter how good or bad the innovation might be (Monge & Poole, 2008; Zorn, Page, & Cheney, 2000). Communication is the catalyst and driver of change (Ford, 1999); however, we will see that change agents cannot be the only driver of change communication. Often top down change communication is, "subject to filtering and loss of content and meaning between numerous layers of bureaucratic hierarchy," (Mueller, 2009, p. 73). Recent research has focused on a more involved and evolving role of various discourse in the change process as well as the opposing themes of leaders communicating a clear and compelling message versus communication that is participatory and empowering (Barge et al., 2008).

The role of communication in innovation by change agents and the communication about the innovation between stakeholders has been widely researched. Whittle, Suhomlinova, and Mueller (2010) in a qualitative case study, examined the role of discourse in change implementation of a new information system. They discussed a "funnel of interests" through which the perceived interests of various groups gets channeled through the discourse that occurs. The researchers' findings suggest that "change agents need to act as a mediator" who constantly interprets the change along the process "rather than a passive intermediary" who passes on the innovation unchanged or adapted to the needs of those involved in the adoption and implementation of change. The researchers believe that change agents, "need to act as change 'translators' by using discourse (among other things) to convince recipients that change is 'in their best interests'," (p. 17). They proposed that change does not involve the simple diffusion of a fixed set of ideas and innovation, but an ever-changing interpretation of the innovation by the change agents and stakeholders, thereby influencing what the change is and negotiating its meaning(s) through discourse. The discourse is "important for how recipients make sense of, and therefore react to, organizational change," (p. 18). It is also a key resource for change agents as they shape and implement change. "Discourse is important in this funneling process precisely because of its elasticity and variability, that is, the ability of agents to change their framing of the situation to align it with their context," (p. 32).

Ford and Ford (2008), sought to develop and test a model for helping change agents see their own conversational patterns as they seek to manage change. Change is produced in and through conversations and discourse (p. 445). How conversations are framed, the interaction of communication between change agents and stakeholders and the resulting actions from these communications has been the focus of much research over the last century (Beckhard & Pritchard, 1992; Beer, 1980; Ford & Ford, 2008; Kotter, 1996; Spector, 1989). Ford and Ford describe four distinct types of conversations used in successful change management: *initiative conversations* that introduce the problems, ideas and possible courses of action, *conversations of understanding* which help adopters comprehend the change and create meaning from information, *conversations of performance* that generate action steps, and *conversations for closure* that intend to complete the change and create commitment to the change. The researchers suggest that in order for a change agent to be successful he/she needs to be able to distinguish between the types of conversations and effectively use them to guide the change process. A look at the conversation profile and a deeper look at the content of conversations can help change agents see that some or much of the resistance they experience when managing change can come from their own discourse.

Ford (1999) begins to change the nature of research of communication in the change process. Often the job of the change agent is to, "align, fit, or adapt organizations, through interventions, to an objective reality that exists 'out there'," (p. 480). It is this reality that Ford calls into question. He believes that this reality is shaped by the conversations that occur during a change process and it is this reality that is dynamic and must be interpreted, constructed and maintained through the discourse of the stakeholders. In a constructivist view of change, "change agents would use interventions not to bring about a greater alignment with a 'true' reality, but rather to construct, deconstruct, and reconstruct existing realities so as to bring about different performances," (p. 480). Through this view, a change agent can see that the types of conversations are important to the overall existence of the organization and that they must work to generate, sustain and complete conversations in order to change into a new network of conversations. Change then becomes, "an unfolding of conversations into already existing conversations," (p. 487). Thus, it is important for change agents to understand that stakeholder participation in the conversations that make up the change can be influenced by how much they feel their contribution to the conversation will be acknowledged and have some influence in the change process.

Balogun (2006) developed a framework to demonstrate the influence, intended and unintended, that communications involving middle managers have on innovations that come from the senior management. This has impact on how managing change is viewed and may potentially change how change agents lead change initiatives. They found that "lateral and informal communication between peers <was the> primary vehicle for developing interpretations of what change is about," (p. 41). They also found that, "Communication <is> seen to be about both conversational and social practices (actions, behaviors, words), and to include formal and informal mechanisms such as rumors, storytelling, gossip, <and> discussion," (p. 41). Change agents should therefore understand that interpretations of the change are constantly developing and capture the stakeholders' responses to the change. The complete reliance on formal communication needs to be replaced with engaging in more informal communication events through multiple conversational methods and forms such as nonverbal communication. If change agents recognize that controlling communication is not possible, they can better position themselves to be a part of the conversations and sense-making rather than attempting to direct it.

Jabri (2010) presents a perspective of change communication as regenerative and ongoing talk and conversations as the norm of managing change. He sees that, "how one communicates depends entirely on whether one views people as participating subjects in the process or objects of the process," (p. 667). The researcher describes two limited models of change communication that change agents work from. "One working model tends to rely on communication as being the instrument of change—whereby they strive to deliver effective messages about predetermined change. Another working model tends to conceive of communication as a means of giving more people a voice in the change process. Communication in the second sense then creates a shared meaning that facilitates a particular change," (p. 669). The researcher feels that neither of those models can really predict the realities of communicating a change since they focus more on the message or the relationships, respectively, but both are important for many reasons. The researcher based his work on that of Makhail Bakhtin (1981), a Russian philosopher, who proposed that creating meaning during the change process involves stakeholders developing their own interpretations of the change and beginning a never-ending process of sense-making, co-constructing, and creating a dynamic and ever-evolving collective meaning. It is this collective meaning that leads to collective action and reduces the typical resistance felt in many change processes. This leads change agents to work to understand the stakeholders in the group as "social beings," and focus on change through dialogue and understand that meaning making is a part of the change communication. "A conversation that actively invites, expects and encourages interpretive participation results in a 'surplus of seeing'," (p. 681). Change agents need to understand that people will change their ideas about the change through their conversations with each other. Allowing and guiding these conversations is a dynamic rather than static creation of meaning that mirrors the social reality of change communication and management. How to bring in the stakeholders' voices during the change process and what allows those voices to be heard, valued and respected should be of great concern to agents of change.

Conclusions

The research on change agency comes from a wide variety of settings and tells a story that varies equally as much as the settings, methods, and participants in each study. Change agency has had a colorful and interesting story to tell us. Coming from colonialist notions of how to manipulate people into adopting a particular innovation, moving through a wide range of theories of change to arrive at a more democratic moment in understanding change as something that is dynamic and shared essentially characterizes the history of change agency.

Through the most recent research we see that change leadership involves change agents being mediators who balance issues of goal setting, employee relations, and bridging gaps between many levels of participants, for example upper level management and workers, top administrators and teachers as well as gaps between the old and the new way of working within the organization or system. Many change agents navigate this balance through activities that bring in to play the organization's social network, which allows for more distributed leadership for implementing the change. Change agency in many organizations and systems has, over the last century, shifted from relying on one controller of the change to a more collaborative culture of change leadership and implementation.

As change agency itself shifts, the need for a different style and level of communication can be seen. Communication has evolved from being focused on making the change look favorable and necessary, with the hope of convincing adopters to implement, to a more collaborative communication network that allows participants to be involved in the change decisions and development. Informal and formal discourse is important to the process. It is therefore important that change agents be aware of the how the conversations influence implementation success. Research suggests that not only is crafting a careful message important, but tapping in to the communication channels, taking advantage of the natural simple conversations as well as being aware of the minority and dissenting voices is crucial to change implementation. Further research on how communication evolves into a more participatory exercise, including those who will ultimately resist the change is necessary to help inform change agents on how to effectively include these individuals in the change process. All of this allows for greater stakeholder participation in the change implementation.

The definition of change agent has definitely had a marked move from a single strong voice within the process of innovation introduction and stabilization to a much more collective group of stakeholders and participants and even to include all those who will be impacted by the change. The key to these shifts has been a recognition of the changes in power that are essential to shift the meaning of change and change agency toward more emancipatory outlines that anticipate decision-making involvement on the part of the entire system. If, and how, this more emancipatory, collaborative change agency guides change implementation should be studied further as the pace and frequency of change continues to accelerate.

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Policies Governing Educational Technology Practice and Research

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Phillip Harris and Donovan R. Walling

Abstract

The purpose of this chapter is initially to examine the nature and characteristics of US federal policy regarding uses of technology for instruction in public elementary and secondary education. As a centering document the authors use *Transforming American Education*: *Learning Powered by Technology*, the US National Educational Technology Plan 2010, issued November 9, 2010. Subsequently they use this examination to frame a discussion of policy and technology from an international perspective. A key question concerns the multiple roles of research. Thus, the authors broadly survey US federal policy on educational technology and support for research on such technology as identified in policy. This discussion is then extended to sample international viewpoints on policy, research, and practice in various nations. Included in this discussion is consideration of English as the de facto language of technology and how English dominance affects teaching and learning.

Keywords

Connected teaching • Educational technology • Research funding • Technology transfer • Transformative policy

The purpose of this chapter is initially to examine the nature and characteristics of US federal policy regarding uses of technology for instruction in public elementary and secondary education. We subsequently use this examination to frame a broad discussion of policy and technology from an international perspective.

As a centering document we use *Transforming American Education*: *Learning Powered by Technology* (Office of Educational Technology [OET], 2010). This National Educational Technology Plan 2010 was arrived at through an extensive development process that began in 2009 and included contributions and reviews by individuals and groups and was augmented by public comment periods. The final document was issued November 9, 2010. The agency of focus in this portion of our discussion is the one responsible for this plan, namely, the Office of Educational Technology in the US Department of Education (ED).

A key question that we examine concerns the multiple roles of research. We broadly survey US federal policy on educational technology and support for research on such technology as identified in policy. For this examination we necessarily look for guidance at how research has been used in past policy development, implementation, review, and evaluation. This discussion is then extended to sample international viewpoints on policy, research, and practice in various nations. We include in this portion of the discussion consideration of English as the de facto language of technology and how English dominance affects teaching and learning.

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To begin, we discuss the nature of policy. We disambiguate the guises of policy and the nuanced influence various forms of policy exert. This portion of our discussion is definitional, and concomitant to it must be an understanding that by *technology* we mean what some have termed "new technology," such as computers, software, micro-electronics, and the Internet, that meaningfully enhances learning and facilitates innovation and creativity.

In examining educational technology policy in general, the *Transforming American Education* plan, and policy-driven practice and research in the USA and other nations, we also consider policy disincentives that may limit potential benefits to teaching and learning. We discuss how policy explicitly and implicitly directs research in ways that dissuade some researchers from inquiring into areas of technology or instruction that other researchers and practitioners may view as important. This discussion also touches on issues of funding.

Finally, we briefly consider how US federal policy affects and is affected by policy, practice, and research at state and local levels. We then extend this discussion to include the dynamic interaction of policy, research, and practice in several other nations in order to provide an international sampling. Policy on educational technology and related research, regardless of locale, is constantly evolving, influenced by advances in technology, changes in assessment, social-cultural shifts, political changes, and other factors.

The Nature and Influence of "Policy"

To understand how policy directs educational technology practice and research, it is first necessary to be clear about what we mean by *policy*. "Policy" in this instance is distinct from "a policy." We use the term *policy* as a generic label that encompasses more specific types of statements, oral and written, that elaborate principles or prescribe guidelines, or even rules, that shape decisions intended to produce certain outcomes. Policy in general is distinct from a specific policy, which, in fact, may bear some other designation, such as *rule* or *regulation*, *guideline*, *goal* or *objective*, *plan*, *order*, and so forth.

Policy writ large speaks to intent or aspiration. For example, an executive declaration, such as when the US President Jimmy Carter (1978) declared, "Human rights is the soul of our foreign policy, because human rights is the very soul of our sense of nationhood," constitutes a general statement of policy. Other individuals—federal agency officials, for instance—molded the complementary, specific policies and plans that served to guide American statecraft in foreign relations during the Carter administration.

For another example, consider China's former President Jiang Zemin, discussing the Internet and press freedom in 2009 with Mike Wallace on the US interview program, *60 minutes*: "We do have freedom of the press, but such freedom should be subordinate to and serve the interests of the nation." Thus, President Jiang went on, saying that certain Internet sites might be banned. "We need to be selective. We hope to restrict as much as possible information not conducive to China's development" (CBS News 2009). This executive declaration also was policy writ large. President Jian's comments did not merely articulate China's national stance on Internet technology and free expression—one still in place under China's current leader, President Xi Jinping—but also framed subsidiary policies and practices that then enacted this general policy.

Recently US President Barack Obama has made general policy statements about harnessing technology to teach young people and to address many of the challenges that the USA faces. A specific iteration of this general policy was the designation of economic stimulus money for educational technology, some $650 million. This amount more than doubled the federal budget for this category, thus, as commentator Alexandra R. Moses (2009) noted, "proving that President Obama's commitment to technology is more than just words." The funding was designated for the US Department of Education's Enhancing Education Through Technology (EETT, or Ed-Tech) program that distributes money to the states to distribute to local school districts. Specific policies consequently have been promulgated (or are in process) by federal offices, state education departments, and local school districts to guide using the funds from this program. These state and local policies will be required to be consistent with the specific guidelines set forth at the federal level.

From a definitional viewpoint, policies differ from rules in that policies guide where rules compel. Policy in the generic sense does not require this distinction. Policy may be broad or narrow, vague or detailed. And in this overarching sense policy also may be codified as law. Laws, in turn, may be broad—and consequently open to wider interpretation—or detailed. But they invariably are implemented through subsequently developed rules and procedures—in other words, more policies.

Consider this example: The pervasive law in American education, known as the Elementary and Secondary Education Act (ESEA), forms a basis of federal policy on education. President Lyndon Johnson came to the executive office in 1963, after the death of President John F. Kennedy, with a lifelong commitment to education, born in his own early career as a teacher in the 1930s. He made education the centerpiece of his Great Society initiative and had the votes in Congress to pass this comprehensive act of 1965. Thus, the general policy of the Johnson administration to combat poverty and ignorance with education was codified in law.

ESEA, which initially was intended to last until 1970, has since been reauthorized every 5 years, encoding policy shifts concomitant with changes in public policy under successive administrations. During the administration of President George W. Bush, ESEA was retitled the No Child Left Behind Act (NCLB), passed in 2001. NCLB was enacted in large measure to reify a general policy of standards-based education reform, thus spawning a myriad of specific policies, rules, guidelines, plans, and so forth by which the law could be carried out. For example, NCLB required states to develop basic skills assessments to be administered to students in designated grades in order for the states to receive federal school funding.

President Obama in 2010 called for a sweeping overhaul of NCLB, retaining some aspects of the Bush-era version of ESEA but changing others to match his administration's education policy. The *New York Times* reported, for example, that President Obama's reform "would replace the law's pass-fail school grading system with one that would measure individual students' academic growth and judge schools based not on test scores alone but also on indicators like pupil attendance, graduation rates and learning climate" (Dillon, 2010, np). This policy shift will necessarily require complementary revisions in subsidiary policies, rules, plans, and so on.

In the discussion of policies governing educational technology practice and research that follows, it must be understood that policy in general is constant only in the broadest, least definitive sense. This tends to hold true regardless of the nation under consideration. General policies change according to the beliefs and priorities of policy makers, and specific policies, plans, rules, and so forth are developed, redefined, modified, or discarded accordingly. Consequently, the ever-changing policy landscape means that analysts stand not on solid ground but on shifting sand.

Case Focus: National Educational Technology Plan 2010

In presenting *Transforming American Education*: *Learning Powered by Technology* to Congress in November 2010, US Secretary of Education Arne Duncan remarked on the impetus for the National Education Technology Plan:

> Once the global leader in college completion rates among young people, the United States currently ranks ninth out of 36 developed nations. President Obama has articulated a bold vision for the United States to lead the world in the proportion of college graduates by 2020, thereby regaining our leadership and ensuring America's ability to compete in a global economy…. The plan calls for applying the advanced technologies used in our daily personal and professional lives to our entire education system to improve student learning, accelerate and scale up the adoption of effective practices, and use data and information for continuous improvement. (OET, 2010, p. v)

Thus, from an executive declaration—"By 2020, America will once again have the highest proportion of college graduates in the world," uttered by President Barack Obama during a speech to Congress on February 24, 2009 (OET, 2010, p. v)—the Office of Educational Technology crafted a policy document of almost one hundred pages.

Practically speaking, the overriding goals of the new plan are to use technology to raise the percentage of American students graduating with college degrees from about 41 to 60 % by 2020 and to close the achievement gap so that "all students graduate from high school ready to succeed in college and careers" (OET, 2010, p. ix). But note also Secretary Duncan's other point, that doing so would ensure "America's ability to compete in a global economy." We will revisit this point in a later section.

Many educational technology advocates favored this approach at the time the plan was announced. However, some worried that President Obama's complementary proposal to eliminate Ed-Tech, funded since 2002, by moving that effort, in essence, into a larger initiative—Effective Teaching and Learning for a Complete Education—would actually reduce the federal government's funding for K-12 educational technology. According to *Education Week*'s Ian Quillen,

> The latter's price tag of just over $1 billion includes $450 million for literacy; $300 million for science, technology, engineering, and math, or STEM, subjects; and $265 million to support a "well-rounded education." (Quillen, 2010, np)

To understand more fully how policies affect practice and research, it is necessary to some extent, in the words of the cliché, to follow the money. Ed-Tech, or EETT, is not mentioned in the new plan. This is consistent with its elimination from President Obama's 2011 budget. Ed-Tech initially was included in NCLB to provide competitive and formula grants to states for purposes related to improving student academic achievement through the use of educational technology. The startup 2002 Ed-Tech appropriation was $700,500,000. Over the years, the appropriation amount dropped steadily, dipping to $100 million for 2010. EETT got a temporary bonus in 2009, when the Recovery Act added $650 million to the appropriation.

The 2010 midterm elections that took place only days before the new technology plan was announced also shifted the congressional balance, returning the House to Republican control, which, to some observers, seemed likely to make proposals that would require new federal funds difficult to realize, as indeed they have. We return to the topic of funding in later sections of this chapter.

The six goals articulated in *Transforming American Education* center on learning, assessment, teaching, infrastructure, productivity, and research and development (R&D). To summarize:

Learning: Engage and Empower means that "all learners will have engaging and empowering learning experiences both in and out of school that prepare them to be active, creative, knowledgeable, and ethical participants in our globally networked society" (OET, 2010, p. 9). The report writers ground this goal by defining an emphasis on individualized, personalized, and differentiated instruction, giving examples such as "New York City's School of One pilot, a 2009 summer program that allowed students learning mathematics to learn at their own pace and in a variety of ways" (OET, 2010, p. 12).

The writers also cite the National Technology Standards for Students, developed by the International Society for Technology in Education (ISTE) (OET, 2010, p. 14). This goal section includes discussions of "how people learn" through factual and procedural knowledge and motivational engagement, "who needs to learn" by means of a "universal design," and "serving the underserved," namely low-income and minority learners, English language learners, learners with disabilities, early childhood, adult workforce, and seniors. The writers conclude with a section titled "Enabling All Learners to Excel in STEM," which leads to five recommendations.

Assessment: Measure What Matters establishes a goal that "our education system at all levels will leverage the power of technology to measure what matters and use assessment data for continuous improvement" (OET, 2010, p. 25). In the opening section for this goal, "What We Should Be Assessing," the writers quote President Obama, speaking to the Hispanic Chamber of Commerce on March 10, 2009:

> I'm calling on our nation's governors and state education chiefs to develop standards and assessments that don't simply measure whether students can fill in a bubble on a test, but whether they possess twenty-first century skills like problem-solving and critical thinking and entrepreneurship and creativity. (OET, 2010, p. 26)

Consequently, the assessment focus is directed toward using technology to assess "complex competencies" that are themselves often achieved through technology-mediated instruction. The writers cite, for example, changes in the National Assessment of Educational Progress (NAEP) program, which began in the late 1980s and in recent years has incorporated "technology-based assessments involving complex tasks and problem situations" (OET, 2010, p. 28), and the more recent ED initiative, Race to the Top, which dates from 2009 and includes an assessment competition. Attention is paid to formative as well as summative assessment and the use of technology in the assessment of students with disabilities. In fact, one subsection is devoted to how "adaptive assessment facilitates differentiated learning" (OET, 2010, pp. 30–32).

Teaching: *Prepare and Connect* means that "educators will be supported individually and in teams by technology that connects them to data, content, resources, expertise, and learning experiences that can empower and inspire them to provide more effective teaching for all learners" (OET, 2010, p. 29). The writers articulate a concept referred to as "connected teaching," which they aver would combat teacher isolation and lead to both better preparation of teachers and greater retention of new teachers in the profession. They envision schools in which

> classroom educators are fully instrumented, with 24/7 access to data about student learning and analytic tools that help them act on the insights the data provide. They are connected to their students and to professional content, resources, and systems that empower them to create, manage, and assess engaging and relevant learning experiences for students both in and out of school. They also are connected to resources and expertise that improve their own instructional practices, continually add to their competencies and expertise, and guide them in becoming facilitators and collaborators in their students' increasingly self-directed learning. (OET, 2010, p. 40)

Infrastructure: *Access and Enable* offers a goal that "all students and educators will have access to a comprehensive infrastructure for learning when and where they need it" (OET, 2010, p. 51). The thrust of this goal is toward "broadband everywhere" (with specific reference to the Federal Communications Commission (FCC) National Broadband Plan, which includes a recommendation to change the E-rate; access devices for every student and educator; and open educational resources (OER), meaning "teaching, learning, and research resources that reside in the public domain" or have been released for use in teaching and learning (OET, 2010, pp. 52–56).

It should be noted that in September 2010 the FCC "upgraded and modernized" the E-rate program that provides Internet connectivity at a discount for schools and libraries. According to a September 23, 2010, FCC news release: "The program has achieved remarkable success—97 % of American schools and nearly all public libraries now have basic Internet access" (FCC, 2010, np).

Productivity: *Redesign and Transform* means that "our education system at all levels will redesign processes and structures to take advantage of the power of technology to improve learning outcomes while making more efficient use of time, money, and staff" (OET, 2010, p. 63). This goal is less concrete than the preceding goals. It is largely an exhortation, "a call to action for education leaders," in which the role of the Department of Education is "to identify strategies for improving productivity in education and to work with states and districts to increase their capacity to implement them … encouraging states and local education agencies to make changes to practices, policies, and regulations that prevent or inhibit education from using technology to improve productivity" (OET, 2010, pp. 64–65).

R&D: *Innovate and Scale* is the least concrete goal, as it hinges mainly on an ambitious but loosely defined initiative that the writers state in this manner: "If we are to achieve our goal of leading the world in education, we must be leaders in the design and implementation of a more effective education system. To that end, this plan calls for a new approach to R&D for education that focuses on four areas" (OET, 2010, p. 75). They identify these areas, including creating a new organization with the mission of serving the public good through R&D at the intersection of learning sciences, technology, and education (OET, 2010, p. 76).

This new organization is a National Center for Research in Advanced Information and Digital Technologies (also called Digital Promise), the establishment of which was authorized in the Higher Education Opportunity Act (P.L. 110–315), passed in August 2008 (OET, 2010, p. 76). This center, a 501(c)(3) nonprofit, "would be able to accept contributions from the public and private sectors to support the R&D needed to transform learning in America." Furthermore,

> The National Center for Research in Advanced Information and Digital Technologies would support research at scale, facilitating the participation of educators, schools, and districts as partners in design and research. It would also promote transparency and collaboration, encouraging multiple researchers to work with the same data and interoperable software components and services. Its unique charter is to identify the key research and development challenges in the education field and coordinate the best combination of expertise for addressing them. These characteristics, along with an emphasis on public-private collaboration, distinguish the National Center for Research in Advanced Information and Digital Technologies from existing centers that help state and local education entities identify and implement established best practices in learning technology. The center's work would also be distinct from field-initiated research on the effectiveness of technology-based interventions. (OET, 2010, p. 76)

This summary cannot do full justice to the wealth of detail in this lengthy plan, but it is sufficient for purposes of this chapter to ground the commentary that follows.

In February 2011 President Obama's 2012 fiscal year budget included funding a new Advanced Research Projects Agency-Education (ARPA-ED) "to support research on breakthrough technologies to enhance learning" aimed at K-12 education (Strategy for American Innovation, 2011). At the time of this writing, whether the new agency eventually will survive the congressional budget battles remains uncertain.

Policy-Driven Educational Technology Practice and Research

Examining US federal policy is like viewing Earth's largest oceans from an orbiting satellite. At that distance the oceans look flat and placid. Once policy devolves to the state, district, school, and finally classroom level, one realizes that the seas are turbulent and teeming.

Most of *Transforming American Education* is phrased as "states should"; to wit:

- States should adopt standards and assessments that prepare students to succeed in college and the workplace and compete in the global economy.
- States should build data systems that measure student growth and success and inform educators about how they can improve instruction.
- States should recruit, reward, develop, and retain effective educators, especially in underserved areas where they are needed most.
- States should turn around their lowest-achieving schools (OET, 2010, p. 7).

Federal policy often serves as an extension of the President's bully pulpit, giving a gloss of leadership that may or may not have much substance or, indeed, much effect. *Transforming American Education* is an ambitious plan. The extent to which it will be actualized will depend on a number of factors, such as whether funds are provided to put in place actions based on the plan's goals and recommendations not only at the federal level but also at state and local levels; whether state departments of education, district leaders, and classroom educators buy into the goals and subsequent programs are developed based on the recommendations; and whether such programs, when implemented, achieve the desired results.

Such conditional influence raises questions about this plan, for which answers lie in the future. Therefore, it may be helpful in understanding how policy affects practice and research—and how this new plan may fare—to look at a prior policy/plan/program that was incorporated in NCLB and mentioned previously: Enhancing Education Through Technology (EETT, or Ed-Tech). EETT was established in Part D of Title II of the Elementary and Secondary Education Act, as amended by the No Child Left Behind Act of 2001 (P.L.107–110).

Ed-Tech was funded from 2002 to 2010 for the purpose of improving K-12 student achievement through the instructional use of technology, much like the new plan. Of particular interest is the emphasis—or lack of emphasis—on research at the national level. In the rules for Ed-Tech, under Section 2421, National Activities, the law specifies:

1. STUDY—Using funds made available under section 2404(b)(2), the Secretary—
   (a) Shall conduct an independent, long-term study, utilizing scientifically based research methods and control groups or control conditions —
      - On the conditions and practices under which educational technology is effective in increasing student academic achievement.
      - On the conditions and practices that increase the ability of teachers to integrate technology effectively into curricula and instruction, that enhance the learning environment and opportunities, and that increase student academic achievement, including technology literacy.

   (b) Shall establish an independent review panel to advise the Secretary on methodological and other issues that arise in conducting the long-term study.

(c) Shall consult with other interested Federal departments or agencies, State and local educational practitioners and policymakers (including teachers, principals, and superintendents), and experts in technology, regarding the study.

(d) Shall submit to Congress interim reports, when appropriate, and a final report, to be submitted not later than April 1, 2006, on the findings of the study (See http://www2.ed.gov/policy/elsec/leg/esea02/pg35.html).

It should be borne in mind that "funds made available under section 2404(b)(2)" are limited to 2 % of allocated funds and also must cover dissemination of research and technical assistance to state education agencies (SEAs), local education agencies (LEAs), and other entities receiving funds under the Ed-Tech program.

Like many other federal programs, funds were used under EETT mainly as grants to SEAs, which then passed funds along to local entities. States were permitted to hold back five percent for state-level activities but were required to award the rest to eligible LEAs. The funds could be used for a broad range of activities, such as

> the support of continuing, sustained professional development programs and public-private partnerships. Activities also include: the use of new or existing technologies to improve academic achievement; the acquisition of curricula that integrate technology and are designed to meet challenging state academic standards; the use of technology to increase parent involvement in schools; and the use of technology to collect, manage, and analyze data to enhance teaching and school improvement. (ED, 2010, np)

During the 7-year funding period, more than $4 billion was appropriated for Ed-Tech. Some central questions at the intersection of policy, practice, and research must be: Was the money well spent? Was the purpose achieved? How do we know; in other words, what does research show? These are extraordinarily complex and difficult questions, given wide dispersal of funds to a vast array of projects with various purposes, procedures, and participants. States developed their own Ed-Tech plans, many of which can (or could at this writing) be viewed at the ED website for EETT. But in many ways such diffused assessment is like dropping a fishing line into that metaphorical turbulent and teeming sea. The resulting catch is only a small sample, a glimpse of what happened, or is happening, rather than a comprehensive view.

In 2007, during ED Secretary Margaret Spellings' tenure, SRI International presented a review of EETT. The report, titled *State Strategies and Practices for Educational Technology*: *Volume I—Examining the Enhancing Education Through Technology Program*, was produced under contract (ED-01-C0-0133) from the Department of Education and issued through the Office of Planning, Evaluation, and Policy Development. (A second volume looked specifically at *Supporting Mathematics Instruction with Educational Technology*.)

The report describes state-level educational technology policies in the implementation of EETT during the program's initial operational years, 2002–2003. The authors drew on survey data collected by the National Educational Technology Trends Study (NETTS) from state educational technology directors and district-level coordinators to form their assessment. While preliminary in the life of the program, the report does highlight some of the effects of federal policy on state-led implementation. For example, the SRI International writers concluded, "In the first years of the program, states reported emphasizing professional development, technology integration, and student achievement, in keeping with the intentions of ESEA" (Bakia, Mitchell, &Yang, 2007, p. 6). This 2007 report also indicated that a further study would "examine the quality of the activities funded through EETT and their alignment with the goal of raising student achievement" (p. 6).

In 2008 the same SRI International writers presented *National Educational Technology Trends Study Local-level Data Summary*, examining Ed-Tech from 2004–2005 under the same contract from the Department of Education. This summary presents data with little text and no conclusions. The data are arranged in nineteen "exhibits"—lists or tables—to compose a report that "provides descriptive analyses of district and school implementation of the EETT program, focusing on issues that are central to the program: distribution of funds; EETT district investment in educational technology; teacher and student access to technology; technology-related teacher professional development; and technology integration in teaching and learning," according to the writers (Bakia, Yang, & Mitchell, 2008, p. 1).

Neither of these reports, or NETTS as a project, actually speaks to a key question: Does emphasizing educational technology in the way that Ed-Tech has done really improve student achievement? Indeed, SRI International explicitly defined NETTS as a study to "examine the *implementation* of the Enhancing Education through Technology Program (EETT) (Emphasis added; see http://www.ctl.sri.com/projects/displayProject.jsp? Nick = netts). There is certainly logic in avoiding the measure of what may, for various reasons, be unmeasurable, namely whether improvement in student achievement, if obtained, can be directly attributed to increased availability and use of educational technology. As a side note: National Assessment of Educational Progress (NAEP) scores in reading and mathematics did improve during the period covered by EETT (Kerachsky, 2009). These improvements cannot be tied directly to educational technology—or any other particular factor. But neither can educational technology be discounted as a factor in the improved scores. This fish does not define the ocean.

A final report was issued in 2009, reifying this disjunction of aims and outcome measures. While *Evaluation of the Enhancing Education Through Technology Program*: *Final Report* (Bakia, Means, Gallagher, Chen, & Jones, 2009) again cites the program's goals, including "to improve student academic achievement," the research focused on "teachers' and students' access to technology, technology-related professional development, technology integration, and student technology literacy" (p. vii), notably *not* student achievement.

A portion of this disjunction also can be laid at the door of time, or lag time—that is, the time between implementation of educational technology and the gathering and analysis of data to assess whether such technology has had an effect on student achievement. The authors of *Transforming American Education* seem to take a realistic approach in this regard, commenting that "research on the effectiveness of learning technology typically comes after products and services have been deployed—when it is too late to result in major improvements—if it comes at all." (OET, 2010, p. 75). We return to this point about lag time between implementation and results assessment later.

Policy Disincentives for Educational Technology Practice and Research

Policy often contains disincentives, both inadvertent and intentional (for example, specifically to limit the use of certain practices or technologies), that can blunt anticipated effects. The complexity inherent in assessing academic achievement or assigning a cause for improvement, as suggested previously, can be overwhelming to the point of discouraging states, districts, schools, or individual educators from attempting to implement policy as fully as it was intended.

Often, inadvertent disincentives are recognized after the fact. In November 2010 *T.H.E. Journal* interviewed several former directors of the federal Office of Educational Technology. One of the questions was: "Research was emphasized in No Child Left Behind. But in some cases, has the reliance on scientific evidence for making changes served as a barrier to technology growth?" Among the three interviewees there was consensus, perhaps best expressed by John Bailey, who was director of the office from 2001 to 2004, at the start of EETT:

> Scientifically based research has a role, but it can be a limiting factor to certain innovations, in the sense that these types of studies are very expensive and complicated, particularly given how "messy" our education system and the types of students we serve are. (*T.H.E. Journal*, 2010, np)

NCLB, in fact, has been roundly criticized by many educators since the law was enacted, and though it has been modified in some ways it still raises controversy. Moreover, because NCLB is a revamped version of ESEA, it also faces congressional debate for reauthorization—something that should have been happening about the time the new plan was released but wasn't. Within days of the release of *Transforming American Education*, for example, the National Education Association (NEA), the nation's largest teacher union, called on ED Secretary Arne Duncan for "regulatory relief" (subsequently approved in 2011) from certain NCLB requirements because reauthorization was still held up in Congress. In his November 15, 2010, letter (released to *Education Week*) NEA Executive Director John I. Wilson reiterated the union's concerns, namely that

> despite massive budget cuts, layoffs and ballooning class sizes, thousands of public schools are continuing to strive to meet federal mandates imposed by No Child Left Behind…. Many of these narrow and punitive mandates are widely thought to be unreasonable, and even counterproductive, and would be difficult if not impossible to meet under the best circumstances…. While many education-related mandates must be ameliorated through the legislative process, others may be readily addressed through regulatory changes and guidance. (Wilson, 2010, np)

Thus, a disincentive may be that a policy lacks a consensual basis, which can occur when policy is driven by a particular ideology rather than sound theory or research. Disincentives also occur when the rules are unclear, overly complex, burdensome, or expensive—especially when a policy mandate is "unfunded," that is, required by policy (or law) but not provided for in federal appropriations. In the mid-2000s, for instance, nine state legislatures were taking steps to block or opt out of using state funds to support NCLB initiatives not funded federally (Toppo, 2004, np). Indeed, a major complaint of SEAs since the federal government's role in education began to increase during the 1950s has been that states are expected or required to enact federal mandates without adequate federal funding to pay for them.

The development of *Transforming American Education* included extensive input from groups and individuals, which would seem to mitigate disincentives arising from lack of consensus. Reference is made throughout the new plan to existing research to ground the plan's goals. However, the sheer scope of this new plan may be a disincentive. Most federal policy is carried forward not by a single office or agency, but by several, each taking on some aspect of the overall plan. This is the case with *Transforming American Education* as well. In the context of R&D alone, for example, the following offices and organizations are mentioned: the Department of Education's Investing in Innovation Fund, the National Science Foundation (specifically the Cyberlearning Transforming Education, or CTE, program), and the new National Center for Research in Advanced Information and Digital Technologies (also called Digital Promise) (OET, 2010, pp. 75–80). If the new plan follows a course similar to Ed-Tech, additional offices also will be involved, such as the Office of School Support and Technology Programs (SSTP, the program office for Ed-Tech) within the Office of Elementary and Secondary Education (OESE). OESE oversees a mind-boggling array of programs and projects. Consequently, simply navigating the alphabet soup of federal offices can be daunting enough to be a disincentive for full policy implementation.

Beyond US Federal Policy: State and Local Education Units

However lofty federal education policy in the USA may be, it must be remembered that K-12 education is largely a state and local matter. As noted on the ED website, of the estimated $1.1 trillion that would be spent nationwide on education at all levels in 2009–2010, about 89.5 % would come from nonfederal sources. This means that

> the Federal contribution to elementary and secondary education is about 10.5 %, which includes funds not only from the Department of Education (ED) but also from other Federal agencies, such as the Department of Health and Human Services' Head Start program and the Department of Agriculture's School Lunch program. (See http://www2.ed.gov/about/overview/fed/role.html, accessed November 29, 2010)

While federal policy may be influential, it is by no means the only determinant of state and local policies and programs. Even within the context of federal policy, states usually decide what to emphasize, de-emphasize, or ignore completely. A glimpse into how federal policy translates to the state level can be seen in a few of the state plans for EETT that can be found on the Ed-Tech website (http://www2.ed.gov/programs/edtech/techstateplan.html).

In Florida, for example, EETT prompts an annual technology survey, administered by the Florida Department of Education Office of Technology Learning and Innovation, that provides important information about technology integration and capacity in Florida schools. The state also conducts an Inventory of Teacher Technology Skills (ITTS) and a Student Tool for Technology Literacy (ST2L), which provides "a snapshot of student technology literacy in the areas of technology operation and concepts, construction and demonstration of knowledge communication and collaboration, independent learning and digital citizenship." Like much of the research driven by EETT, however, these measures seek mainly to gauge "inputs" (what forms of technology are available in schools, how much are they used) and usage abilities (or technological literacy), rather than try to connect technology use to school achievement—not that such studies are entirely absent.

A contrasting example is the West Virginia plan for 2007–2010, which includes two brief reports of research findings. One report is *Research Findings from the West Virginia Virtual School Spanish Program*, in which, according to the researchers, "analysis of the data helped us identify factors that characterize effective implementations and that are statistically associated with students' achievement and engagement." The other, *The Results of Professional Development About Technology*: *A Report of West Virginia's Statewide Technology Model Schools Program*, according to the researchers, shows that the Technology Model Schools program "dramatically increased the use of technology by teachers and students in classrooms, and that increase is associated with gains in mathematics and reading/language arts."

These West Virginia findings related to student achievement are rare among the research reports associated with Ed-Tech. And, as is apparent, when achievement-related research is done, it is a hit-or-miss undertaking, given the specific nature of the various research projects. Can one state's virtual Spanish program be replicated in other states with similar success? Has that already been done and the research simply has not been shared or is hard to find?

And, for an even longer stretch, do such programs in some way help to ensure "America's ability to compete in a global economy"? If so, how? Are there ways to research these larger questions and so assess whether, in fact, policy and practice in educational technology actually do affect national competitiveness, be it in the USA or elsewhere.

Educational Technology Policy Implementation Through ITT

Educational technology policy is being implemented throughout the world, even in places that might seem unlikely because of cultural or economic factors. Much of this implementation has been facilitated through international technology transfer, or ITT. This body of implementation strategies arose during the 1960s as a field of inquiry with the emergence of significant technology developments and applications (especially those involving computers) across a spectrum of scientific and industrial endeavors. Technology trade between countries takes place by various means, such as foreign direct investments (FDI), joint ventures, original equipment manufacturer (OEM), licensing, and subcontracting. In the early 1980s, according to researchers Contractor and Sagafi-Nejad (1981), the "latest technologies … are concentrated in relatively few companies in a few industrial countries" (p. 113). Thirty years later, that is no longer the case.

Miyake (2004) writes with respect to East Asia, including China, for example, that ITT "is generally recognized as having played an important role in the industrial development of those countries that successfully achieved industrial development during the second half of the 20th century" (p. 16). Furthermore, Miyake states:

> An appropriate technology transfer policy, assisted by a good political framework and business conditions, contributed to *competitiveness in domestic and international markets worldwide*, while also contributing to the attainment of a global sustainable industrial development (SID). (p. 16, emphasis added)

In this we note, as we did in Secretary Duncan's remarks in the second section of this chapter, specific reference to global competitiveness. Miyake also points out that newly industrializing economies (NIEs) have historically chosen various mechanisms. OEM—original equipment manufacturer—is a specific form of subcontracting whereby a local firm produces technology (or equipment) to the specifications of a foreign company, which then markets it through its own distribution channels. This method, according to one historical analysis, was dominant in technology acquisition in Korea, Taiwan, and Hong Kong; whereas, in Singapore the dominant mechanism was foreign direct investments (Miyake, 2004, p. 17).

Korean researchers, however, have suggested that the Korean government's research and development (R&D) policy dating from the late 1990s—focused on public-to-private technology transfer—bears reexamination because it has become an impediment to technology transfer (Moon et al., 2004). According to these researchers, the resulting

> regulations, especially those regarding national R&D programmes, cover large-scale programmes with compulsory guidelines, and thus should have a great impact upon the transfer of the technology resulting from such programmes. However, the regulations are seen to be ineffective: each governmental department applies its own guidelines when managing its R&D programmes, even though all departments are supposed to work in a uniform manner. (p. 31)

This mix of complexity, idiosyncrasy, and inevitable gaps and duplications mirrors the challenges inherent in most large-scale, government-led endeavors, including those already discussed in relation to the case focus of this chapter on the 2010 National Educational Technology Plan in the USA. Disincentives thus abound.

Egypt presents another example of how national policy affects the acquisition and use of technology. Kadah (2003) noted that Egypt's Peoples Assembly (national congress) adopted a National Strategy for Technological Development (NSTD) in 2000. The goals included:

> increasing economic growth, promoting exports, improving competitiveness in local and world markets, making use of advanced technologies in reducing production costs and product prices, confronting high unemployment, contributing to environmental protection, enhancing human capital development, and supporting national independence and economic capability. The NSTD relies on two main premises: transferring, absorbing, adapting, and further developing foreign technologies, and enhancing technological self-dependence. (p. 4)

"Generally," wrote Kadah, "Egypt gives high attention to science and technology through education, human capital development, as well as a degree of support to local science and technology institutions" (p. 6). This emphasis nearly a decade ago downplayed the potential positive effects of ITT, which the government aimed to improve through the NSTD.

Recently in Egypt there has been more recognition of the value of ITT. For instance, in September 2010 the American University in Cairo (AUC) inaugurated newly established technology transfer offices at AUC, Cairo, Assiut, and Helwan universities, as part of an Enterprise-University Partnership (EUPART) project. The offices are intended to support the transfer of ideas, research, and innovation from the university to business and industry. This thrust is an iteration of Egypt's current national policy as it has evolved from the NSTD of 2000. The new offices also are a reification of international idea trading. According to university officials:

> AUC is leading the project with collaboration and expertise from Freie Universität Berlin, Germany, Polytechnic University of Turin, Italy, Linkoping University, Sweden, Vienna University of Technology, Austria and the European Patent Office. (AUC, 2010, np)

It is worth noting that teasing out strictly educational technology initiatives from broader applications of technology in industry, commerce, and other areas often is difficult because of the interconnectedness of education initiatives, particularly in higher education, with everything else. While the AUC initiative, for example, is at root an education enterprise, the new offices will influence a broad range of technology transfer both directly and indirectly affecting business and industry, not only in Egypt but between Egypt and its technology trading partners.

Research Related to Educational Technology from an International Perspective

Research related to educational technology is being conducted everywhere; the diversity is too great to be adequately summarized in a few sentences. Generally speaking, the subjects of capacity and professional development ("inputs") tend to predominate internationally as they do in the USA. For example, a study by researchers at two universities in Taiwan examined *Teachers' Perceptions of the Dimensions and Implementation of Technology Leadership of Principals in Taiwanese Elementary Schools* (Chang, Chin, & Hsu, 2008). The authors of this study involving elementary principals in seven cities concluded:

> As a result of this evaluation and assessment information, Taiwan's Department of Education could sponsor preparation programs providing professional development for principals to improve classroom technology use, evaluate teacher and student strengths and needs in technology, and develop a practical and useful technology plan. (p. 242)

Mention of the Taiwan Department of Education raises a point of difference between the USA and many other nations, namely, that elsewhere a central or national education department or ministry usually exercises control over K-12 (and higher) education, rather than delegating primary authority to states or provinces. It is difficult, often impossible, to discern at a distance whether research such as this study is funded, mandated, or directed by the Taiwan education department. But such connections are, conjecturally, likely to be stronger abroad than they are in the USA.

Another example of the capacity-building focus is a study from Turkey that looked at elementary teachers' use of instructional software by sampling 471 teachers in seventeen primary schools in the city centers of Elazig and Malatya (Kazu and Yavuzalp, 2008). "Inputs" again are the target of consideration, arguably missing the more important question of whether the instructional software positively affected teaching and learning.

At the same time, some researchers *are* looking at the results of incorporating educational technology into teaching and learning—again in diverse locations. For example, a field study in Croatia surveyed ninety students and included interviews of twelve to examine how early elementary children use the Web (Librenjak, Vučković, & Dovedan, 2010). At the opposite end of the age spectrum, another Croatian study examined computer use in secondary schools and the effect on students' performance in informatics at the university level (Cicin-Šain, Vukmirovic, & Cicin-Šain, 2008). Both of these studies provide glimpses into practice resulting from policy-driven "inputs."

Finally, there also are cross-national education and research efforts that center on or incorporate educational technology. A prime example is the initiative of the German Federal Ministry of Education and Research (BMBF), which undertakes tasks in a number of areas in cooperation with the Länder (states) within Germany, such as educational planning and the promotion of research, but also extends its reach internationally. In iteration of its catchphrase, "success through international networking," BMBF has created specific partnerships with a number of education ministries and like organizations across South America (see http://www.bmbf.de). These partnerships promote innovation and research primarily involving science and technology.

English as the De Facto Language of Educational Technology

Of particular interest in a discussion of policy, research, and practice related to educational technology from an international perspective is the dominance of English as the *lingua franca* of the Digital Age. A number of researchers have taken up this aspect of the "digital divide" (a term popularized by Norris, 2003), that chasm between the technology "haves" and "have nots." That divide often is characterized by access, but a key factor is the language of access.

Wolk (2004), for example, studied the relationship of English language, Internet usage patterns, and infrastructure in nearly two hundred countries. He divided the countries into "developed" and "developing," and then divided each of these groups into English speaking and not English speaking for purposes of comparison. Two factors emerged as prominent in defining what Wolk viewed as a linguistic digital divide: government policy and e-commerce (or Ecommerce). According to Wolk:

> Evidence of English language dominance in global Ecommerce has created a de facto protocol for the growth of the Internet. While English sites seldom have other language options, many foreign sites have an English language option…. The competitive advantage for developed English speaking countries is evident. Studies on variables of culture, infrastructure, government policy and monopolies are all important, but English fluency monopoly may be the strongest factor in the Digital Divide. (np)

The most populous country to take note of English dominance and to craft a national policy that mandates the teaching of English specifically (though not exclusively) to ensure that it will be among the digital "haves" is China. Tang (2009) has noted,

> For English learners in China, learning English is instrumental. A knowledge of English gives individuals opportunities for higher education, for career advancement, for better jobs with better pay in foreign-funded joint ventures, and for study and travel abroad…. For the country, education is of strategic importance. Teaching and learning English as a foreign language is a tool for the achievement of national, political and *economic* goals. (p. 9, emphasis added)

According to Li and Moreira (2009), economic and social factors in China have "transformed English learning into a fashionable trend" (p. 181). They point out:

> The spread of English has made it the dominant foreign language in China and given it a status no other language can challenge. Moreover, it has the support of the Chinese government, which has recognized it as an essential tool for scientific and technological advancement. (p. 183)

All public schools in China, from kindergarten to university, offer English language instruction, which is mandated by government policy as a "compulsory core subject from middle school to university" (p. 183). However, like the USA, China is a vast, highly economically, culturally, and socially diverse nation, with all of the attendant inequalities. Li and Moreira comment that

> foreign language education varies considerably between different regions, depending on economic level. The educational gap between regions is very large, with more developed provinces or autonomous regions in the East and the South, and backward educational standards in Western or Northern China. (p. 184)

This disparate situation is exacerbated by conflicting national policies, in themselves disincentives to implementation in any uniform way. While the policy of teaching English universally expands access to language instruction, materials, and technology—albeit unevenly across regions—the national policy of restricting public access in China to government-approved media (see President Jiang's comments in the first section of this chapter) perpetuates unequal educational opportunities to learn and practice English. For instance, say Li and Moreira, because of "restrictions on the entry of English media to the Chinese mainland…it is difficult for Chinese people to have access to English language and Western cultural customs in their daily lives" (p. 184). And Chinese students in urban areas are likely to have greater access than those living in rural regions. Still, Li and Moreira conclude, the spread of English in China has produced a "strong and irreversible impact in the educational domain" (p. 191). This cannot help but affect China's acquisition and implementation of educational technology going forward.

Tilfarlioğlu (2011) offers another perspective from a different geographical region, derived from a descriptive analysis study of students in Turkey and Iraq who are using Web 2.0 technologies to learn a foreign language, namely English. The randomly chosen subjects in this study numbered about 550 and came from six universities and three high schools. The author contends that Web 2.0 technologies—defined as "Web based applications and services that provide users visual, textual, audial [sic] communication, interactive information, shared content, collaboration, authenticity and digital literacy" (p. 89)—have changed the way educators use the Web, particularly in foreign language teaching. Tilfarlioğlu found that more than half of the students, both high school and university, used Web 2.0 tools. Their perceptions of these technological tools varied, however, leading the author to conclude that "the most important thing that may affect their perceptions is the implementation of these tools into classroom" (p. 92). Thus, Tilfarlioğlu comments that

> if teachers were educated in the field [using Web 2.0 technologies], the use of Web 2.0 could contribute significantly to English language learning. Thus, regarding Web 2.0 tools as an opportunity for English language learning will be inevitable for the learners of the 21st century. (p. 92)

This conclusion seems obvious, but perhaps it is worth reiterating. Policy—whether national, regional, state, or local—may establish a goal or expectation. Regardless of location, however, the teaching-learning interactions between instructors and students as they integrate available technology will have the greatest effect on learning. This point is similar to the one stressed under the rubric of "connected teaching" in *Transforming American Education* (see the second section above).

Recent statistics (as of July 2011) give English 26.8 % dominance on the Web, with Chinese coming in next at 24.2 % of all Internet users. All other languages are in single-digit percentages. With China's commitment to teach English as its universal second language, it would appear that English dominance will continue for the foreseeable future (see Internet World Stats, http://www.internetworldstats.com/stats7.htm).

Conclusion

The shifting sands of education policy in the USA and around the world are a constant challenge for those charged with implementation and research. Recent history, say, from the mid-twentieth century onward is illustrative. Readers will recall that US science and technology education gained considerable emphasis in the late 1950s when the Soviet launch of the first Sputnik satellite on October 4, 1957, moved US President Dwight Eisenhower to call for improved science education. Millions of television viewers and radio listeners witnessed a presidential speech within a month of the Sputnik launch, in which the President "urged Americans to give higher priority to science education and basic research" (Wang, 2008, 82). Technology got a further boost from the space race that ensued during the presidency of John F. Kennedy and was a beneficiary within the general emphasis on education when ESEA was enacted during the Lyndon Johnson era. (It should be mentioned that science and technology education in the Soviet Union was receiving similar attention during this period.)

Still, dissatisfaction with US science and technology—and education in general—persisted. In a March 3, 1970, address to Congress, President Richard Nixon opened with the sentence, "American education is in urgent need of reform." He went on to say:

> We must stop pretending that we understand the mystery of the learning process, or that we are significantly applying science and technology to the techniques of teaching—when we spend less than one half of one percent of our educational budget on research, compared with five percent of our health budget and ten percent of defense. (np)

In the late 1970s education received much more than lip service when President Jimmy Carter signed the Department of Education Organization Act on October 17, 1979, thereby creating the modern US Department of Education (ED). However, President Ronald Reagan came into office in 1981, only months after ED became operational, vowing to dismantle the new department. Ultimately, he was unable to do so, but federal education policy—including how technology should be used in teaching and learning—has continued to be a vehicle for political ideology cloaked in various guises as "improving" American education, NCLB being a notable example. Most recently rightwing "Tea Party" candidates have been elected who have expressed again a desire to dismantle ED, which most observers believe will not happen.

Lag time between promulgation of policy, implementation, and follow-up research and analysis can be considerable—and policy may well have shifted significantly over the period in question. We pointed out previously that the authors of *Transforming American Education* were cognizant, saying that "research on the effectiveness of learning technology typically comes … too late to result in major improvements—if it comes at all." (OET, 2010, p. 75). However, recognition of this problem does not mitigate its consequences.

Another limiting factor in discerning trends and conclusions based on research—and considering how to respond to them—is the lack of a central repository for research studies. The US Department of Education funds several clearinghouses that hold research reports and data in which information about educational technology can be found, including:

- Educational Resources Information Center (ERIC) (http://eric.ed.gov/)
- National Clearinghouse for Comprehensive School Reform (http://www.csrclearinghouse.org/)
- National Clearinghouse for Educational Facilities (NCEF) (http://www.edfacilities.org/)
- What Works Clearinghouse (http://ies.ed.gov/ncee/wwc/)

None of these clearinghouses is comprehensive, and at least a couple of them have come under heavy criticism. ED was criticized in 2003, for instance, for closing the subject-oriented ERIC clearinghouses, which were located around the USA at various universities. A centralized, web-based clearinghouse remains but is incomplete. ED also has been criticized over narrow, ideologically based standards for accepting research in the What Works Clearinghouse, which was established in 2002 under President George W. Bush by ED's Institute of Education Sciences (IES). The standards were broadened somewhat after President Obama was elected, but What Works is still a limited collection.

While not specific to educational technology, another effort is the Networking and Information Technology Research and Development (NITRD) Program (see http://www.nitrd.gov/). NITRD, according to its website, seeks to be the "primary source of Federally funded revolutionary breakthroughs in advanced information technologies such as computing, networking, and software." NITRD was formed based on the High-Performance Computing (HPC) Act of 1991 (P.L. 102–194) as amended by the Next Generation Internet Research Act of 1998 (P.L. 105–305) and is a collaboration of fourteen federal research and development agencies, including the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and others with connections to K-12 education.

A number of other, nongovernmental repositories have been tried with varying degrees of success—and with varying amounts of international inclusion. For example, at least as recently as 2009 the International Society for Technology in Education (ISTE) was referring readers to a sub-organization, the Center for Applied Research in Education (CARET), which was founded in 2000 with funds from the Bill and Melinda Gates Foundation to review research in the area of educational technology (see Redish and Williamson, 2009). While CARET showed promise as a review service and clearinghouse, a check of the website (http://caret.iste.org) as of November 2010 showed no apparent activity past 2005.

On a smaller scale the Research Center for Educational Technology (RCET), located at Kent State University in Ohio (see http://www.rcet.org/), is an example. RCET, which opened its doors in 1998, includes a network of fourteen universities, forty-five university researchers, and a laboratory classroom where K-12 classes can meet daily for six weeks at a time. According to the RCET website, the classroom also has "served as a field site for over 490 College of Education, Health, and Human Services (EHHS) pre-service teachers including student teaching, in classroom observations and virtually through connections to 18 classrooms."

The international scene is similarly fragmented, often regionally. For example, the International Educational Technology Conference (IETC, originally International Educational Technology Symposium, or IETS) has been operating for slightly more than a decade, based largely in Turkey. IETC publishes extensive conference proceedings, usually papers from researchers and practitioners in Turkey and other nearby nations, including China. Another example is IEEE, originally the Institute of Electrical and Electronics Engineers. It now characterizes its organization as "the world's largest professional association for the advancement of technology" and provides a wealth of research reports on many aspects of technology, including educational technology. IEEE has some 400,000 members, more than 45 % outside the USA. Finally, the Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEAP), affiliated with the United Nations, has a specific capacity-building mission. CSSTEAP functions primarily as a coordinating association with little in the way of published resources, however.

In summary, US policy governing educational technology practice and research is complex—far more complex than might be supposed from reading the new National Educational Technology Plan 2010, *Transforming American Education: Learning Powered by Technology*. Implementation of federal policy is far from coherent or comprehensive, in part, because the field is as vast, complicated, and ever-changing as American education writ large and, in part, because federal policy influences more than it dictates state and local policies. This also holds true virtually everywhere in the world, even in centralized education systems that are highly controlled through national policy initiatives, as is the case in China.

Widespread—literally global—belief in the efficacy of educational technology to improve student achievement is intuitive, rather than research based. While research linking technology to school improvement and higher student achievement is accumulating, it often is difficult to locate and to aggregate, as we discussed in the fifth section of this chapter. Moreover, far more research has been done to date, both in the USA and in other nations, that assesses the availability of educational technology in schools and whether professional development has occurred, rather than whether the use of educational technology produces significant positive effects on student learning.

It is possible to make one particular generalization that applies across nations, which is that technology policy and practice are implicitly and often explicitly intended to help a nation be more "competitive" in a global sense and mostly in an economic sense. Whether one examines the rhetoric of national leaders, as we sampled in the first and second sections, or looks at policy language such as that used in *Transforming American Education*, the observer cannot help but be struck by the emphasis on technological advancement as synonymous with being more competitive in the global economy. ED Secretary Arne Duncan, for example, was specific, as quoted in the second section above, that using technology to improve education would ensure "America's ability to compete in a global economy." Other nations' policies express a similar belief. This belief, like the belief that educational technology will improve student achievement, is intuitive, rather than research based. If effective research strategies can be identified, it may be possible in future to treat this belief as a hypothesis and put it to the test. To date, that has not been done.

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51 Student-Centered, Open Learning Environments: Research, Theory, and Practice

Michael J. Hannafin, Janette R. Hill, Susan M. Land, and Eunbae Lee

Abstract

New learning environment designs and frameworks have emerged that are consistent with constructivist-inspired views of learning. Collectively, student-centered, open learning environments provide contexts wherein the individual determines learning goals, learning means, or both the learning goals and means. The individual may also establish and pursue individual learning goals with few or no external boundaries as typical during spontaneous, self-initiated learning from the Web. The approaches represent fundamentally different learning and design paradigms and philosophies. However, student or self-directed learning has been criticized for lacking compelling evidence to document effectiveness. As new models emerge and technologies develop, we need to both document evidence that supports and challenges student-centered approaches and refine our approaches to designing effective environments. This chapter provides an overview and critical analysis of student-centered learning, and proposes directions for advancing needed research, theory, and practice.

Keywords

Student-centered learning • Self-directed learning • Problem-based learning • Open learning environments

Introduction

Numerous frameworks, consistent with constructivist epistemology for the design of student-centered learning, have evolved that represent alternative learning and design paradigms and philosophies. Myriad student-centered approaches reflecting epistemological variants have emerged including anchored instruction (Cognition and Technology Group at Vanderbilt, 1992), problem-based learning (Hmelo-Silver, 2004), cognitive apprenticeships (Collins, 2006), computer-supported collaborative learning (Stahl, Kosch-mann, & Suthers, 2006), learning-by-design (Kolodner, 2006), project-based learning (Tal, Krajcik, & Blumenfeld, 2006), and games and simulations (Clark, Nelson, Sengupta, & D'Angelo, 2009). Though operationalized differently, these environments share basic foundations and assumptions regarding the centrality of the individual student in assigning the meaning and relevance of learning.

Similarly in student-centered learning environments, the individual determines the learning goal, the means to support learning, or both (Hannafin, 2012). This chapter focuses on student-centered, open learning environments (SCOLEs) in which students negotiate learning via unfettered and largely unstructured or ill-structured Web resources to address individual learning needs (Hannafin, Hannafin, & Gabbitas,

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2009). As these approaches expand and new technologies emerge, disciplined methods are needed to integrate digital resources, tools, and connectivity to support open, student-centered learning. Research is needed to examine the evidence and viability related to underlying theories and assumptions associated with such learning.

In this chapter, we focus primarily on student-centered, open learning environments where students assume responsibility for both identifying and monitoring individual learning goals and selecting and utilizing means to support their learning. We provide an overview of the evolution of SCOLEs, describe a series of examples of these principles in practice, critically analyze evidence for and against SCOLEs, and propose strategies and directions for advancing needed research, theory, and practice.

To identify commonalities and distinctions among learning environments, both similarities between and distinctions among the foundations, methods, and models associated with direct and open learning environments were presented (Hannafin, Land, & Oliver, 1999). While different approaches build upon foundation research and theory, the underlying epistemologies and associated assumptions separating directed and open learning approaches varied substantially. Given different learning goals and adherence to assumptions as to the nature of learning and understanding, a learning environment design necessarily reflects underlying differences. This became the core premise of grounded design practice for open learning environments (Hannafin, Hannafin, Land, & Oliver, 1997; Hannafin, Hill, & Glazer, 2011; Kim & Hannafin, 2008).

Evolution of Open Learning Environments

In the early 1990s, work in open learning environments was triggered by studies examining learning in the absence of formal instruction. Open learning environments have been described using terms like informal learning, self-choice learning, spontaneous learning, resource-based learning, and self-directed learning. Building upon different assumptions, as well as associated theory and research, the foundations and assumptions of student-centered learning provided "… interactive, complementary activities that enable individuals to address unique learning interests and needs, study multiple levels of complexity, and deepen understanding" (Hannafin & Land, 1997, p. 168).

Hill and Hannafin (2001) adapted this perspective for Resource-Based Learning Environments (RBLEs): "RBLEs support the individual's effort to locate, analyze, interpret and otherwise adapt information to meet particular learning needs" (p. 42). RBLEs open learning components were classified as comprising enabling contexts, resources, tools, and scaffolds. Resources (static and fixed, and dynamic and variable) provide core information assets available to support learning. Contexts, ranging from externally directed, to individually generated, to negotiated between the individual and external agents, establish the situational conditions within which learning is mediated. Tools (searching, processing, manipulating, communicating) "enable learners to organize and present their understanding in concrete ways" (p. 43). RBLE scaffolds (metacognitive, procedural, conceptual) support individuals as they identify relevant goals, pursue and monitor efforts toward those goals, and reconcile differences in their understanding (see also, Hmelo-Silver, Duncan, & Chinn, 2007). RBLE structures and principles were subsequently extended to informal learning and negotiated learning environments (Hill, Domizi, Kim, & Kim, 2012).

Student-Centered, Open Learning Environments

SCOLE frameworks emerged within and have since been refined by learning scientists and learning systems designers. SCOLEs facilitate student- or self-directed learning by guiding and supporting students as they engage complex, often ill-structured, open-ended problems. The approaches are designed to support individual student sense-making using technology tools, resources, and scaffolding (Quintana, Shin, Norris, & Soloway, 2006). SCOLEs provide contexts wherein the individual determines the learning goal, learning means, or both the learning goals and means (Hannafin, 2012). An individual may establish and pursue specific individual learning goals with few or no external boundaries as typical during spontaneous, self-initiated informal learning. Alternatively, the individual may have access only to specific, defined resources to pursue individual learning goals during free-time learning in formal settings; where learning goals are externally established as in most formal school settings, the individual determines how they will be pursued. In essence, the cognitive demands shift from externally mediated selecting, processing, and encoding during directed learning to individually anticipating, seeking, and assessing relevance based on unique needs and goals (Hannafin, Hannafin, et al., 2009; Hannafin, Hill, Oliver, Glazer, & Sharma, 2003; Hannafin, West, & Shepherd, 2009).

SCOLEs emphasize the individual's capacity to identify relevant resources and mediate cognitive demands (Hannafin et al., 1997). Since neither goals nor means are explicitly specified a priori, scaffolding often assumes the form of self-checking, navigation guidance, reassessing and evaluating progress, reexamining goals and progress, reflecting on state of understanding, and resetting and refining goals or strategies. SCOLE scaffolds may help to identify initial understanding in order to build from and refine, rather than to impose canonically correct or generally accepted views on, existing beliefs and dispositions (Kim, Hannafin, & Bryan, 2007).

SCOLE Assumptions

SCOLEs share important assumptions of situated learning theory (Barab & Duffy, 2000) which suggests "… a reformulation of learning in which practice is not conceived of as independent of learning and in which meaning is not conceived of as separate from the practices and contexts in which it was negotiated" (p. 26). Barab and Duffy noted that communities of practice (COPs) comprise "a collection of individuals sharing mutually defined practices, beliefs, and understandings over an extended time frame in the pursuit of a shared enterprise" (p. 36). Understandings develop through participation in authentic contexts (practices, situations, and processes) that shape how knowledge acquires meaning and is applied in context.

SCOLEs emphasize the (a) centrality of the learner in defining meaning; (b) scaffolded participation in authentic, often ill-structured tasks, and sociocultural practices; and (c) access to diverse perspectives, resources, and representations; and (d) importance of learner prior experiences in meaning construction. SCOLEs support the individual's efforts to construct personal meaning. External learning goals may well be established, but the learner determines how, when, and if to proceed based on emergent understanding.

Understanding multiple perspectives is assumed to be critical to deeper, divergent, and more flexible thinking processes. SCOLE advocates assume that individual understanding is deepened by providing varied rather than singular perspectives, resources, and representations. Such approaches may employ teacher–student or student–student interactions to model reflection and performance (see for example, Palincsar & Brown, 1984). Shared understandings across teachers, experts, and peers may be represented as community knowledge from which learners evaluate and negotiate varied sources of meaning (Scardamalia & Bereiter, 2006).

Multiple representations are assumed to be supported through tools that aid in visualizing and manipulating "hard-to-see" concepts enabling learners to consider ideas and perspectives otherwise inaccessible to them. Simulations, GPS data and maps, and virtual worlds allow learners to visualize and experience complex representations of concepts, thus adding to the richness of perspectives available on the topic. These externalized representations enable new forms of discourse and engagement (Roth, 1995), thus enhancing, augmenting, or extending thinking or perspectives (Pea, 1985).

Individual prior knowledge and experience play critical roles for all learning, but present unique challenges for SCOLEs. Prior knowledge and experience are assumed to form the conceptual referent from which new knowledge is organized and assimilated, as learners' prior knowledge and beliefs influence what they perceive, organize, and interpret (Bransford, Brown, & Cocking, 2000). Understanding dynamically evolves as ideas are generated, expanded, tested, and revised (Land & Hannafin, 1996); learners may evolve durable but naïve and incomplete beliefs and models rooted in their everyday experience. While personal models can be tacit and at odds with accepted notions, they form the basis through which learners interpret and explain new concepts. Interpretations and explanations may persist in the face of contradictory evidence (Strike & Posner, 1992), suggesting that individual beliefs, understandings, and misunderstandings are not readily modified by simply providing authoritative information or confronting with competing evidence. Because novice learners often lack important background and strategic knowledge for managing their learning processes, they can become overwhelmed by options available and encounter difficulty directing their investigations and make effective decisions (Quintana et al., 2004). Managing the demands of an open-ended task requires tracking findings, deciding what to pursue next, determining how available tools and resources are useful in a problem, and reflecting on what is being learned.

Initial understandings, including canonically accepted conventions as well as misconceptions, are also assumed to influence the ability to detect, interpret, and synthesize knowledge (Bransford et al., 2000). Canonical understandings do not supplant initial conceptions but rather serve to challenge and extend initial assumptions (Jonassen, 1991). Thus, prior knowledge and experience influence the individual's ability to mediate their own learning—a central assumption of student-centered learning.

In order to build upon student understanding, SCOLE contexts emphasize connections with everyday experiences. Understanding and sense-making, uniquely shaped by the individual's prior knowledge and experience, influence both what and how something is known. When learning is anchored in everyday contexts, learners are more likely to understand how concepts are applied and why they are useful, facilitating transfer (Bransford et al., 2000). Making connections to everyday contexts guides students to enrich and integrate schooling and life experiences and to develop meaningful, long-lasting interests and understandings (Bell, Lewenstein, Shouse, & Feder, 2009).

To facilitate understanding and meaning-making, SCOLEs assume that authentic experiences or realistic simulations serve to stimulate engagement and interaction (Bransford et al., 2000; Collins, 2006; Edelson & Reiser, 2006). These contexts help students to identify learning goals, formulate and test predictions, and situate understanding within the individual student's experiences while enabling them to understand ordinary practices from a real-world perspective.

Given the importance on decision-making, self-monitoring, and attention-checking skills, learners are provided opportunities to make choices and pursue individual interests. This is assumed to afford opportunities to cultivate deeper understanding of and responsibility for learning. Rather than compliant understanding based on external expectations (McCaslin & Good, 1992), learners are assumed to hone personal strategies, plan and pursue goals, integrate new knowledge with existing, formulate questions and inferences, and refine and reorganize their thinking (Bransford et al., 2000).

SCOLEs also assume that knowledge, understanding, and application are enhanced when practical utility is apparent and relevance for interpreting, analyzing, and solving real-world problems are apparent. While all learning is considered to be contextually based, SCOLEs assume that rich learning contexts support the meaningful activation of personal knowledge and experience. Solving classical textbook mathematical equations independently of authentic contexts may promote isolated, naive, and oversimplified understanding (Brown, Collins, & Duguid, 1989). The knowledge, however, may be of limited utility and applied mainly to near-transfer problems (e.g., other textbook problems) where the algorithm can be equivalently matched but fail to flexibly apply or support critically reasoning for far-transfer or novel tasks (Perkins & Simmons, 1988).

Finally, while the role of the individual in both uniquely defining and monitoring understanding is assumed to be essential to promote autonomy and ownership of the learning process, these processes may not occur spontaneously without support. To support the individual's learning, therefore, SCOLEs scaffold thinking and actions to facilitate ongoing management and refinement of understanding. These cognitive and metacognitive demands are often supported through structures and guidance embedded within the environment.

SCOLE Examples

Land, Hannafin, and Oliver (2012) detailed diverse student-centered environments across domains which feature the primacy of students in selecting and mediating individual learning. The Web-Inquiry Science Environment (WISE), for example, scaffolds middle-grades science learning (Linn, 2006; Linn, Clark, & Slotta, 2003). Students interact in a virtual laboratory to inquire, experiment, and compare predictions about everyday scientific phenomena in their environment. Students are supported as they conduct investigations, use simulation tools to develop, test, and refine explanations of their findings, and compare and contrast their assumptions and conclusions to integrated WISE problems (e.g., how far does light travel?). Individuals initiate inquiries to understand, interpret, and build upon what they know.

In Stickler and Hampel's (2010) collaborative language learning environment (*Cyber Deutsch*), students interact using assorted tools and practice language via authentic communicative practices. They videoconference and participate in asynchronous discussion forums and question each other as they practice their language skills by blogging and contributing to wikis.

The *Jasper Woodbury Series* (Young, 1993) presented a variety of open-ended dilemmas that anchored mathematics in rich, video vignettes. Using the *anchored instruction* framework (CTGV, 1992), video vignettes present stories about everyday problems faced by the story's lead character, Jasper. The information needed to solve the problem is embedded within the story itself rather than presented and practiced in isolation. One Jasper dilemma involves determining whether or not sufficient time is available to drive a newly purchased boat home before sunset. Information relevant (as well as irrelevant) to solving the dilemma is embedded naturally within the story, and students must identify and generate potential problems and sub-problems. For instance, mile markers, periodic fuel readings, amount of fuel purchased, and time of day are embedded naturally within the story. Once the macro-context is introduced, students identify relevant information prior to generating potential sub-problems to the multifaceted and complex dilemma.

The *Jasper* series and anchored instruction frameworks have been successfully applied to encompass varied problem sets and contexts. The *Blueprint for Success* episode, for example, requires learners to apply geometry concepts to design a virtual playground. Another problem asks learners to consider whether Jasper will be able to transport a wounded eagle to safety using his ultralight airplane, while a different problem asks learners to design a school fair and to design and fill a dunking booth for teachers. *Jasper* also addresses transfer issues through a series of analog and extension problems. By presenting pairs of related adventures (e.g., trip planning) students are scaffolded in analyzing which concepts are generalizable across contexts and which are specific to the given context.

Learning communities, sometimes tacitly and often explicitly, manifest SCOLE foundations, assumptions and features. Within learning communities, "there is a culture of learning in which everyone is involved in a collective effort of understanding" (Bielaczyc & Collins, 1999, p. 271). The *Knowledge Forum*, for example, emphasizes collectively building and improving upon emergent understanding. Technology tools are used to post ideas and notes as well as to comment on and organize individual and shared understandings (Scardamalia & Bereiter, 2006). Students act as agents of their own understanding while generating and contributing both individual and collective knowledge. Recently, technology tools have also been employed to support informal learning communities of practice (COPs). Company

Command (Hoadley & Kilner, 2005), an online COP for US Army officers, brings together remotely distributed military commanders to support each other's leadership practice. Similar COPs have been employed to support communities as diverse as novice and beginning practicing teachers (Barab, Barnett, & Squire, 2002) and distributed automobile sales and service personnel in improving practices (Land et al., 2009).

SCOLE games and simulations have also seen widespread growth in interest and use. *Civilization III*, a hybrid game/simulation, has been used in education contexts to cultivate learning related to historic events and nation building. Using program rules (e.g., food needed to sustain a given population; land needed to produce required housing and food), authentic scenarios induce students to initiate or defend against war or compete with other civilizations online. Charsky and Ressler (2011), for example, scaffolded ninth graders' emergent conceptual understanding of global history, but noted that in-game support seemingly compromised autonomous gaming activities.

In *Crystal Island*, students engage scientific decision-making at a virtual research station to examine why scientists became ill. The simulation embedded conceptual and metacognitive scaffolds within character dialogues, and procedural scaffolds in the form of virtual lab tools for testing hypotheses. The scaffolding strategy adapted support based on ongoing student understanding and decision-making. For example, if students failed to apply a reasonable, systematic approach to address the problem, the simulation initiated strategic scaffolds requiring students to reconsider key components before proceeding. Students who successfully applied their knowledge were able to rule out unlikely hypotheses and generate appropriate hypotheses (Spires, Rowe, Mott, & Lester, 2011).

Plantation Letters is a collection of nineteenth century letters written to and from American plantation owners. The letters are used to support inquiry across a range of questions, topics, and issues. Students access the letters using health-related tags to study conditions contributing to medical problems among the enslaved population (Oliver & Lee, 2011). Multiple perspectives on medical crises can then be referenced by reading across cases involving chronic health problems as well as by accessing recent medical crises brought about by natural disasters. Students share their approaches and develop a consensus to address the health crises via a social network. In a different lesson, scaffolds guide students in historical inquiry to pursue themes of personal interest. Students index information about their selected source, note contextual information within the source, draw inferences regarding broader historical questions, and monitor their assumptions and interpretation. Teachers can also utilize Web-based tools to support this work. *The History Engine* provides opportunities to publish interpretations of primary historical sources and engage historical experts and students during analysis (Benson, Chambliss, Martinez, Tomasek, & Tuten, 2009).

Klopfer and Squire (2008) embedded augmented reality within a GPS-enabled handheld device in *Environmental Detectives* which presents an open-ended environmental problem where the problem source could not be immediately identified. They "create[ed] an experience where players had to think about the nature of the problem, design data collection strategies, reflect on their data collection in progress, analyze and interpret data, and then revise hypotheses, data collection strategies, and emerging theories of the problem" (p. 216). Their development process included rapid prototyping, learner-centered design, and contemporary game design.

Finally, Lindsay and Davis (2007) examine and compare perspectives on the influence of contemporary trends on world connections. *Flat Classroom* supports students as they traverse individual and class-level inquiry, attempt reconciliation of alternative global perspectives, use technology tools in support of constructivist projects, and enable peer and adult scaffolding. Middle- and high school classrooms worldwide use asynchronous and synchronous communication tools to exchange views and co-construct wiki spaces and video artifacts of their understanding, incorporating resources from partner schools to encourage and facilitate collaboration. Geographically distributed students convene virtual summits where they share work while receiving experts' feedback.

Reexamining SCOLE Research, Theory, and Practice

The perspectives of researchers and theorists often vary dramatically with respect to the importance of underlying assumptions and associated strategies. In this section, we contrast perspectives opposed to and in support of SCOLEs.

The Case Against

To scholars who emphasize externally defined learning outcomes, SCOLE principles and practices lack empirical foundation and are applied in misguided ways (see, for example, Clark & Feldon, 2005). These criticisms are bolstered by research indicating the need for and effectiveness of direct instruction over general advice (Kester & Kirschner, 2009; Kirschner, Sweller, & Clark, 2006; Sweller, Kirschner, & Clark, 2007) and the consequences of stimulus overload in loosely- or ill-structured learning environments (Mayer, Heiser, & Lonn, 2001). R. Clark recently described "pitfalls" and shortcomings of constructivist-inspired learning environments such as discovery learning research and practice, citing examples to support his assertion that fully guided, direct instruction results in superior performance in virtually all cases (Clark & Hannafin, 2011). Similar arguments have been presented for constructivist-inspired learning strategies and environments including student-centered learning, inquiry-based learning, and self-directed learning (Kirschner et al., 2006).

Clark also suggested that empirical evidence generated from directed-learning studies is applicable to all types of learning independent of the associated epistemological roots. He suggests personal perspectives might unduly sustain the popularity of minimally guided approaches in the absence of empirical evidence. He cautioned: "Far too many in our field are avoiding inconvenient evidence in favor of self-serving beliefs and opinions" (Clark & Hannafin, p. 375). He further questioned the preparation and motivation of nonadherents: "few people have the motivation or training necessary to invest the effort required to carefully review complex research on learning and instruction…ambivalence about research training in our instructional technology and instructional systems graduate programs is certainly a contributing factor" (p. 375). Clark concluded that programs that do not heed his advice "risk causing harm to people who depend on us" (p. 375).

These perspectives are not isolated, and similar opinions have been advanced by leading figures in the instructional design field. Merrill, Drake, Lacy, Pratt, and ID2 Research Group (1996), for example, stated that the instructional design field had misguidedly strayed from its empirical research and theory roots and become enamored with unproven fads and trends and abandoned the discipline and scientificism of learning researchers. They argued strenuously to reclaim instructional design from those who have shifted away from the science of instruction and the technology of design. Merrill and ID2 colleagues characterized the trend as being fomented by wild speculation and extreme, unscientific philosophy. Similarly, Walter Dick (1991) questioned the applicability and appropriateness of constructivism, perhaps the most commonly ascribed epistemological basis for SCOLEs, as a viable frame for designing instruction and evaluating student performance.

These criticisms have been well-documented in the instruction and instructional design fields, though significant developments have become apparent both within and beyond the instructional design field. While gaining considerable momentum and traction, disagreements have emerged in the past and continue to emerge at the present time.

The Case For

Although critics' arguments have face validity, their conclusions have been based largely on externally mediated learning: All learning is not mediated by engineered instruction. Instead, individuals learn and interact continually and dynamically, negotiating meaning and understanding and learning within their everyday environments. This is evident in how and why we access the Web to identify a wide range of everyday resources, including to locate resources for formal school lessons and projects, plan travel, identify activities of interest for children, plan for retirement, shop comparatively online, and a virtually unlimited number of planned and spontaneous learning tasks. Instruction comprises one significant option to promote and support learning, and in many cases it may be the best option but clearly not the sole or exclusive approach.

SCOLE proponents suggest that the goals, assumptions, and learning contexts of student-centered learning differ substantially from those of direct instruction. Clark et al.'s perspectives, methods, and findings are at odds with widely adopted approaches advanced by other reputable theorists, researchers, and practitioners. Kuhn (2007), for example, suggested that instructional methods should be considered in light of the broader context of instructional goals about *what* is important to teach, and that alternatives to direct instruction are warranted. Hmelo-Silver et al. (2007) challenged use of the critics' term minimal guidance: "problem-based learning (PBL) and inquiry learning (IL), are not minimally guided instructional approaches but rather provide extensive scaffolding and guidance to facilitate student learning" (p. 99). Optimal guidance is needed where learning outcomes are not or cannot be explicitly predefined. Further, McCaslin and Good (1992) noted, "the intended modern school curriculum, which is designed to produce self-motivated, active learners, is seriously undermined by classroom management policies that encourage, if not demand, simple obedience" (p. 4). The authors suggest that both teachers and students require sustained opportunities and support in order to adapt and implement significant pedagogical changes.

Hannafin et al. (2009) contrasted time-tested cognitive principles supporting externally mediated learning with student-centered learning, noting "fundamental shifts in cognitive requirements as well as the foundations and assumptions underlying their design and use" (p. 196). The *locus and nature of knowledge*, the *role of context* in learning, and the *role of prior experience* are central to both externally mediated and student-centered approaches, but the associated assumptions and implications vary considerably. Among objectivists, knowledge has been viewed as existing independently of individuals, and is to be acquired and understood according to canonical conventions. Learning contexts comprise stimulus elements and their proximal relationships, and prior knowledge and experience establish and reify strength of association and relationship within complex schemata. In contrast for student-centered learning researchers and theorists, knowledge and meaning do not exist independently from each other but are constructed dynamically by individuals; context and knowledge are inextricably tied and are mutually interdependent, and prior knowledge and experience influence initial beliefs and understanding and must be acknowledged and addressed for learning to become meaningful to the individual.

Unlike the time-tested principles underlying externally mediated instruction, the research and theory base underlying SCOLEs is still emerging. Some have suggested that learning demands become increasingly complex since individual "meaning" is influenced more by the diversity between than the singularity across learners. According to Land (2000, pp. 75–76) without effective support,

> misperceptions, misinterpretations, or ineffective strategy use … can lead to significant misunderstandings that are difficult to detect or repair…metacognitive and prior knowledge are needed to ask good questions and to make sense.

Optimal not absolute guidance is indicated where learning outcomes are not or cannot be explicitly predefined. We need to understand diverse perspectives and assess their potential implications and not either blindly accept or dismiss them. The case against student-centered learning has been advanced; Duffy and Jonassen (1992) presented their case for the emergence of constructivism and its impact on instruction. Tobias and Duffy (2009) compiled chapters authored by well-known proponents as well as critics of different perspectives. Both similarities between and differences among perspectives need to be recognized and understood.

The Future: Where Should We Go from Here?

Although SCOLEs have the potential to deepen learning when strategies are followed, associated strategies are often unutilized, misutilized, or underutilized. For example, few researchers have documented conclusive evidence for effective metacognitive scaffolding during student-centered learning. To be effective, students need key domain knowledge and the ability to regulate cognition as they formulate and modify plans, reevaluate goals, and monitor individual cognitive efforts. Such knowledge and skill is necessary but often insufficient, however, as students fail to invoke and regulate their skills when engaging learning tasks that are too easy or too difficult, where they lack motivation to engage the tasks, or when they perceive a lack of relevance. We highlight several areas of particular concern.

Prior Knowledge and Experience

Prior knowledge and experience are considered critical during SCOLEs, but are often incomplete and inaccurate (Land, 2000). Lacking adequate background, learners fail to detect inaccurate information or reject erroneous hypotheses upon encountering contradictory evidence. Rather than building from and refining initial understanding rooted in personal experience, misconceptions become reified. Without appropriate guidance and support, misinformation may go undetected as beliefs associated with misunderstandings are strengthened rather than reconciled.

Scaffolding

How much support is needed, and appropriate for, the different aspects of student-centered learning? Some have suggested that maximum guidance (scaffolding) is most effective for *all* types of learning, but the basis and rationale for this conclusion have been challenged. Soft scaffolding, provided dynamically and adaptively by teachers, peers and other human resources to accommodate real-time changes in needs and cognitive demands, has proven inconsistent in implementation frequency, quality and impact on student learning. Similarly, technology-enhanced support (hard scaffolding) has proven effective in learning basic information, but often ineffective in promoting the generalizable reasoning and thinking valued in student-centered learning. Clarebout and Elen (2006), for example, were able to scaffold college students' performance during open-ended learning tasks using pedagogical agents, but only with fixed (versus adaptive) advice.

Assuming scaffolding is provided, how should we measure individual student-centered learning and performance? How will we (or will we be able to) assess success or failure of SCOLEs to attain individually generated goals? Any approach should yield superior results when assessments are appropriately aligned: SCOLE students should not perform as well as those receiving direct instruction when assessments are focused solely on externally defined knowledge and skill requirements; predictably, students receiving maximum guidance would not perform as well as on assessments of SCOLE thinking or reasoning. Given increased accountability expectations with unpredictable variations in individual prior knowledge and experience, research is needed to study how scaffolding variations are utilized individually, how meaning is influenced by individual needs and goals, and how individual needs are (and are not) addressed.

Metacognition

Metacognition may be among the most important yet potentially most problematic cognitive constructs associated with SCOLEs. Since student-centered learning emphasizes learning in un-, less-, or ill-structured environments, the ability to monitor one's cognitive processes is fundamental to evaluating progress toward meeting individual learning goals and means. Students who have, or develop, metacognitive strategies tend to perform more successfully than those who do not. Thus, research is needed to clarify the extent to which learners must possess initially, require advance training prior to, or can develop the requisite skills needed to monitor their progress during student-centered learning.

Cognitive Demands

Existing cognitive load research and theory present possible explanations for managing cognitive demands, but given the cognitive demands associated with student-centered learning we need to better understand how, when, and if individuals manage cognitive load. Intrinsic cognitive load reflects the difficulty inherent in the information to be learned, germane cognitive load reflects the effort needed to create relevant schemas and models for future learning, and extraneous cognitive load reflects nonrelevant cognitive requirements associated with the instructional materials, methods, and environment. Ton de Jong (2010) argued that different types of cognitive load are often indistinguishable, variations in instructional format influence both the nature and distribution of cognitive load, individual learner differences are rarely accounted for, and efforts to measure cognitive load often do not provide valid or differentiated estimates. He proposed that cognitive load efforts be directed to measure perceived "difficulty of the subject matter… of interacting with the environment itself…helpfulness of the instructional measures used" (p. 119).

These issues are particularly critical during student-centered learning where distinctions between and among different types of cognitive load are individually differentiated. In SCOLEs, it is not possible to anticipate which resources and activities are extraneous, intrinsic, or germane independent of individual learning goals, background knowledge, and experience. Given the ill-structured and highly individualistic nature of student-centered learning, little inherent organization is available to clarify the intrinsic importance, or difficulty of, to-be-learned information. Normally, this support is managed and brokered within structured instruction. Individuals, unable to distinguish important from unimportant information (thereby increasing extraneous load), lack the structures normally provided to support cognitive processing, construction, and schema activation.

Given equivocal findings, many question whether students *can* manage the cognitive demands associated with SCOLEs. Bannert (2002) described potential influences of internally managed cognitive load: "it appears very important to find out … which training format learners would choose if they were able to decide themselves and also to examine if learner-control treatments would also be superior with respect to training efficiency and transfer performance" (pp. 145–146). Since students must assess veracity and relevance while addressing individual learning goals and monitoring understanding, research is needed to examine how cognitive load theory and constructs vary as learners become increasingly facile with, or frustrated by, their individual learning tasks. While cognitive load scholars continue to question the viability of self-regulated learning, Bannert (2002), DeSchryver and Spiro (2009), and de Jong (2010) underscore the significance and potential of further research in student-centered learning.

Methods

What research questions need to be addressed and what types of methods are needed? Are findings from SCOLE-related research fundamentally flawed? According to Clark and colleagues, the methodologies are misguided. No doubt there is insufficient and questionable rigor in many published reports, but the questions posed necessitate methodologies that differ from experimental approaches. Disciplined methods appropriate to student-centered approaches have been advanced and practiced by well-regarded researchers. It is inappropriate to apply methods and standards that are not aligned with or address the questions posed; it is also naive to categorically discount such research simply for not employing experimental methodologies. SCOLE research paradigms place increased emphasis on the study of technological and pedagogical innovations in situ—that is, within authentic classroom contexts. Design research (McKenney & Reeves, 2012) reflects a methodological shift to better address the situated nature of SCOLE research, theory, and practice.

Lingering Questions

How do students perceive student-centered learning? Contradictory findings have been reported related to students' preferred learning style (Kumar & Kogut, 2006). While some allege that students are most comfortable with traditional didactic approaches, others report that students prefer to be active and engaged in their learning process (Dochy, Segers, van den Bossche, & Struyven, 2005). In either case, significant reliance on self-directed learning will continue whether or not directed teaching options are available.

Similarly, do SCOLEs trigger and sustain students' motivation? Many laud SCOLEs for stimulating intrinsic motivation. Blumenfeld et al. (1991) investigated the influence of student-centered, project-based learning on triggering and sustaining motivation. According to self-determination theory, students who experience autonomy, relatedness, and competence should demonstrate greater volition and motivation to engage activities that enhance performance, persistence, and creativity (Deci & Ryan, 2000). Assuming increased student agency in establishing and pursuing individual learning goals, we might expect such outcomes, but findings from research to date remain equivocal.

Conclusions

Teaching and learning needs are sometimes straightforward (or can appear such), but often they are not. We cannot always anticipate a priori the unique learning needs of each individual in order to judge how much or little they already know, how relevant the knowledge is to the current learning goal, how well-founded their current understanding is, or how, when, and where different learning needs will surface. It is not possible to predesign maximum guidance or direct instruction to support infinite differences in prior knowledge, ability, learning goals or the spontaneous circumstances within which they emerge.

To the contrary, the lack of success with and satisfaction for didactic approaches have stimulated theory, research, and development to support higher-order thinking, reasoning, and decision-making. We may well continue to adhere to individual or community biases and beliefs, but it has become clear that significant scholars in the broad community are invested in refining SCOLE theory, research, and practice.

While guidelines have been offered to support SCOLE design, often they lack adequate theoretical or empirical framing. There are commonalities across SCOLE approaches, but no unifying theory exists to guide their design or consensus methodology to validate their findings. Some disagreement seems to reflect basic differences in the underlying epistemology while other disagreements appear rooted in what is considered valid methodology. We need to identify frameworks for analyzing, designing, and evaluating SCOLEs. Given underlying differences, such frameworks may not satisfy skeptics with disparate epistemological beliefs, but they should facilitate clearer specification as to how SCOLE variants do, or not, share common foundations and assumptions.

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52 Preparing Instructional Designers: Traditional and Emerging Perspectives

Monica W. Tracey and Elizabeth Boling

Abstract

While official definitions and textbooks in the field reflect a conception of design in which little has changed in decades, there has been a growing awareness since the early 1990s that broader conceptions of design could benefit practice in instructional design. Preparations of instructional designers in college programs traditionally include the use of instructional design models and processes incorporating project work. Approaches based on studio design are recently emerging in some programs. Research on design practice and the effectiveness of design pedagogies in the field are called for.

Keywords

Design • Design knowledge • Precedent • Studio pedagogy

To address the question of preparing instructional designers, we first consider what it is they are being prepared to do. In a detailed analysis of the most widely adopted textbooks and official definitions of the field, Smith and Boling (2009) establish that conceptions of designing in the field have changed little over the 40 years covered by those materials. Summarized, these conceptions of designing in the field comprise the view that design is a systematic process, represented by models, based on theory and grounded in data while focused on problem solving. As these conceptions are clearly outlined in the most widely adopted textbooks in the field we can presume that these perceptions guide the preparation of instructional designers. The International Board for Training, Performance, and Instruction (IBSTPI) competencies (Richey, Fields, & Foxon, 2001) are currently the most widely accepted standards for instructional design practice, although several other organizations including the International Society for Technology in Education (ISTE), the IEEE Technical Committee on Learning and Technology's competency-based perspective on curricula and assessments for Advanced Learning Technology (Hartley, Kinshuk, Koper, Okamoto, & Spector, 2010), and the United Nations Educational, Scientific, and Cultural Organizations (UNESCO) have also recommended competencies related to technology and instruction/education (Sims & Koszalka, 2008). The intent of the competencies is to provide a guide for professional practice and preparation for that practice.

Traditional Methods of Preparing Instructional Designers

Major textbooks in the field are organized around process models (Smith, 2008), and current preparation in instructional design programs most often begins with an introduction to the instructional design process via one or more models, even when instructors report that they are not sure why they do so (Boling, Easterling, Hardre, Howard, & Roman, 2011). As recently as 2009 a new textbook appeared (Branch, 2009) centering squarely and solely on ADDIE as

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the conceptual framework and process model for designing, and presenting the traditional view of designing as the appropriate basis for teaching novices how to design. Novice designers are also taught the foundations of the field, including descriptive and prescriptive theories from multiple domains, as well as methods for analysis, preparing objectives, and other activities within the larger process frame (Richey, Klein, & Tracey, 2011). Although acknowledging that instructional designers adapt their practice to cultural norms in their own countries, Campbell, Kanuka, and Schwier point out their realization during a recent symposium organized specifically to explore such practices that "most international instructional designers with graduate preparation have been enculturated with a North American view of ISD" (2010; p. 15) owing to their having studied in U.S. programs or in programs modeled on these.

Providing IDT students an opportunity to practice ID in the context of an authentic project has become conventional in many IDT programs (Cennamo & Holmes, 2001; Knowles & Suh, 2005; Quinn, 1994; Tracey, Chatervert, Lake, & Wilson, 2008) while still emphasizing traditional process models and the use of generalized principles applied to designing as exemplified by Cennamo and Holmes (2001). Using an apprenticeship model, Collins, Brown, and Holum (1991) documented the design and application of a clinical course, which immersed their instructional design students in practice. Results indicated that overall, students needed guidance in *extrapolating general design principles from a specific design experience*. The authors suggest that the extensive use of design cases, discussions with expert designers, and experiential learning opportunities within graduate programs are important in the effort to prepare students for instructional design practice after graduation.

Match Between Formal Preparation and Practice

Using established competencies, theories, principles, and process models as a guide to preparing students for professional practice may be fundamentally sound, but research indicates that additional knowledge and skills are needed in practice. In 2000, instructional design students participating in a study on the use of case studies indicated that the instructional design knowledge and skills they needed for actual practice was well beyond what they learned in the classroom (Julian, Kinzie, & Larsen, 2000). In 2010 Villachica, Marker, and Taylor analyzed 85 surveys from employers in the field and discovered that the skills they expect new employees to bring to the job are required for 22 activities that fit into the broad conceptual categories associated with ADDIE, but that graduates trained in this field were unable to perform those activities as expected, or were only able to do so with "a lot of assistance" (p. 33).

While Larson (2005), in researching whether alignment exists in instructional design preparation and practice with respect to general instructional design competencies, found that graduates felt well prepared overall by their programs to apply those competencies in practice, a review of actual ID practice reported in classic research studies (Holcomb, Wedman, & Tessmer, 1996; Kirschner, Carr, van Merrienboer, & Sloep, 2002; Rowland, 1992; Tessmer & Wedman, 1992; Visscher-Voerman & Gustafson, 2004; Wedman & Tessmer, 1993; Winer & Vazquez-Abad, 1995) identified substantial variation in actual practice using the competencies (Leigh & Tracey, 2010). Some of the essential IBSTPI competencies are not frequently used in actual practice by instructional designers because of (a) lack of time and resources, (b) control in decision making, (c) the designer's perception of a task, (d) underlying philosophical beliefs, and (e) designer expertise (Leigh & Tracey, 2010).

Research focused on identifying what instructional designers actually do indicate a difference in the use of tools used to prepare designers and how designers actually approach design (Kirschner et al., 2002; Leigh & Tracey, 2010; Wedman & Tessmer, 1993; Winer & Vazquez-Abad, 1995). Practitioners in the field do not always use the tools that were used to teach them and this seems to have been true for some time (Rowland, 1992). It is not necessarily the case that designers in practice are prevented from carrying out their work as they were taught to do it in school, although some do report this view (Boling et al., 2011). Kirschner et al. (2002) speculate that, "while ID models often inspire designers, their activities typically don't reflect the systematic, step-by-step approach as prescribed in traditional ID models" (p. 91), and Visscher-Voerman and Gustafson observe that, although often prepared to approach design in a systematic manner, most designers in practice approach design in an individual, iterative, and context-driven manner (2004). Despite this, Smith and Boling (2009) note that descriptions of how designers impact design are absent in the textbooks and definitions published by the field.

Preparation for Design Practice

When looking at student preparation in other design professions, including graphic design, engineering, and architecture, it is evident that these designer preparation programs do not solely focus on process. Instructors teaching design in these fields discuss teaching technical methods, but focus on teaching designers to be "ethical, to define their own talents, to understand the world, have passion for design, acquire their own voices…" [the concern is with] "transforming students into designers, rather than teaching students the process of design" (Bichelmeyer, Boling, & Gibbons, 2006; p. 42).

In part this difference in focus stems from the problems and limitations of teaching based on models and prescriptive guidelines for process. Siegel and Stolterman (2008), working in human–computer interface design, address one of the difficulties novices encounter as they study design in a way that may be familiar to instructional design educators, saying that "Naive designers expect to memorize algorithmic solutions to problems; experienced designers learn to deal with ill-structured problems, seemingly paradoxical situations and design thinking" (p. 378). Groeneboom, renowned product designer (quoted in Lawson & Dorst, 2009), expresses the view that offering algorithmic solutions, represented in his field by design methods, is counterproductive. "The big disadvantage [of design methods] is that through this kind of teaching we take away the insecurity of the students. It is a way of quickly and efficiently explaining design but that is deadly. Students have to learn to deal with uncertainty, and we take that away by this kind of teaching … In the end, I would say that dealing with uncertainties is the core of our design profession" (p. 33). Part of the problem may be that the novice designer "takes models literally, [while] experts adapt" (Gibbons & Yanchar, 2010, p. 20). Another may be that designing is such a complex activity that no one model can capture or explain it sufficiently well to engender rich practice (Lawson & Dorst, 2009). In fact, Cennamo et al. (2011) state that "the education of engineers, instructional designers, architects, landscape designers, and the like must, by necessity, prepare students to solve the very complex and ill-structured design problems with which they must grapple as professionals" (p. 13) and describe the methods used to do this in an industrial design class, an architecture class, and three human–computer-interaction classes.

Studies on examining design expertise indicate general agreement that expertise is a significant factor in designer's problem solving (Le Maistre, 1998), in their strategy selection (Christensen & Osguthorpe, 2004), and in managing the process of the design situation (Tracey & Morrison, 2012). In a classic study of how designers actually think when they design, Kerr (1983) explored how 26 novice instructional designers cope with making design decisions. He determined that beginners have difficulty articulating a design problem to themselves and to others, have problems entertaining multiple design solutions and eliminating alternatives rapidly, and do not know when and how to determine when to stop the design process. Experienced designers on the other hand draw on their knowledge of previous designs and "seem to have learned the value of rapid problem-exploration through solution-conjecture. They use early solution attempts as experiments to help identify relevant information about the problem" (Cross, 2007, p. 46). Where novices work diligently attempting to understand the problem before considering solutions, experts use solution ideas to help clarify the problem (Lawson, 2004a, 2004b).

Even instructors who do not begin teaching from a process model may subscribe to the idea that novices can perform like experts if they are told how to do so. Verstegen, Barnard, and Pilot (2008) studying the use of methods to support novice instructional designers working on a complex design problem, provided 11 support interventions to novices during design. Support included solving the design problem with specific instructional design guidelines, managing the design process with specific process-oriented guidelines, gathering information using specific templates, and communication throughout the design process with specific guidelines for exchanging information. Results indicated that novice designers could solve complex design problems when given enough time and adequate support for the given task. However, in spite of the extensive support, variation in the quality of the designed product was evident. This may be partially because "students entering design fields are saddled with naive or misconceptions about design and design activity" (Newstetter & McCracken, 2001a; p. 63). These scholars in design education at the Georgia Institute of Technology explain that student conceptions, or mental models, concerning design are strong and that "having students follow prescriptive models of design does not constitute confrontation of the sort that can begin the dismantling of [these] mental models" (p. 66). They call for a science of design learning, involving extensive and rigorous study of novice designers and their learning.

Evolving Views of Designers and Designing

Scholars and instructors focused on design discuss specialized activities and particular habits of thought termed *design thinking* (Cross, 2007; Lawson & Dorst, 2009) and *reflective designing* (Lowgren & Stolterman, 2004). In this view, no single approach to designing can address every future situation effectively, so the designer must be prepared to appreciate design situations subtly and with discipline, invent and reinvent processes, and take personal responsibility for the effects of their designs rather than handing off responsibility for quality outcomes to a single process or theory (Nelson & Stolterman, 2003). Designers act as human instruments, analogous to researchers in a naturalistic study, bringing their own acknowledged perspectives to the enterprise, working within emergent frameworks and adapting to situations unknown and unknowable in advance (Boling, 2008). Students of instructional design and technology (IDT) bring different backgrounds and abilities to the classroom along with very different understandings of what design is and their role in it. Historically, IDT has focused on the systematic design process, client, and content, with very little on the designer role in design situations. However, those who view design as a tradition distinct from science and who study how it occurs in practice, present design not as a smooth systematic process, but instead that designer's values, belief structures, prior experiences, knowledge and skills, and their approach to design affect the final outcome (Nelson & Stolterman, 2003).

Observations of designers carried out by researchers reveal that they reason from previously encountered solutions rather than from theories or first principles, recognizing the affordances of a solution and using it as a gambit—holding it up to the problem and interrogating the result to refine their view of the problem—then selecting another solution as a gambit, and so on in a tight circle of progress toward the final design (Lawson, 2004a). The knowledge required for this activity is *precedent*, episodic memory of existing designs and other influences, categorized by the designer more and more effectively as her experience grows (Oxman, 1994). Related to this use of specialized knowledge, researchers also observe designers selecting a *primary generator*, a preliminary and strategic idea of how a solution in a given design situation might play out and using this as both a fulcrum and a filter to manipulate other elements of the design problem, revealing and reshaping it in order to handle its complexity (Darke, 1978).

Other scholars address the nature of design situations rather than the nature and behaviors of designers. Goel (1995) discusses design problems as distinct from those that may be rationalized and addressed using regular symbol systems. He characterizes the complexity of design problems in detail, including the critical feature that design problems do not contain the data that will dictate their solutions and they do not include "stopping rules" by which the designer may be assured that a complete solution has been found. Lawson & Dorst (2009) presents a three-dimensional model of the constraints on designs, a view not intended to represent all facets of designing, but one which casts the designer not as a traveler along a winding process path, but as an actor in a space shaped both externally by constraints and internally by the designer himself (p. 131). In this view, designers have to appreciate and impose constraints, and they have to manipulate the conceptual space in which they are working in response to those constraints.

Tatar (2007) describes *design tensions* as a paradigm that conceptualizes "design not as problem solving but as goal balancing. They [design tensions] draw explicit attention to conflicts in system design that cannot be solved but only handled via compromise" (p. 415). These intertwined design tensions assist in organizing rationales about goals and about consequential design choices. Tatar explains that design tensions do not set boundaries or simplify the problem, but provide a framework for creating a space of relevance. Rather than a focus on simplifying a problem, design tensions provide a framework in which the designer can manage complexity and trade-offs.

Designers may also be seen as change agents, rather than simply as creators of artifacts and experiences. The instructional designer's role is to alter knowledge, skill, and/or the performance of the learner (Spector, 2008), which means that they work as active change agents in numerous social and cultural contexts and should be prepared to work in various organizational cultures. Larson and Lockee (2009) in their 2004 *Instructional Design Career Environments Survey*, solicited feedback on preparation and practice of instructional designers, discovering a gap between the culture and value systems of business and industry environments where instructional designers practice and the educational environments in which they are prepared. Design practitioners identified six cultural workplace issues that were challenging in practice including workplace politics, trade-offs between quality, timeliness, and cost, project resources, freedom given to make decisions, employer attitudes toward change, innovation and risk, and workload (p. 18). Strategies identified by faculty in the study to assist in preparing designers to work in various organizational cultures include collaborative teamwork activities to develop interpersonal communication skills (Julian et al., 2000), authentic ID projects involving client relations to promote designer reflection (Knowles & Suh, 2005; Tracey et al., 2008), design cases (Boling, 2010), and case studies (Ertmer & Quinn, 2003) providing designers an opportunity to interact with design problems; and internship/apprenticeship opportunities (Rowland, Parra, & Basnet, 1994).

Schwier, Campbell, and Kenny (2004) address social constructivism, placing the individual designer in learning communities of practice supporting a shared identity, interdependence, and shared culture. Christensen and Osguthorpe (2004), when studying how ID practitioners make ID decisions, discovered designers most often select instructional strategies by brainstorming with others involved in a project. Designers also reported that they learn about new theories, trends, and strategies more often from interactions with their peers and coworkers than by other means. These views point to forms of knowledge shared across designers, not always in tangible ways and not always available for explicit transmission to novice designers. Boot, Botturi, Gibbons, and Stubbs (2008) address yet another facet of designing; the development by communities of designers of languages specific to what they do. Such languages are seen to bring community members together in a shared understanding different than that available through more general discourse, but also to offer a means of considering designs that would not be possible without these languages.

Studio-Based Education

Studio-based education is the norm across multiple domains of design education. Lawson and Dorst (2009) trace the development of university-based design education as it is carried out around the world in multiple disciplines from the days when designers learned their craft as apprentices in the field through the period of "highly conventional pattern of progressive exercises" employed at the … cole des Beaux-Arts and on to the working and learning communities of the Bauhaus and HfG Ulm schools "connecting art and industry through design" and setting the primary features of design schools as we know them today: studio, design tutorial, critique, and libraries of materials (pp. 220–224). Schon (1985) studied this pedagogical pattern rigorously; laying out its features, mechanisms, and benefits, and 25 years later Shulman (2005) has sparked discussion in multiple content areas by arguing that studio-based pedagogy offers distinct advantages for teaching complex performances in the professions. Over a decade ago, Tessmer and Wedman (1995) and Quinn (1995) discussed the potential for studio-based practices in instructional design to provide preparation for instructional designers aligned with evolving conceptions of designing. More recently, Brandt et al. (2010) are studying studio-based design across multiple domains of design education, identifying its key properties and the ways in which they support development of design capabilities in students.

Design education incorporating features of studio-based education has been, and continues to be, practiced in the field of instructional design and technology. Clinton and Rieber (2010) document a 10-year implementation of a studio curriculum at a southeastern U.S. university, focusing on the application of theory to practice in preparing students in instructional design. Three successive masters courses meet together in one common learning space with a team of instructors and a mix of more and less experienced students working side by side. As part of a 6-year study, Boling and Smith (2010) report on the design activities of students enrolled in a studio-based course within an instructional design program at a major U.S. institution. Over the course of the study, structured time in the course (lectures, planned demonstrations, organized discussion) has been reduced to zero, while traditional studio activities (desk critique, group critique, independent project work) have replaced it. Clinton & Hokanson (2011) organized a panel session during the annual meeting of the Association for Educational Communications and Technology at which representatives of five major programs around the country (including the two previously mentioned here) described studio-based experiences in place or soon to be in place to prepare instructional designers for practice.

The Open University offers a design education program at a distance in an effort to offer a universal education model "appropriate to our emerging post-industrial society and technology" (Cross, 2007, p. 45). The program operates on the premise that design education must be accessible to everyone, must be a life-long process in order to keep practitioners up to date and well educated on changing skills and knowledge, and finally, that it is explicit—meaning that design education involves well-articulated and understood principles. The philosophy of the faculty in the program is that design often occurs in an unsystematic way. In an effort to prepare designers for practice, the focus is not on a systematic process, rather the clarification and instruction of elements of design ability.

Lawson and Dorst (2009) do raise questions regarding the assumption that traditional design pedagogy is the best or only way to teach design. Others also entertain questions about the limitations of studio pedagogy (Habraken, 2007), about specific practices in the studio (Anthony, 1991), and about power relationships enacted in the studio (Dutton, 1987). Clinton and Rieber (2010) also report that the Studio experience is not the ideal method to prepare every student. As the faculty state, "The studio curriculum is best suited to those who bring some background knowledge of multimedia development into the program with them" (p. 775). For novice students with no prior background, this preparation approach may be most beneficial after successful completion of other design experiences providing students with the background necessary for the studio. In an earlier report on their studio experience, Boling and Smith (2009) discuss the design tensions accompanying the incorporation of studio experiences into a traditional curriculum, including the problems of securing appropriate space, shifting perspectives as an instructor, and managing student expectations in a setting unusual for them.

Emerging Concepts in Design Education

Recently, whole-task models, "instructional models that apply a holistic approach in which complex contents and tasks are analyzed and taught from their simplest yet, still meaningful, version toward increasingly more complex versions" (Van Merrienboer & Kester, 2008, p. 442) have been introduced in response to criticisms of teaching learners complex concepts too simply. This holistic approach to present instruction to learners may also be a design approach for instructional designers. According to constructivist theories, it is important to apply a holistic or systemic approach that considers all of the instructional factors in increasing detail throughout the design process (Kirschner et al., 2002). Applying holistic design may include a systemic approach, or one where you begin with the finished product in mind and work backwards, then continue to circle throughout the design and repeatedly revise the instruction (Gibbons & Yanchar, 2010).

Efforts continue to improve traditional instructional design education and to explore the question of expertise development in our local domain. Ertmer, York, and Gedik (2009) are working to incorporate the experiential knowledge of expert designers into the curriculum, correlating this knowledge with existing standards. Hardre, Ge, and Thomas (2006) examine the multiple dimensions of students studying instructional design for their effects on the development of expertise, suggesting that design education be responsive to these differences.

Newstetter and McCracken (2001b) discuss, not a specific approach to design education, but the need to develop a science of design learning through posing and answering difficult research questions regarding how design happens "that have dogged design researchers over the last thirty years" (p. 3). This effort from within our field echoes the earlier effort by Cross, Christaans, and Dorst (1997) to investigate valid methods for exploring design cognition and activity by setting up rigorously prepared design sessions and capturing a rich data set from them, then giving these to multiple researchers who then presented and published their separate analyses. The emerging approach in both of these cases is to focus on studies of designing before creating or recommending tools for designing or methods for teaching design.

Future Research

Two gaps are apparent in our knowledge regarding the preparation of instructional designers; one involves the basis for that preparation—understanding how designers actual work—and the other involves development and validation of methods for teaching the complex performance that is design.

Broad and intensive study of competent design practice in the field is needed. This investigation must be carried out in a spirit of curiosity and exploration, asking what designers in the field do, rather than measuring them against what academics think they should be doing. We need, as part of this effort, to identify and describe the conceptual tools actually used by practicing designers. We need descriptions and models for aspects of designing in our field that move beyond process to describe designers and design teams, the individual activities and tools of design, and the mechanisms of invention. These should be viewed as tools of scholarship and tools for expert designers, and not simplified into starting points for novices who are forming their design character.

We also need to conduct empirical studies of the effect that methods used in design education have on the activities and thinking of novice designers during their studies, as well as on those same designers as they practice in the field. We need a detailed examination of the progression from novice to competent and expert practice by instructional designers, bearing in mind that this progression will not be monolithic but will be affected by those who study with us and the varied experiences they bring with them.

Conclusions

In 1999, Nigel Cross concluded his contribution to a special issue of *Design Issues* devoted to research in design observing that "We still know relatively little about the mystery of design ability … this is the goal for design research" (p. 10). Since then, Lawson and Dorst (2009) have built on multiple studies, most carried out in architecture and product design and examining the actual nature of designing, to present several models of designing intended to be used in tandem to consider the education that will build design expertise. In this field research is needed specifically to expand and enrich our understanding of designing as designers carry it out, to provide the foundation on which we prepare our designers for practice.

Such research will describe what designers are doing as they work, rather than producing more guidelines for how they should work or what decisions they should make. As Holt (1997, p. 120) noted in discussing engineering design education, when an exclusively scientific world view—or "attempts to fit design education into a … scientific mould"—dominate, "the exercise of judgment is reduced to choosing the right formula." He points out that "every advance, or change of direction, in the design process is the result of the designer's judgment. But the notion of judgment is somewhat elusive" (p. 113). This remains the case today, and part of the research agenda related to design education in the field must focus in this direction.

These foci in research are prerequisites to effective design education. Systematic study is also required to determine, in the context of instructional design education, how novice designers conceive of the activity of design and of problems in design and their solutions. Study is required to understand when and how students of instructional design develop these views, what obstacles exist for them in the development of professional judgment and character, and how they surmount those obstacles in the course of their education. Studio education, as applied to the preparation of instructional designers, needs to be studied as it is practiced to determine the effective adaptations that can be made to the basic pedagogy and the limitations it presents for this field. Studies will need to be carried out among students of instructional design who are simultaneously employed in the field to understand their dual development as professionals and student-professionals.

Although such an agenda may be lagging 20 years behind the research in traditional fields of design, if we begin to focus on these efforts, we may be able to use emerging perspectives on preparing instructional designers to improve practice in the field.

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Technology-Based Instructional Design: Evolution and Major Trends

53

Gilbert Paquette

Abstract

This chapter surveys ICT-based tools and methods that support instructional designers in planning the delivery of learning systems. This field has evolved since the 1970 through several paradigms: authoring tools, expert systems and intelligent tutoring systems, automated and guided instructional design, knowledge-based design methods, eLearning standards and social/cognitive Web environments. Examples will be given to illustrate each paradigm and the major trends will be uncovered. ICT has evolved rapidly, enabling new approaches to emerge, helping more people to design learning environments and building learning design repositories. More and more people are learning on the Web, using learning portals, information pages and interacting with other people, but still with insufficient educational support. New challenges make this field an exciting and blooming research area that has a bright future.

Keywords

Instructional design • Instructional engineering • Knowledge-based design • Educational modeling • eLearning standards • Web-based learning environments

Introduction: Defining the Field

Some authors trace the origin of *Instructional Design* to John Dewey, who, a century ago, "called for the development of a linking science between learning theory and educational practice" (Reigeluth, 1983, p. 5; Dewey, 1900). Others (Dick, 1987) situate the beginning of ID after World War II. But it is really at the beginning of the 1960, that we see the beginning of the new discipline, mainly under the influence of the work of B. F. Skinner on programmed instruction, Jerome Bruner on the cognitivist approach and David Ausubel (Reigeluth, 1983). In the 1970s and 1980s, research on instructional theories blossomed as illustrated by t he: (a) the development of a cybernetic approach (Landa, 1976), (b) the exposure of learning conditions (Gagné, 1985), (c) the identification of instructional strategies based on structural learning theories (Scandura, 1973), (d) the development of a cognitive teaching theory based on enquiries (Collins & Stevens, 1983), and (e) the analysis of instructional strategy components (Merrill, 1994).

Based on these various research efforts, Instructional design is today a collection of theories and models helping to understand and apply instructional methods that favor learning. Instructional Design as a method or a process helps produce plans and models describing the organization of learning and teaching activities, resources and actors' involvement that compose an instructional system or a learning environment. Compared to the theories developed in educational psychology, instructional design can be seen as a form of engineering aiming to improve educational practice. Its link with educational science is analogous to the link between engineering methods and the physical sciences, or between medicine and life sciences.

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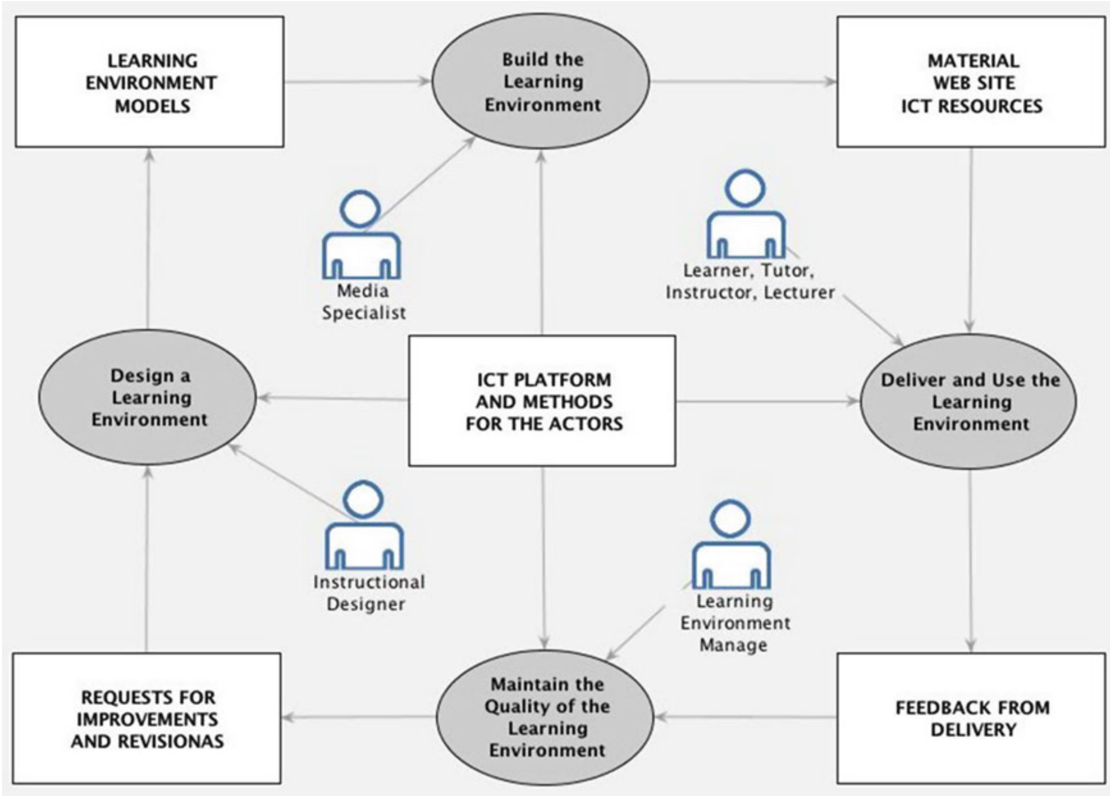

Fig. 53.1 The basic life cycle of a learning environment

The life cycle of a learning environment is presented in Fig. 53.1. This figure shows four main processes going from creation or design, production of a learning environment, and then to its delivery. Finally, a maintenance and revision process serves to detect deficiencies revealed by the delivery of the learning system, leading to improvements proposed to the instructional designers, closing up the loop and starting a new cycle.

Figure 53.1 also shows the products of each process and the main actors that produce them. While there is a sequential progression between these main processes, it is best to picture the global process with subprocesses more or less parallel, sharing information between them with frequent interaction between the actors. In this chapter, we will focus on the instructional design (ID) process, methods, and support tools, but in some case, we will identify the interaction of pure ID with the other three processes, in particular with the production process.

Using this general picture of an instructional system, the following sections will present the main paradigms that propose ways to use information and communication technologies (ICT) to support the instructional design process. These paradigms are authoring tools and languages, knowledge modeling of instructional design methods, automated and guided instructional design, eLearning standards and social/semantic Web environments. Finally, in the last section, we identify the major trends and issues, synthesizing the evolution of Technology-Based Instructional Design.

Authoring Tools and Languages

The use of computers in education started 50 years ago, at the beginning of the 1960s. The first applications were influenced mainly by programmed instruction strategies (Crowder, 1959; Skinner, 1954). Most authoring tools and languages for computer-assisted instruction were limited to present information, ask a question and branch to another unit. Two early authoring systems attempted to go beyond such simple templates, in order to provide more complete learning strategies.

One specialized programming languages, TUTOR, was developed starting in 1965 for use on the PLATO system at the University of Illinois at Urbana-Champaign. TUTOR had powerful answer parsing and answer judging commands, and it had features to simplify student records by instructors. TUTOR's flexibility, in combination with PLATO's computational power (running on what was considered a supercomputer in 1972), also made it suitable for the creation of games and simulations that could be used for learner-centered education.

Later, templates were developed to ease the programming part of courseware creation. For example, (Schultz, 1975) presents MONIFORMS, a set of partially completed coding formats in the TUTOR language that could be adapted by instructional designers in order to implement instructional tactics.

The TICCIT system (Merrill, Schneider, & Fletecher, 1980) attempted to provide built-in complex instructional templates in the mid 1970s. The student had access to a set of learner-controlled keys: Rule, Example, Practice, Objective, Help, Advice, Easy, Hard, and Map. The author provided information accessible behind these keys, to be displayed to the student studying some the rules and concepts for which the information provided. The system also provided a map or hierarchy diagram from which the student could choose the next content to study, but with some help from the system.

With the advent of multimedia and Internet technologies, there has been an explosion of the number of authoring tools. Widely used commercial tools have included Macromedia's Authorware, IconAuthor and Click2Learn's ToolBook. More recent learning content management systems (LCMSs), such as BlackBoard, Learning Space, TopClass, WebCT, and Moodle, are totally oriented towards building Web-based courses. There has been also a proliferation of authoring tools providing templates. However, not many of them offer multiple instructional strategies (Liao, Lo, Oyuki, & Wing Li, 2003).

Moreover, while LCMSs, authoring tools or templates help produce resources for delivery environments based on the more or less limited set of strategies they support, they are essentially helping in the production process. They do not provide much support for instructional designers to analyze learning needs, structure target knowledge and competencies, integrate resources in learning scenarios or plan the production of resource and delivery environment. In particular, they provide no help to select teaching/learning strategies before deciding which authoring tools or templates should be used.

Modeling Instructional Design and Job Aids

With the evolution of technology-based learning, the instructional designer must make a larger set of interrelated decisions. What kind of delivery model shall we use: classroom, Web based, blended? What kind of learning activities do we need for this course? Should it be predefined, offer multiple learning paths or be learner-constructed? Which actors will interact at delivery time, what are their roles, what resources do they need? What kind of interactivity or collaboration should be included? What materials can be reused, adapted or built anew? How distributed resources are to be managed on the networks? What kind of eLearning standards will be used? How can we support interoperability and scalability of the learning system? How can we promote their reusability, sustainability and affordability? To cope with all these decisions and others, an instructional design methodology and a tool set are needed more than ever.

The MISA instructional systems engineering method (Paquette, Aubin, & Crevier, 1994; Paquette, 2004) is a long-term effort to address these new needs of the instructional designers. It has provided a mature methodology at the turn of the century that continues to evolve. As shown in Fig. 53.2, MISA is structured into six phases and four axes under which the main 35 design tasks and their subtasks are distributed. The four axes are deployed from construction of the model or document its properties.

The MISA method is the result of applying knowledge engineering to the instructional design domain. Using the MOT language and editors, the products, the task and the principles of instructional design have been modeled and their interactions identified. The relationship between tasks is represented using a process graph for each of the phases and each of the axes. The design documents produced by each of the 35 main tasks are modeled as concept objects with a certain number of attributes that have well-defined values. The knowledge model describing MISA ensures the consistency of the method. It also help guide the navigation of the designer through the method. Contextual help or intelligent advice can be given by a supervisor or a software agent for each design task, based on the relationships between it and the other tasks in the method and also on the consistency of values for the different attributes in a design document.

The complete model of the MISA method enabled the production of computerized Job aids or design tools. The first one was AGD, a standalone performance support system for ID (Paquette et al., 1994). Later, an improved version of MISA enabled the construction of job aids as a set of Word and Excel templates, supplementing the MOT visual knowledge editor. In 2001, a WEB tool, ADISA was built and is presented in the next section. More recently, MISA/ADISA design scenarios can be edited and processed by the ontology-driven TELOS system (Paquette & Magnan, 2008).

Expert Systems and Automated/Guided ID

Beginning also in the 1990s, expert systems and artificial intelligence techniques started to be applied to the field of instructional design to provide methodological support and intelligent help (Winkels, 1992) to instructional designers. Many expert systems were built for focused ID tasks where they have had generally more success than more general applications (Locatis & Park, 1992). A second category of systems is concerned with helping designers construct Intelligent Tutoring Systems (Wenger, 1987); the Generic

Phase 1- Definition	100 Organization's Training System; 102 Training Objectives; 104 Learners' properties; 106 Present Situation; 108 Reference Documents			
	Knowledge Axis	**Pedagogy Axis**	**Media Axis**	**Delivery Axis**
Phase 2 – Initial solution	210 Knowledge Model Principles **212 Knowledge Model** **214 Competencies**	220 Instructional Principles **222 Event Network** 224 Learning Unit Properties	230 Media Principles	240 Delivery Principles 242 Cost-Benefit Analysis
Phase 3 – Architecture	*310 Learning Unit Content*	**320 Learning Scenarios** 322 Activity Properties	330 Development Infrastructure	340 Delivery Planning
Phase 4 – Detailed Design	*410 Learning Resource Content*	420 Learning Resource Properties	430 Learning Resource List **432 Media Models** 434 Media Elements 436 Source Documents	**440 Delivery Models** 442 Actors and resources 444 Tools and Telecom 446 Delivery Services
Phase 5 – Eval	540 Test Planning; 542 Revision Decision Log			
Phase 6 – Delivery Plan	610 Knowledge/ Competency Management	620 Actors and Group Management	630 Learning System/ Resource Management	640 Maintenance/ Quality Management

Fig. 53.2 Overview of the MISA instructional system design method

Tutoring Environment (GTE), is a good representative of that category of system (Elen, 1998). We will here focus on a third category of Expert System applications that aim to support the general Instructional Design process. We present here three of them:

- ID Expert (Merrill, 1998), an expert system for designing courseware, which evolved into a commercial system called Electronic Trainer
- GAIDA/GUIDE (Spector, Polson, & Muraida, 1993) provides a guided approach to ID Advising
- Templates and the intervention of an intelligent advisor

The purpose of ID Expert and Electronic Trainer is to provide a consultation system that could be used by inexperienced instructional designers to assist in instructional design decision-making, prior to the programming stage. The expert system gathers information from the user/designer and makes recommendations on the goal of instruction, the content structure that corresponds to the goal, the elaboration of the content structure, the modules that are necessary for teaching the content, the instructional transactions that are best for each module and guidance for elaborating and instantiating each transaction. The output of the consultation is a design specification that provides a skeleton from which instructional materials can be built. The domain of the first ID Expert was limited to goals involving concept classification with a kind-of taxonomies content structure and goals involving procedures for device operation with a path algorithm content structure. ID expert 2.0 extended the initial set of goals and provided a delivery interface. The commercial Electronic Trainer linked the ID expert to authoring capabilities that produced the corresponding learning material. Unlike many expert systems, which are directed toward a single main decision, the ID expert makes recommendations on a series of decision and allows the designer to confirm each recommendation as the reasoning proceeds.

The GAIDA advisory system was developed to support lesson design as part of the Advanced Instructional Design Advisor project at Armstrong Laboratory (Spector et al., 1993). The system uses completely developed sample cases to help less experienced instructional designers construct their lesson plans. GAIDA is designed explicitly around the nine events of instruction (Gagné, 1985). It allows users to view a completely worked example, shown from the learner's point of view (see Fig. 53.3). The user can shift from this learner view to a designer view that provides an elaboration of why specific learner activities were designed as they were.

ADISA is the successor of the AGD system. It is a Web-based system developed to enhance the performance level of instructional designers, in particular to assist teams who

Fig. 53.3 A screen from GAIDA/GUIDE

create Web-based distance learning courses. It embeds a large set of educational knowledge including 17 typologies of educational concepts from the MISA 4.0 method, each offering a set of options for the designer to choose from. It provides an editing part for 35 documentation elements (DE), either forms or graphic models to be produced by tasks of the MISA method. An important feature is the data propagation from one DE form or model to another, based on the MISA 4.0 process models.

What can be learned from the research on automated or semiautomated ID systems? First, productivity improvements have been observed due to performance support

While results vary, using design support tools can achieve an order of magnitude improvement in the productivity of a design team. Second, learning can result for designers using such systems. GAIDA has been evaluated in numerous settings with both novice and expert designers (Gettman, McNelly, & Muraida, 1999). Findings suggest that expert designers found little use for GAIDA, whereas novice designers made extensive use of it for about 6 months and then no longer felt a need to use it. MISA/ADISA has been used by novices and experienced designers for a variety of domains ranging from well-structured to ill-structured knowledge domains (e.g., training lawyers). Paquette and colleagues (2004, 2010) found consistent improvements in both productivity and consistency of the ID products. But probably the most important result gained from these systems is the deeper understanding of ID concepts, processes, and principles. To build these systems, operational expertise in ID must be uncovered, implemented, validated, and again improved in successive versions of a system through its use in various knowledge domains.

eLearning Standards for ID

As the number of ICT-based learning platforms or authoring tools increases during the years, reusability has become more important. The goal is to enable the reuse of learning objects (or resources) in new educational contexts across a variety of e-learning delivery systems. This goal requires standard ways to describe and store learning objects or educational resources. The elaboration of international standards for learning resources has been initiated by organizations such as IMS global, IEEE-LTSC, AICC, and ISO. Duval and Robson (2001) presented a review of the earlier phases in this evolution of standards including the Dublin Core metadata initiative up to the publication of the Learning Object Metadata (LOM) standard by IEEE in 2002. Since then a host of other specifications have been published by IMS Global1. ISO has started publishing at the end of 2010 the first documents of its new Metadata for Learning Resource (ISO-MLR, 2012) standard, based on the W3C (2004) Resource Description Framework (RDF).

The work on Educational Modeling Languages (Koper, 2001), and the subsequent publication of the IMS Learning Design Specification (Griffiths, Blat, Garcia, Votgen, & Kwong, 2005; IMS-LD, 2003; Koper & Tattersall, 2004), is the most important initiative to date that integrates instructional design modeling into the international standards movement. This specification is a formal way to represent the structure of a Unit of Learning and the concept of a pedagogical method. A basic learning design involves three kinds of entities with relations between them: actor's roles, activities and environments grouping learning resources and services. Activities, performed by actors are organized in a tree structure called a method, decomposed into alternative plays, each decomposed into a series of acts, further decomposed into activity structures down to terminal learning or support activities.

IMS-LD embeds and generalizes other IMS specifications such as MD (metadata), SS (simple sequencing), CP (content packaging), RDCEO (learning objectives and prerequisites), QTI (questionnaires and tests), LIP (learner information profile) and others. SCORM, the Sharable Content Object Reusable Model supported by the ADL Technical Team (2004), can be seen as a specialization of IMS-LD to single-user simpler hierarchical activity structures. IMS-LD expands SCORM specifications in many ways:

- IMS-LD describes methods as multiactor workflow processes
- IMS-LD can provide alternative plays adapted to different target populations
- IMS-LD integrates the description of collaboration services
- IMS-LD integrates (at Level B and C) some user modeling and cross-users notifications
- Most important, IMS-LD favors instructional strategies like collaborative learning, problem solving, project-based learning, communities of practices, and multifacilitators support as found in more advanced learning strategies

With regard to the tool set, a form-based tool, RELOAD (2004), was an improvement from previously used XML editors, but it imposes too many constraints on the design process. Visual representation techniques and tools aim to free instructional designers from these constraints. Although well suited for software engineering purposes, UML graphs and diagrams, as proposed by the Best Practice and Implementation Guide (IMS-LD, 2003), pose many difficulties for instructional design. There exists more user- friendly instructional visual design software like LAMS (Dalziel, 2005), or the first MOT knowledge editors. These are useful in an inception phase, but cannot produce compliant IMS-LD executable files. This has led the construction of new visual design tools like the MOT+LD specialized editor (Paquette et al., 2005) and, more recently, the G-MOT scenario editor, the central aggregation tool in TELOS (Paquette, 2010a, 2010b).

Besides their strong influence on the standardization and interoperability of authoring tools, IMS-LD and other eLearning standards have also helped stress the importance of instructional design. IMS-LD is just a reusability format, but it has opened the spectrum of possible learning strategies that can be supported by standardized authoring tools. So the need becomes more evident for front-end methods and tools to support designers in producing high quality Learning Designs. Furthermore, the learning object paradigm has move the focus towards aggregating resources and interactions, instead of producing more text, multimedia, or Web-based document. In this new approach to ID, the learners and the facilitators are resources themselves, interacting within activities using and producing learning resources, a more cognitive and constructivist process than simple information transmission.

Social/ Semantic Web Environments

In the last decade, the now-ubiquitous Web has evolved through overlapping generations that are most of the time called the *Information Web*, the *Social Web (Web 2.0)* and the *Semantic Web (Web 3.0)*. Web 2.0 technologies are there to stay because they make the use of Internet a brand new social experience, just as the first Internet browser did 15 years ago with information access. Semantic Web technologies have the same potential to dramatically improve Web 2.0 activities that are often limited to superficial chats or simple information transmission. The new Web 2.0 and Web 3.0 technologies have an enormous potential if they are blended to support knowledge-intensive social processes.

This is now a very active research area internationally that corresponds to individuals' and organizations' needs. Here are a few research orientations that will orient the future of Web 2.0/3.0 learning environments and learning design:

1. *Modeling knowledge-Intensive social processes*. Both for work and educational scenarios, much attention is given today to multiactor workflows, but leaving aside the crucial issue of knowledge and competency acquisition that occur during these processes. On the contrary, knowledge and competency models must be at the forefront of the new learning environments to enable a transfer of competency from content experts to learners or to novice workers through collaborative knowledge exchanges. Unexplored research problems occur when the scenario or workflow is built while collaborating, in an emergent way such as in project-based learning where the learners become their own designer.
2. *Taking into account knowledge contexts of use, privacy, and trust issues in collaborative learning processes.* A huge amount of information is available for learning but it is locked from potentials users due to security and privacy concerns. These problems must be solved especially for the mobile learners whose location, device limitations, and task at hand change all the type. Context

model must be linked to task models and knowledge/competency models.

3. *Personalizing learning environments and creating more intelligent tools*. Nowadays, the abundance and popularity of Web applications, such as blogs, discussion forums, social and professional networks pose a great challenge. Web personalization and recommender systems are two important areas that attempt to cope with such information overload problems. Web personalization systems organize the Web environments based on the users' personal interests and preferences. Recommender systems suggest information, products or peer-to-peer communication in accordance with the user's personal demands and properties.
4. *Building Semantic Media User Interface*. The continued growth and importance of the Social Web has resulted in information taking many forms, including text, images, video, and more recently augmented or virtual reality environments such as Second Life. Furthermore, this information is accessible through desktop and laptop computers, and through intelligent mobile phones or tablets that bring unique constraints in terms of computing resources and user interfaces. The vast amounts of data coming out of the Social and Semantic Web entails a need for more intelligent human interfaces and visualization capabilities.
5. *Aggregating Social-Semantic tools into Learning Environments.* Data Mashups have been identified by the Horizon study (2008) as one of the leading trends for 2010–2011. Using social environments like Facebook or Wikipedia, users become Web designers, assembling text, pictures, and sound according to their needs. The issue of learning quality then comes to the forefront, while the impact of these new technologies on ID methods and tools must be investigated.

The Social and Semantic Web shapes the new learning environments, posing new challenges to Instructional Designers, fostering the need for new advances in the ID methodology and tool set. One interesting approach is to see instructional design as a knowledge-intensive collaborative multiactor process where the actors interact within a Web 2.0/3.0 environment to assemble actors, activities, and resources for learning or knowledge management.

In such a setting, personalized assistance must be given both to designers and to the user of the learning environments they produce based on semantic Web techniques, an area part of the *Adaptive Semantic Web* (Dolog, Henze, Nejdl, & Sintek, 2003) that we call *Ontology-Based Assistance Systems*. Recent research on assistance systems at LICEF (Paquette & Marino, 2011) proposes that advisor agents be grafted on environments/scenarios, built in the context of the TELOS system (Paquette & Magnan, 2008; Paquette, Rosca, Mihaila, & Masmoudi, 2006). TELOS is a service-oriented, ontology-driven system that helps build online environments for learning or for work. Its basic principle is the aggregation of resources into visual activity scenarios. In TELOS, the task model (the scenario) may represent multiactor processes or workflows integrating a variety of control patterns between tasks or activities such as splits and joins. These scenarios can be intended for any kind of actors: for engineers who aim to extend the services given by the system, for technologists who build designers' platforms, for designers who built courses or work scenarios and for the final users who interact in these scenarios.

Figure 53.4 presents the upper graph of a design process (build by an educational technologist) to help designers produce IMS-LD compliant designs: in the first activity, a designer produces the upper structure of a learning scenario (i.e., a method); in the second one, each Act in a Method is identified and defined; in the third one, a scenario model is built of each act as well as a knowledge/competency model and the association between the two structures. This third activity has a complex submodel not shown on the figure where knowledge and competencies are associated with actors, activities and resources.

When such a scenario is executed by TELOS, a Web environment is produced for the members of a design team to help them produce a learning environment model intended for learners and facilitators, to be run in the same way by the TELOS system.

Trends and ID Issues

As a conclusion, I present here four trends in methods and tools for instructional design with a set of corresponding issues that present today a challenge to the field.

From Tutoring to Open Learning Design

As shown in section "Introduction: Defining the field", at the advent of ICT in learning, it seemed natural to use ICT for the creation of learning programs. The terms CAI (Computer Aided Instruction) and CBT (Computer-Based Training) put the focus on instruction instead of learning. In this paradigm, the computer program was the teacher or a teacher aid, displaying information, asking questions and presenting more information depending on the learner's answers to previous question. Respecting the learners' pace and adapting to its answers was advocated in support for this approach. But soon, ICT in education evolved towards a more learner-oriented focus. Typically, learners would interact with computerized simulations and games, solve problems by programming the computer, search for relevant information or realize projects using software tools like text/graphic editors, database or

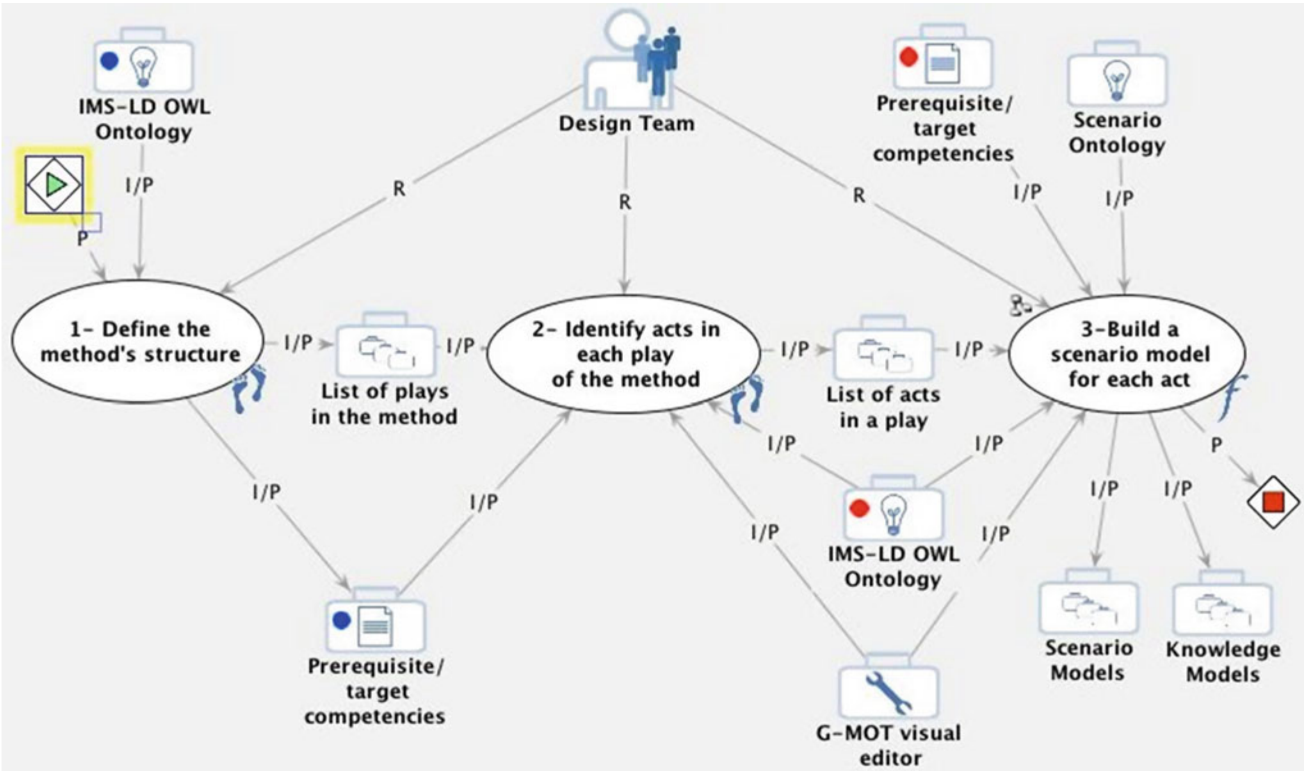

Fig. 53.4 A multiactor design scenario

spreadsheets. Nowadays, even though there are many programmed instruction courses that are useful in some cases, the trend is clearly towards more open environments where the learner uses the computer as a tool instead as a static and rigid teacher. Typically, a set of ordered activities, a scenario, is provided on the Web, where the learner is invited to find useful information on the Web, to use computer tools or to program the computer to address some question. Supporting this trend, the Web acts as a universal encyclopedia, provides a highly interactive communication system between learners and teachers, presents aggregation functions for the end user to assemble it own environment and e-portfolios.

This evolution brings to light some provocative ID issues. The first one is the challenge made to instructional design as a process distinct from delivery, some proponents even advocating the end of ID. On the contrary, others pretend that the new possibilities offered by the Web must be planned even more carefully if we want open environments to provide quality learning. Just like software engineering has brought quality that could not result from hasty coding, should not instructional engineering provide support to cope with complexity, with the larger set of decisions that face designers? But the emphasis in ID now has to shift from simply organizing information to designing activity scenarios and communication between learners and facilitators based on sound and well-proven instructional strategies and methods.

A second important issue is the quality of the information available for learning, whether the learner or teacher selects it. We are in an expanding context of billions of pages available on the Web, some providing unreliable information. On the Web, we find the good, the bad and the ugly. One solution that has been proposed is the use of learning object repositories composed of high-quality educational resources, available using metadata standardized descriptions. But this solution still has a long way to go to become mainstream.

A third issue is the support of learners in their Web-based activities. Too many times, teachers or designers will propose Web-based activities without any support, relying on the younger generation's abilities to use the Internet. Young or adult learners need support to find useful and reliable information, to learn how to communicate within the social Web, to understand the possibilities and limit of technology and their own meta-competencies in using it. Instructional designers must be supported in providing guidance on these questions, even more if the learning environment that they are planning is open and learner-centric.

From Automating to Supporting Instructional Design

Most persons designing instruction are not trained in instructional design. To address this problem, a number of researchers started building systems that could be used by inexperienced designers in their instructional design decision-making process, prior to the production stage. The general idea in the systems presented in section "Modeling Instructional Design and Job Aids" was to have a designer interact with an expert system enhanced with ID knowledge that could recommend design components to be used for the definition or production of a learning environment. So the term "automated design" seems a bit exaggerated. In fact, the design was the result an interaction between the designer and the system acting as a companion or as a tool. So the process was semiautomated. As mentioned earlier, these semiautomated systems have been used in a number of organizations where they have increased the productivity of designers and helped train new designers. Their main achievement was the production of a considerable amount of ID knowledge, but they were only marginally successful, mainly because of their complexity and their lack of flexibility and adaptivity.

These issues can be addressed by building support environments for designers in the form of mash-ups produced using workflow or scenario editors. Such editors produce executable sets of design tasks linked to tools and documents from various sources, operated by the actor(s) that perform the tasks. These scenarios can be limited in complexity, adapted to individual or team work, range from a single task to larger series of design tasks, adapted to the needs of a designer, a design team or an organization. From time to time, tasks can be reordered in the design scenario, support documents and tools can be replaced, participating actors can be added, deleted or tasks can be redistributed among actors, thus providing the needed flexibility for adaptation to a design context.

From Individual to Distributed and Collaborative ID

The first generation of instructional design tools and methods were intended for individual teachers at the design phase or in the production phase of a learning environment. Typically, an individual would sit in front of a single computer and interacts with a single software, building a design model and/or producing a CBT courseware. In more recent distance learning systems and LCMSs, the focus is also on individual designers; however, the design software is Web-based and can integrate resources available anywhere on the Web in addition to the tools provided by the LCMS. Still, the most widely used design/production environments like WebCT or Moodle do not support teamwork very well. They do not integrate an ID method. In fact, they provide generally a single set of design tasks aiming at the rapid production of a Web-based environment.

Methods like MISA and the IMS-LD specification presented above integrate a multiactor design process, taking in account the fact that in distance education and company training, the learning environments are usually designed and built by a team with members playing different roles. This links well with Web 2.0 software such as Wikipedia or GoogleDocs where documents can be built collaboratively. Flickr and YouTube offer repositories of pictures or videos to be populated by a design team. Facebook can provide some collaborative support to a design team. These social software tools must of course be integrated into design scenarios implementing parts of an Instructional Design method to produce, for example, SCORM or IMS-LD interoperable learning environments. Bringing all these elements together can provide a stimulating distributed and collaborative ID environment.

From Information-Based to Knowledge Model-Based ID

If we go back in history, preparing instruction has been mainly based on information processing. A scholar would read extensively, think a lot and synthesize large amounts of information into content documents or lectures that could be communicated to learners and novices, hopefully in a pedagogical way. Preparing lectures has been done and is still being done by most professors in much the same way, except that now the Internet provides a web of information sources. But we are now in the knowledge age where the exponential growth of available information is the rule. The use of an ever larger set of components makes the task of designing instruction much more difficult.

There are many reasons for instructional design to evolve towards ontology-based educational modeling (Paquette, 2010a, 2010b). First, within the Semantic Web framework, resources on the Internet can be described by the knowledge they support using domain ontology models. Moreover, learning environments must have a structured executable representation of the knowledge to be processed in order to help users based on their present and expected state of knowledge and competency. A third reason is that the learning process or scenario is also the result of a knowledge modeling activity using an educational modeling language. Knowledge-based ID focuses on the interaction between two models: a knowledge model of a domain (usually an ontology) that is the subject of learning and instruction, and a process model (generally a multiactor workflow or scenario) of the learning and teaching activities grouping tasks, resources used and produced by actors in the scenario. These scenario components are referenced by knowledge and competencies described in domain ontologies. Such model-based ID is necessary to cope with the inherent complexity of instructional design today, while providing flexibility and adaptability.

Conclusion

We have underlined some of the difficulties of instructional engineering, taking into account the great number of factors the designer must consider, and the constraints he must work with. Beyond the possible improvements mentioned above, it is important to develop various means of adaptive assistance for instructional engineering and to integrate them to computerized tools that support designers. This assistance cannot rest only on templates and model libraries. The implementation context must also be taken into account.

It is not easy to implement any method in an organization. It suffices to consider the time it took to convince programmers and their customers to adopt software engineering methods. The increasingly complex and vital character of information processing systems, however, provides strong arguments in favor of the adoption of such methods, making gradually anachronistic the spontaneous programming approach that marked the first decades of software production. In the field of instructional engineering, we haven't reached this point yet, although we can already see that during the next years, the same type of evolution will be increasingly necessary due to the demands of the knowledge economy. Still, ICT-based instructional engineering has a promising future for practical use in organizations. It remains also a challenging and rewarding research field.

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Section VII
Emerging Technologies

M.J. Bishop and Jan Elen

While instructional technologists must avoid the temptation to allow any technology to drive pedagogical decision making, there is little question emerging technologies bring along with them new opportunities and affordances upon which we can capitalize (for a complete review, see Clark, 2001). The purpose of this section of the Handbook, therefore, is to present research on new technologies, especially with regard to their potential impact on learning and teaching.

Given that the technologies presented in this section are quite new, in many cases the reader will discover that the research presented in these chapters will be somewhat limited. When that is true, chapter authors have indicated where questions remain about those specific technologies with regard to their application to teaching and learning and have provided insights into how one might conduct research in those areas. It is important to note that one apparent theme across many of these authors' research methodology recommendations is the movement away from randomized controlled trials in sterile lab-based settings toward the use of mixed-methods design research conducted in realistic, applied environments. While studies conducted in naturalistic settings are often expensive, conceptually difficult to conduct, and sometimes less "productive" in terms of theoretical insights, many of the authors in this section argue that this is the best approach to truly understanding how emerging technologies might help to optimize learning from the environments we design.

The first four chapters in this section are grouped together because their focus is largely on new hardware devices that promise to broaden our perspectives on instructional technologies beyond computer-based delivery with which learners interact via traditional mouse- and keyboard-based input in hopes of some digital or paper-based output. For example, recent developments in desktop manufacturing technologies allow one to design 2D and 3D objects on the computer screen, and then "print" them out on a fabrication device as tangible products. While these systems have only recently become affordable for schools to purchase, Glen Bull, Jennifer Chiu, Robert Berry, Hod Lipson, and Charles Xie argue that they hold great promise for enhancing pedagogical approaches to science, technology, engineering, and mathematics (STEM) topics. Their chapter discusses these possibilities and points readers to the many fruitful avenues of research to be done in this area, particularly those aimed at helping teachers understand how to capitalize on these technologies to optimize learning.

Next, Michael Evans and Jochen Rick explore recent developments in interactive surfaces (tablets, tabletops, whiteboards) and spaces (smart rooms) with which learners manipulate digital information directly with their fingers, feet, and other body movements as opposed to traditional mouse-and-keyboard-mediated interactions. The authors argue that these "natural interfaces"—many with multiple access points for groups of learners to collaborate—provide unique opportunities for designers to support colocated collaborative and more kinesthetic learning experiences. The authors discuss the technology development projects under way, review the existing empirical research to date, and point to the additional work needed to advance educational practice in this area.

The next chapter explores "smart toys," which Kursat Cagiltay, Nuri Kara, and Cansu Cigdem Aydin define as toys that facilitate two-way interactions between the child and toy in order to carry out purposeful tasks. The authors suggest that, because these toys can potentially have significant effects on children's cognitive development, they should be designed and developed from a strong foundation in developmental theory. This chapter, therefore, explores the relationships between smart toys and children's developmental stages.

In the last of the hardware-specific chapters in this section, Ann-Louise Davidson and Saul Carliner explore e-books and their affordances within learning contexts.

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Granted, e-books are not necessarily hardware specific—the authors suggest that any device that can open e-book file formats in some sort of "reader" application might be considered an e-book. However, the proliferation of e-book-specific devices like the Kindle and Nook muddies the existing research in this area and continues to make it difficult for educators to know what direction to take when considering adoption in school-based settings. In this chapter, the authors help to clarify where the technology currently stands, discuss the issues, and suggest areas for future research.

The remainder of this section moves away from hardware-specific technologies in order to explore applications that are more or less device independent. For example, the next two chapters explore the opportunities that virtual worlds and augmented reality technologies present for contextualizing learning. First, Lisa Dawley and Chris Dede review recent developments and design considerations for creating virtual worlds and immersive simulations intended to enhance learners' engagement and situate learning. Then Matt Dunleavy and Chris Dede continue the discussion by focusing on the use of augmented realities, which enable participants to interact with digital information embedded within the physical environment. The authors suggest ways these technologies can be used to scaffold authentic inquiry, active observation, peer coaching, reciprocal teaching, and legitimate peripheral participation among groups of learners.

Next, Yu-Chang Hsu, Yu-Hui Ching, and Barbara Grabowski review Web 2.0 communication tools and technologies and explore their affordances for instructional contexts from a "learning through collaboration" lens. While their review uncovers many promising classroom-based practices for Web 2.0 applications such as blogs, wikis, collaborative documents, social networking, video sharing, and the like, the authors also identify many unexplored opportunities and challenges to be addressed in terms of both research and practice. They suggest further that until we understand more about how these technologies can enhance learning experiences, we will not realize the real potential of Web 2.0 applications for instruction.

According to George Veletsianos and Gregory Russell, "pedagogical agents" are "anthropomorphous virtual characters employed in online learning environments to serve various instructional goals." Pedagogical agents have been touted by proponents as being adaptable and versatile while also capable of providing realistic simulations, addressing learners' socio-cultural needs, improving motivation, and enhancing learning. However, the authors note from their review of the recent research on pedagogical agents that empirical support for the claims made about the utility of these technologies has been somewhat mixed. They recommend further work on the socio-cultural aspects of pedagogical agent use and, like others in this section, suggest mixed method studies in naturalistic settings.

Sabine Graf and Kinshuk's chapter on adaptive learning technologies focuses on environments that "intelligently" adjust to learners' needs based on their learning styles, cognitive abilities, affective states, and the learning context/situation. The authors discuss methods by which these adaptive environments become "aware" of the learners' needs, note the myriad ways in which adaptive technologies are being used across a variety of platforms, and identify areas of future research.

According to David Wiley, TJ Bliss, and Mary McEwen, open educational resources (OERs) are "educational materials either licensed under and open copyright license or in the public domain." Their chapter reviews research in this area around how OERs are produced and shared, as well as the benefits of OERs for learning contexts. The authors note that, while significant obstacles regarding OERs remain unresolved, including definitional issues, this is a promising area of research that needs further exploration.

The final two chapters in this section both explore visual representations, but from different sides of the same coin. Joris Klerkx, Katrien Verbert, and Erik Duval's chapter discusses the ways visualizations that are *generated for the learner* can be used to help them find and understand educational resources, collaborate with others, and reflect on their progress within a learning environment. In contrast, Ton de Jong's chapter explores emerging technologies available to create visualizations *generated by the learner* to organize, analyze, and synthesize information while problem solving. Both chapters explore the variety of affordances that different representational formats offer for learning and synthesize the recent research in these areas.

Like other sections in this *Handbook*, this section is by no means an exhaustive look at all emerging technologies likely to impact teaching and learning in the near future. Notably missing from this review, for example, are mobile technologies, cloud computing, and personal learning environments. In most cases, the paucity of research in these areas precluded the inclusion of these topics at this time. While many of these technologies are discussed less directly elsewhere in this volume, a more complete review of the emerging research in these areas will have to wait for future editions of the *Handbook*.

Reference

* Clark, R. E. (Ed.). (2001). *Learning from media*: *Arguments*, *analysis*, *and evidence*. Greenwich, CT: Information Age Publishing.

* An asterisk next to a reference entry throughout this Handbook indicates a reference that the author(s) considers to be central to the topic.

Advancing Children's Engineering Through Desktop Manufacturing

54

Glen Bull, Jennifer Chiu, Robert Berry, Hod Lipson, and Charles Xie

Abstract

Children's engineering involves design of a solution under specified constraints in response to a particular need or goal. Desktop manufacturing systems enable students to engineer complex solutions with tangible products, expanding the range of possible approaches to engineering education. Desktop manufacturing technologies encompass digital fabrication systems such as 3D printers and computer-controlled die cutting systems and related technologies such as 3D scanners. These systems offer an entry point for advancing children's engineering as well as connecting to other STEM subjects.

Because desktop manufacturing systems have only recently become affordable in schools and are continuing to evolve rapidly, the conditions under which they may be best used in classrooms are not yet well defined. However, there are several promising directions that may guide future research in this area. The design process involved in desktop manufacturing affords an opportunity for connections among multiple representations. The virtual design on the computer screen and the corresponding physical object that is produced are two representations of the same underlying construct. Negotiating these representations offers connections to mathematics taught in schools such as ratios, proportion, and scaling. Computer-assisted design programs developed as learning tools can capture information about student design choices and underlying thought processes. Construction of physical prototypes through desktop manufacturing involves extensive involvement of motor skills that may have linkages with student achievement. Digital objects and designs developed at one school can be disseminated via the Internet and reproduced at other sites, allowing designs to be shared and adapted for specific educational goals.

Keywords

Children's engineering • Digital fabrication • Desktop manufacturing • STEM

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Introduction

This review focuses on the potential of desktop manufacturing to advance children's engineering in schools. Because engineering is the practical application of science and mathematics it can allow students to gain an understanding of concepts in context. The National Academy of Engineering report, *Engineering in K-12 Education*, concluded that existing curricula do not currently fully exploit natural

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connections between engineering and these subjects (Katehi, Pearson, & Feder, 2009, p. 156).

Children's engineering involves design under constraint, optimizing to a goal, with verifiable tasks that allow children to build a solution to an engineering problem appropriate for their age and grade level (Berry et al., 2010). Children's engineering is scaled and scaffolded to fit the context of young learners. It encompasses the elementary and middle school grades (Burghardt, 2000).

Engineering practice must respond to the challenge of globalization (National Science Board, 2007). The outsourcing of engineering jobs has followed the large-scale outsourcing of manufacturing jobs, fundamentally altering national industrial structures (Bradsher, 2010). The health of national economies is now dependent upon the ability of educational programs to prepare students for this transformed environment.

Consequently, innovative academic programs and curricula must be reconceptualized to prepare students to compete in a global economy. Children's engineering provides students with opportunities to learn about and practice engineering design at an earlier point in their education. Early experience is an important element of a larger strategy for addressing the challenge of a global economy (Cunningham, 2009; Hsu, Cardella, & Purzer, 2010; Rogers & Portsmore, 2004).

Technology holds an important key to this imperative educational overhaul (US Department of Education, 2010; Zucker, 2008). Desktop manufacturing is an emerging technology that offers students the opportunity to learn about engineering design through the experience of seeing their ideas realized in physical form (Bull & Groves, 2009). The equivalents of desktop factories are emerging in the twenty-first century. The personal computer revolution made it possible to convert analog media—songs, movies, books—into digital files. The desktop manufacturing revolution completes the cycle and allows digital bits to be converted back into physical atoms.

Personal manufacturing machines (i.e., *fabricators*) are the low-cost descendants of mass manufacturing machines used in factories, ushering in the emergence of the Factory-At-Home (Lipson & Kurman, 2010). These desktop manufacturing systems translate digital designs into physical objects. Digital fabricators can function as 3D copying machines, allowing three-dimensional objects to be scanned and replicated. Original designs can also be created using computer assisted design (CAD) programs such as Google SketchUp.

From an educational perspective, desktop manufacturing systems provide an explicit link between a virtual representation on a computer display and a physical object produced by the digital design. Explicit connections among virtual and physical representations offer rich learning opportunities in science, mathematics, and engineering (Bull, Knezek, & Gibson, 2009; Goldman, 2003). Students can alternate between the virtual and physical worlds and use feedback in both situations to not only improve their designs but also improve their understanding of underlying concepts. Because student designs occur on the computer, there is an opportunity to capture information about underlying thought processes. By allowing students to realize their designs as physical objects, there is an opportunity to develop mental images and connections that can potentially lead to deep understanding of underlying concepts.

Since the opportunity to incorporate desktop manufacturing systems in education has occurred only recently, there is very little prior research on how these systems might be employed to best advantage in instructional settings. However, prior research in STEM subjects provides a framework for identifying future research questions that might be profitably addressed as these emerging tools are adapted for use in educational settings. This chapter reviews relevant literature and technologies of desktop manufacturing, children's engineering, and ways in which the combination of desktop manufacturing with children's engineering has potential for STEM learning through manipulatives and multiple representations.

Engineering Design in Schools

Engineering design is a "systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" (Dym, Agogino, Eris, Frey, & Leifer, 2005, p. 103). Engineering design is difficult to learn, teach, and assess, and is less studied than scientific inquiry (Katehi et al., 2009).

Design thinking represents a sophisticated ability to scope problems, consider alternatives, develop solutions, conduct experiments, and optimize products iteratively using STEM skills. Our understanding of how K-8 students learn engineering design is limited (Katehi et al., 2009). A recent literature review concluded that many educational engineering projects lacked data collection and analysis to provide reliable evidence of learning (Svihla & Petrosino, 2008). Many K-8 projects replicated the "engineering science" model from higher education, which focuses on learning basic science for engineering instead of learning engineering design (Dym, Agogino, Eris, Frey, & Leifer, 2005). Little was learned from these studies about students' learning of design skills. In the absence of in-depth knowledge about students' design thinking and learning, effective instructions for teaching engineering design are difficult to develop. Among a small number of studies on students' design thinking, most focused on the college level (Atman, Chimka, Bursic, &

Nachtmann, 1999; Atman, Kilgore, & McKenna, 2008; Bailey & Szabo, 2006; Kelley, 2008) and fewer on the K-12 levels (Hsu, Cardella, & Purzer, 2010; Mentzer & Park, 2011).

Many elementary and middle school teachers are unprepared to integrate engineering into their classrooms. Although teachers see a need to implement design, engineering, and technology activities into their classrooms, they are often unfamiliar with these topics (Hsu, Purzer, & Cardella, 2011).

Practically, engineering efforts need to align with national and state standards in order for teachers to implement engineering activities in K-12 settings. Introducing additional content into a crowded curriculum, especially in elementary and middle school settings, can be challenging despite the recognized need to enhance STEM education. Integration of engineering design into the mathematics curriculum is under consideration by study groups (Berry et al., 2010). *A Framework for K-12 Science Education* explicitly incorporates engineering into the Next Generation Science Education Standards and gives equal emphasis to engineering design and scientific inquiry (National Research Council, 2011).

Despite these barriers, a number of efforts successfully incorporated engineering projects with hand fabrication of prototypes in K-8 settings (Fortus et al., 2004; Kolodner et al., 2003). Cantrell, Pekcan, Itani, and Velasquez-Bryant (2006) created engineering design units with a partnership of middle school teachers and university faculty. These units engaged students with Web-based simulations and hands-on construction of prototypes. Comparison of eighth-grade science tests revealed that the engineering units may have helped remedy achievement gaps for certain student populations. Hmelo, Holton, and Kolodner (2000) engaged students in design activities to learn about complex systems such as the respiratory system. Sixth-grade students who designed artificial lungs learned more about the structure and function of different parts of the respiratory system than students receiving direct instruction. Silk, Schunn, and Strand-Cary (2009) investigated whether engineering design could help student reasoning in high-needs, urban classrooms. Eighth-grade students engaged in designing alarm systems made significant improvement on understanding energy transfer and electrical circuits. Students in design-based classes also saw larger improvements than those using similar inquiry or textbook-based lessons.

Introducing engineering design into K-8 classrooms can also foster math understanding. Burghardt, Hecht, Russo, Lauckhardt, and Hacker (2010) engaged eighth-grade students in a bedroom design project to learn about shapes and scale. Students used Google SketchUp as a CAD tool to design a room and built scale models with paper and scissors. Students involved in the bedroom design curriculum scored significantly higher on assessments of mathematical concepts than did typical students.

Other efforts bring engineering to elementary levels (Rivoli & Ralston, 2009; Rogers & Portsmore, 2004). *Engineering is Elementary* (EiE) produced by the Boston Museum of Science, has been adopted widely. The EiE curriculum teaches concepts in engineering and technology by using narratives of students solving real-life problems through engineering design. Students investigate and test materials for their designs and engage in final design challenges. Studies have found that EiE students significantly outperform non-EiE comparison groups on science and engineering assessments (Lachapelle & Cunningham, 2007).

Existing studies at elementary and middle school levels highlight considerations that arise when integrating engineering into classrooms. First, studies suggest that students benefit from rapid prototyping at the beginning of a design challenge to focus and frame their attention. Students also benefit from use of rapid prototyping to achieve multiple iterations as they work toward a solution (Hmelo et al., 2000). Studies demonstrate the need for pedagogical support for students engaged with design projects. Finally, many of these studies demonstrate that teachers with no formal engineering training can successfully integrate design into their classrooms, and even teach teachers as well as students (Moskal et al., 2007).

Desktop Manufacturing Technologies

Digital manufacturing is a culmination of advances at the intersection of the Industrial Revolution and the Information Age. *Digital manufacturing* refers to any industrial process in which digital technologies are used to produce physical goods. This term encompasses automated factories with computing systems that cost millions of dollars, as well as desktop manufacturing technologies that are small enough to fit on a desktop and affordable enough for personal use. *Mechatronics* is an emerging field of engineering that combines mechanical engineering with microelectronics such as microcontrollers, motors, and sensors. *Desktop manufacturing* encompasses personal digital fabrication as well as other technologies such as 3D scanning, mechatronics, and even some hand fabrication for final assembly. Some of the elements of desktop manufacturing are shown in Fig. 54.1.

Overview of Digital Manufacturing

Digital controls were used to automate manufacturing as soon as the first computers became available. The industrial revolution increased productivity by amplifying the power of a worker through machinery. For example, a machinist might guide the cutting head of a milling machine to shape an airplane part. Automating the process by replacing the

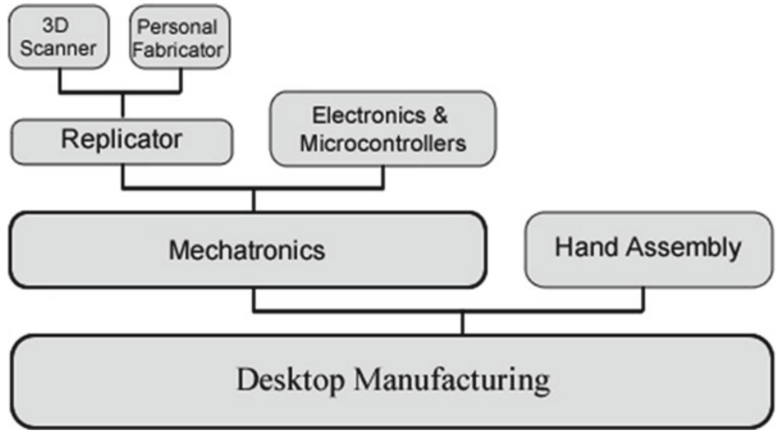

Fig. 54.1 Desktop Manufacturing encompasses a range of technologies that include 3D scanners, 2D and 3D fabricators, and microcontrollers. From http://blog.reprap.org/2008/06/reprap-achieves-replication.html

machinist with a digital control to guide the path of the milling head further increased productivity.

The term Computer Numerical Control (CNC) is used to describe direct control of the milling head by a computer. Computer Assisted Design (CAD) programs allowed components to be designed on the computer and manufactured with CNC machines.

CNC tools employ a subtractive process through control of a milling head to remove material. While a few personal fabricators are scaled-down versions of industrial CNC machines, the advances in desktop manufacturing systems that have made them affordable for consumers have been driven by another technology, additive fabrication.

In the 1980s a new generation of manufacturing technologies created parts by depositing one layer of material at a time. The term *3D printing* is often used to describe this additive process, because the process of creating each layer is analogous to operation of a printer. As multiple layers are printed, one on top of the other, a three-dimensional shape emerges. Advanced 3D printers can print support materials that are dissolved after printing to create an object—such as a crescent wrench—with moving parts. Typically, manufacturing an object with moving parts would require separate fabrication and assembly. The ability to print a complete working object with moving parts can revolutionize the production process. Other digital fabrication systems are used to prototype printed circuit boards and populate them with electronic components. Some 3D printers can even print biological materials to create tissue and organs.

In addition to 3D fabricators that produce three-dimensional objects through additive and subtractive manufacturing processes, a variety of 2D fabricators such as computer-controlled die cutters and laser cutters are widely used to create two-dimensional patterns from materials such as card stock, vinyl, and acrylic plastic. Categories of digital fabricators are summarized in Table 54.1.

Table 54.1 Categories of digital fabricators

Technology	Three dimensional	Two dimensional
Subtractive	CNC milling head	Laser cutter
Additive	3D printer	Embroidery machine

Neil Gershenfeld, an M.I.T. professor, founded the Center for Atoms and Bits at the turn of the twenty-first century to explore the implications. The FabLab (i.e., Fabrication Laboratory) was an early concept that emerged from the Center for Atoms and Bits. A FabLab consists of a model laboratory of 2D and 3D digital fabrication tools. A fully equipped FabLab can cost in excess of $100,000 (Gershenfeld, 2005). Although FabLabs were widely adopted in many colleges of engineering and community colleges, their price and complexity initially placed them beyond the reach of the average K-12 school.

Emergence of Desktop Manufacturing Systems

In 2005 Adrian Bower, a senior lecturer in mechanical engineering at the University of Bath, conceived the notion of an inexpensive 3D printer that could be assembled by an individual. The Replicating Rapid Prototyping (RepRap) fabricator (shown in Fig. 54.2) was developed with this goal in mind.

At about the same time, one of the authors of this chapter (Lipson) and engineering students at Cornell University developed an open-source 3D fabrication kit—the Fab@Home fabricator—for home users (Malone & Lipson, 2006). Creating open-source, affordable manufacturing technologies increased access for developing nations. The Fab@Home system was used in diverse settings that included a FabLab in Africa.

In 2008 a RepRap fabricator was used to print some of the parts for another RepRap system for the first time (Fig. 54.2).

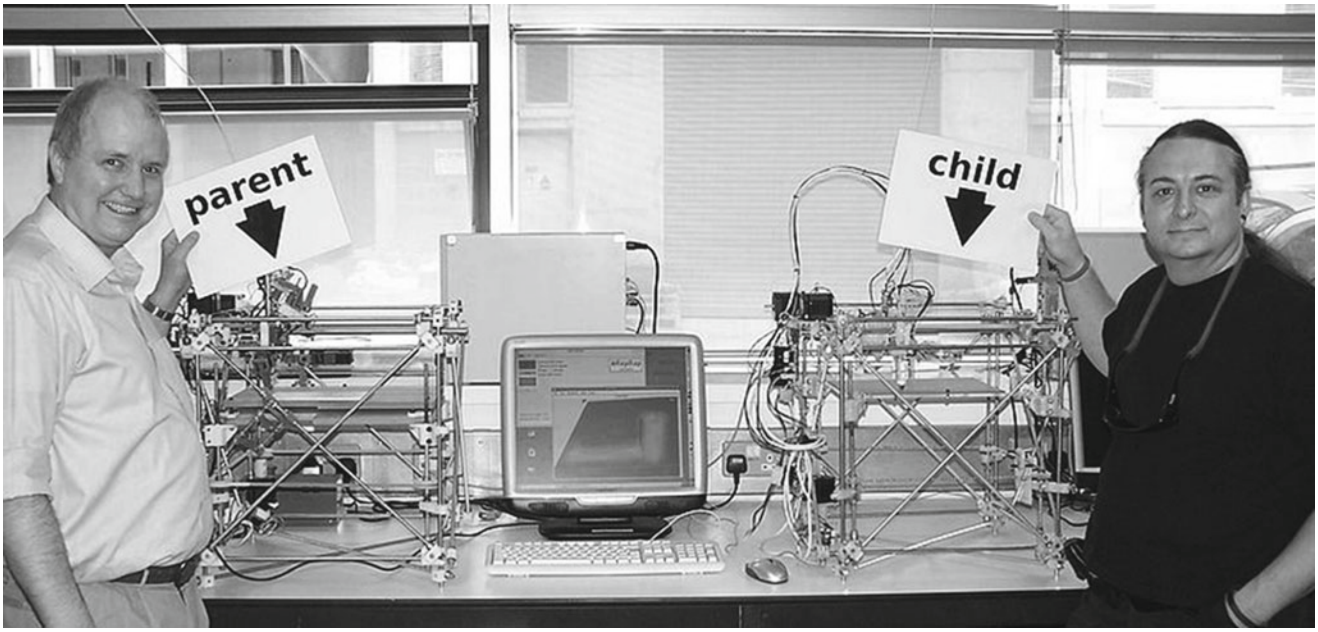

Fig. 54.2 Adrian Bowyer (*left*) with the first Replicating Rapid Prototyping (RepRap) fabricator

Table 54.2 Characteristics of digital fabrication methods

Category	Replicable	Available for personal use	Digital dissemination
Hand fabrication		✓	
Digital fabrication	✓	✓	✓
Industrial fabrication	✓		

Like the Fab@Home system, the RepRap design was released as an open source plan, allowing other developers to modify designs to create their own enhanced variants. The systems inspired development of additional designs for fabricator kits, such as the widely adopted MakerBot.

The release of the open source kit resulted in proliferation of 3D printer designs within the reach of individual consumers. Many of these emerging designs can be constructed for less than a thousand dollars. The widespread diffusion of 3D printing kits, in turn, has stimulated development of inexpensive commercial designs that work out of the box with no assembly required.

Personal fabrication systems allow individual users to replicate objects with perfect fidelity and disseminate the designs via the Internet. In contrast, hand fabrication allows individuals to produce objects using manual tools with potential inconsistencies in the production process. Industrial fabrication methods developed in the nineteenth century made it possible to reproduce interchangeable parts. Table 54.2 illustrates key characteristics of each fabrication method.

The ability to disseminate designs digitally encourages development of derivative designs that build on past work. This is a key characteristic not previously provided by either hand fabrication or industrial fabrication methods. Online databases of digital designs such as Thingiverse (www.thingiverse.com) now allow users to share and collaborate on designs. Consequently, once a design has been developed, it can readily be shared, with particular benefits for educational settings. The types of designs that can be currently accessed and downloaded from this database currently range from a block-and-tackle assembly for an elementary school science project to a microscope mount for a webcam.

Desktop Manufacturing in Schools

The Society of Manufacturing Engineering (2009) concluded that personal digital fabrication will offer significant benefits for both manufacturers and consumers, listing personal fabrication as one of the key *Innovations that Could Change Engineerin*g. The *Economist* predicted that this technology "will have as profound an impact on the world as the coming of the factory did. … Just as nobody could have predicted the impact of the steam engine in 1750—or the printing press in 1450, or the transistor in 1950—it is impossible to foresee the long-term impact of 3D printing. But the technology is coming, and it is likely to disrupt every field it touches." (*The Economist*, 2011, 11)

Education is potentially one of the fields affected. Desktop manufacturing enables students to engineer complex solutions with tangible products, expanding the range of approaches to engineering education.

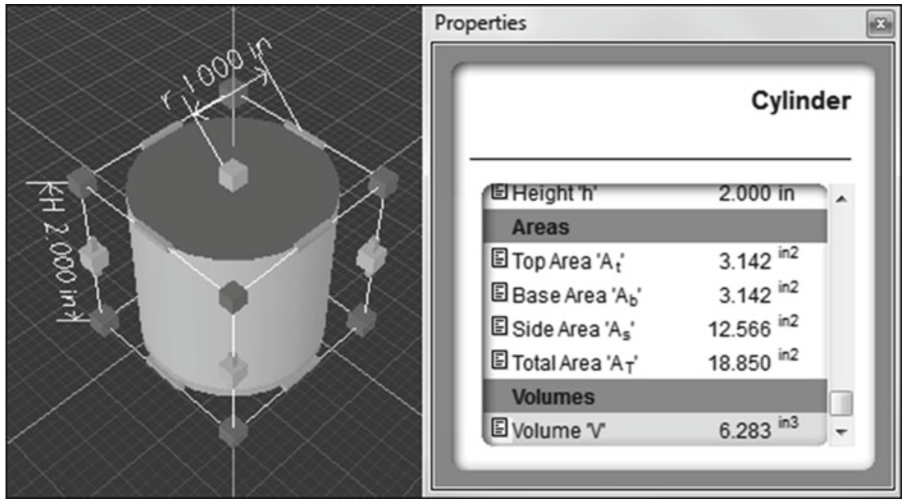

Fig. 54.3 Fabrication software designed for children's engineering can match scaffolding to the learning objective

School Fabrication Hardware

A variety of 2D and 3D technologies employing both additive and subtractive fabrication are emerging that are suitable for schools. At one end of the continuum, computer-controlled die cutters are available for about the same price as an inkjet printer. Computerized die cutters are essentially analogs of mechanical die cutters already in use in schools and, therefore, provide a useful entry point.

Addition of a 3D scanner combined with a 3D printer yields a replicator that can copy and reproduce three-dimensional objects. Inexpensive microcontrollers, motors, and sensors make it possible to incorporate embedded intelligence in replicated objects.

In contrast to the fictional replicators portrayed in shows such as *Star Trek*, the current generation of personal fabrication technologies often requires extensive hand assembly and adjustment. Subcomponents must be assembled and adjusted by hand. Microcontrollers, sensors, and motors must also be incorporated by hand. In school environments, this element of desktop manufacturing may be advantageous for development of fine motor skills in children.

School Fabrication Software

Fabrication software is a crucial element in successful use of fabrication hardware. *A Framework for K-12 Science Education* recommends that CAD tools be introduced to modernize engineering design activities (Section ETS1.B; National Research Council, 2011).

Although general-purpose CAD tools such as Google SketchUp are widely available and can be used in the classroom, fabrication software developed for school use can be designed to support specific learning objectives. For example, the properties associated with a CAD model can be expressed in English or metric units, degrees, or radians, etc. In some cases it may be helpful to display formulas such as area and volume and compute these for the student (Fig. 54.3). If learning objectives include students being able to use formulas to compute values independently, these properties can be hidden. Correct values can be used to provide feedback and allow students to verify their work in instances in which they have entered their own calculations first. The level of scaffolding provided can be matched to the learning objectives and the student's developmental stage, age, and grade level.

FabLab ModelMaker is an example of CAD software designed for educational use that supports both 2D and 3D fabrication in the classroom. In Fig. 54.4, the student has constructed a castle on the left side of the screen. The corresponding representation as a two-dimensional object is shown on the right-hand side of the screen.

This design was initially constructed from cardstock using a computer-controlled die cutter to cut out the shapes. The separate pieces were then assembled into their final form by bending and folding the cardstock as shown in Fig. 54.5.

The same file was later used to produce the model in plastic (Fig. 54.6). Each type of material (cardstock and plastic) has its own characteristics and constraints. Cardstock is useful for rapid production of prototypes. (The model in Fig. 54.5 took less than 5 min to process with a computer-controlled die cutter.) Once a final design has been selected, it can be produced in more durable material. The model in Fig. 54.6 took approximately 45 min to produce.

In the same way that word processors can be used to improve students‘ writing skills (Goldberg, Russell, & Cook, 2003), educational CAD tools can help students improve their design skills by allowing them to visualize their designs. Ease of revision can encourage an iterative process that is an important part of engineering design. Version control can

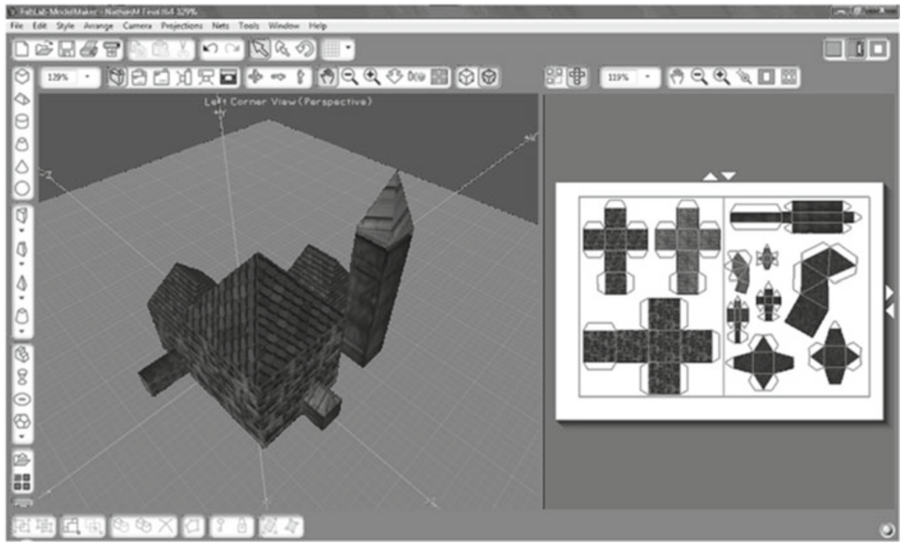

Fig. 54.4 FabLab ModelMaker is a CAD tool for schools that supports 2D and 3D fabrication

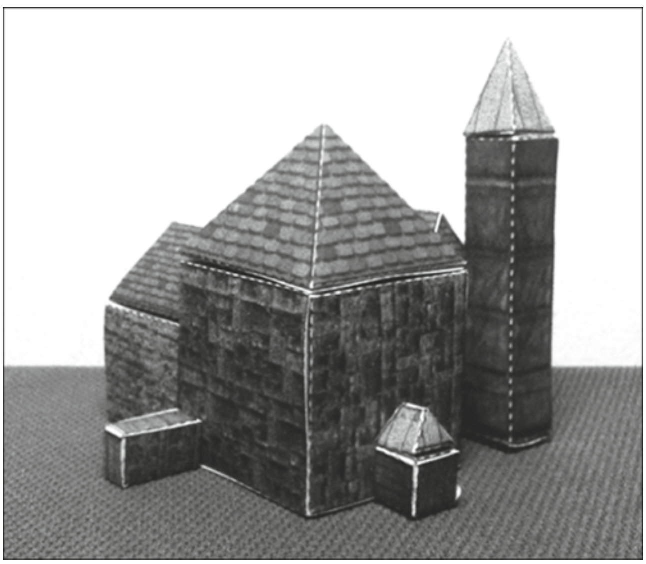

Fig. 54.5 A cardstock building created with FabLab ModelMaker using a computer-controlled die cutter

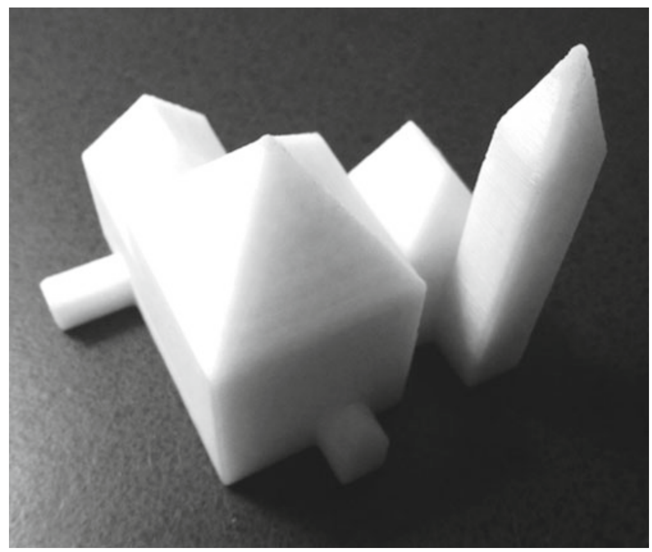

Fig. 54.6 A 3D-printed version of the building shown in the previous figure

allow the teacher to follow the process by which the students revise their work in successive iterations.

Modern CAD programs are becoming more than drafting tools and include generative and analytic tools for conceiving designs. An emerging role of CAD is to assist the designer in diagnosis of potential problems and discovery of creative solutions (Hayes, Goel, Tumer, Agogino, & Regli, 2011; Jonson, 2005; Robertson & Radcliffe, 2009). In the same way that the spell-checking function in word processors can assist students as they write, intelligent CAD tools are able to inspect users' work, detect problems, and suggest solutions while students are solving design challenges. Driven by the industry need for intelligent CAD tools, researchers have explored enhancing CAD with ideation tools and inference engines (Hayes et al., 2011; Jin & Chusilp, 2006; Jin & Li, 2007; Woodbury & Burrow, 2006).

Industrial CAD applications are, by and large, design tools rather than *design learning tools*. Adaptation of analytic design features for education potentially makes it possible to configure them to support specific learning objectives. Energy3D (http://energy.concord.org/energy3d/) is an example of a specialized CAD tool developed for engineering design learning. The 3D user interface allows students to design buildings on the computer that can be fabricated and evaluated for energy efficiency.

In this instance, Energy 3D can be used by students to investigate heat flow and energy usage in structures. For example, a virtual heliodon—a device that simulates solar

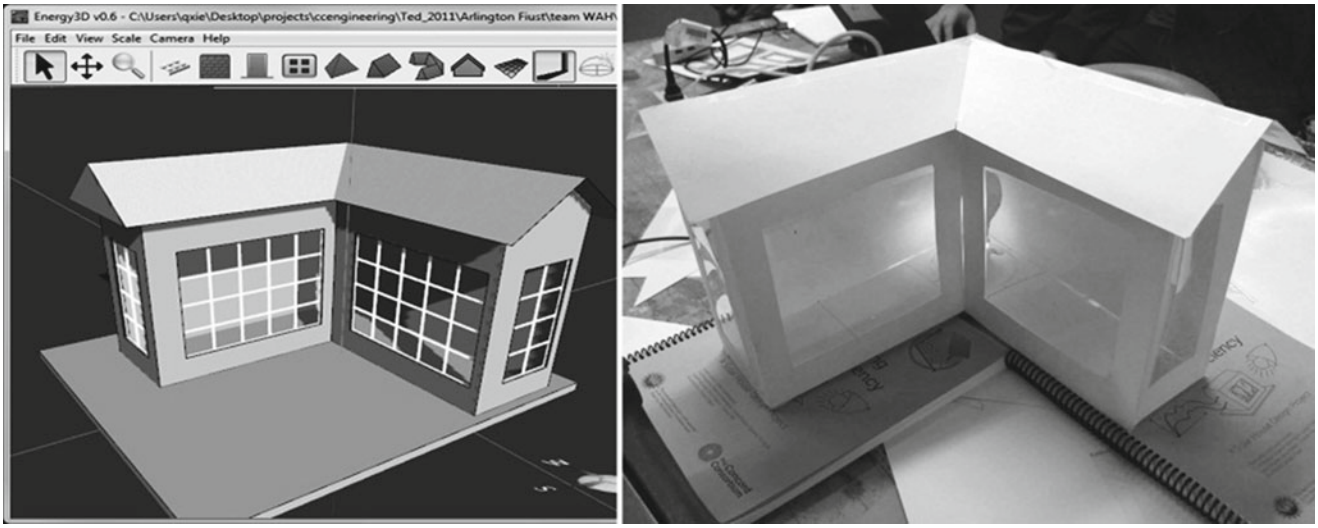

Fig. 54.7 Solar house designed and constructed using Energy3D

radiation at different locations on the planet at different times of the year—can be used to learn about the sun's path and solar heating of buildings. Fluid dynamics and heat transfer simulations allow students to analyze their designs and help them make design choices grounded in science-based criteria. These additional analysis and simulation tools built into CAD software are important because they provide feedback to students during the design process and allow them to evaluate a design rapidly before sending it to a digital fabricator.

Children's Engineering Through Desktop Manufacturing

Engineering design in the context of children's engineering can motivate learning (Berry et al., 2010). Desktop manufacturing facilitates students' ability to construct working physical prototypes of designs they create yielding benefits in the engineering design process. An NSF-supported project (Horwitz, 1995) found that theoretical knowledge alone was insufficient to ensure that students could apply that knowledge in real-world tasks. High school students who scored well on question-and-answer tests of circuits and test equipment could not perform related real-world tasks. Constructing and testing real products can consolidate understanding and close the gap between theoretical and applied knowledge.

An engineering project that does not include construction and testing of a real product would be regarded by many as incomplete. The Engineering Design Clinic at Harvey Mudd College won the National Academy of Engineering (NAE) 2012 *Gordon Prize for Engineering Education* for their hands-on approach to teaching engineering that assigns real-life design problems provided by industry partners to teams of students. Conventional engineering curricula emphasized acquisition of theoretical knowledge, especially in the first years of study, with limited opportunities to apply this knowledge. After the engineering program at Harvey Mudd college demonstrated that an integrated approach that combined theoretical and applied knowledge could be effective, it subsequently became a model for many other institutions, leading to the NAE award (National Academy of Engineering, 2012).

Connections to School Science and Mathematics

Engineering design often requires students to employ spatial, representational, and proportional reasoning. These kinds of mathematical reasoning present challenges as students explore three-dimensional relationships in two-dimensional space. Students must consider the proportional relationship of geometric objects while working with software. The virtual representation of an object in the CAD program and the physical object that results offers the opportunity for interactions with underlying mathematical concepts.

For example, elementary students participating in a children's engineering project, the Fab@School initiative, designed a model skateboard park in one activity. Students designing a ramp (Fig. 54.8) found that the specification of the angle on the screen produced an unexpected result when the object was fabricated (Bull, Smith, & Stearns, 2011). The students attempted to improve the design by creating a ramp with a "more shallow" slope. As a result of the students' incomplete understanding of angle and slope, the fabricator produced a ramp that was steeper, not shallower. The students initially concluded that the computer program "must be broken." Facilitation by the teacher eventually allowed the students to gain a more accurate understanding of the relationship between the virtual and physical representations.

Fig. 54.8 Student design for a ramp in a model skateboard park

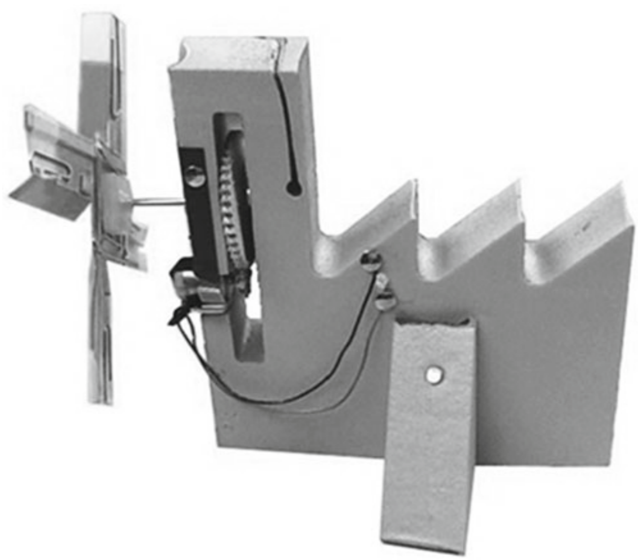

Fig. 54.9 Model wind turbine created through use of 2D and 3D fabricators

Fabricated objects can also take advantage of connections to the science curriculum. Students constructing a model wind turbine, for instance, can gain experience with concepts such as electricity and magnetism, simple and complex machines, rotary motion, angular velocity, torque, and power. The model wind turbine shown in Fig. 54.9 involves moving components and multiple forms of media—turbine blades created with the computer-controlled die cutter, a body created with a foam cutting tool, and gears manufactured with a 3D printer—to create a final design assembled from these parts.

Designing the wind turbine required students to make connections among physical, virtual, and symbolic representations. Students moved among diagrams and numeric representations on the computer screen and the physical objects in cardstock and plastic subsequently produced. Numerous prefabricated science kits allow students to construct wind turbines. Students who employ desktop manufacturing to design and fabricate their own model turbines receive many of the same benefits as students using science kits. However, students using desktop manufacturing have additional opportunities to experiment and test their own designs. Another benefit of desktop manufacturing is that designs of science apparati can be disseminated and shared, allowing other science teachers to adapt and modify a design for a specific use in their classrooms. The *3D Printables* site (http://3dprintables.org) at Cornell is a repository of instructional models for classroom use.

The ability to disseminate fabrication files in this manner creates the possibility for exchange of ideas among students as well as teachers. The importance of audience has long been identified as a motivating factor in the humanities for projects ranging from shared writing to collaborative movies. The ability to share and repurpose files has also contributed to the success of projects such as the M.I.T. Media Lab's children's programming initiative (www.scratch.com). Desktop manufacturing offers the opportunity to explore similar benefits for children's engineering.

Digital fabrication has only recently become both usable and affordable for elementary and middle school classrooms. Consequently, although desktop manufacturing has been used in engineering curricula at post-secondary levels, little research regarding use in K-8 schools has been reported (Chiu, Bull, Berry, & Kjellstrom, 2012). There has been significant research in two related areas that could inform future use of desktop manufacturing in elementary and middle school classrooms: (a) development of fine motor skills and (b) linkages between physical representations of real world objects and more abstract levels of representation. These are discussed in the sections that follow.

Motor Skills and Student Achievement

Construction of a physical prototype through desktop manufacturing involves extensive use of motor skills. Fine motor skills require close eye–hand coordination (Magill, 1996). Young children at school spend approximately 60–70 % of their time completing fine-motor work or activities (Landy & Burridge, 1999; Voelcker-Rehage, 2005). Research suggests that fine motor skills development at school entry is predictive of children's academic success in reading and mathematics at the end of elementary school (Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; Luo, Jose, Huntsinger, & Pigott, 2007). Research has found relationships between fine motor skills and mathematical performance in prekindergarten and lower elementary grades. Funk, Sturner, and Green (1986) found that preschool children's fine motor skills predicted their mathematics achievement in first and second grades.

The development of mathematical understanding through actions and movements using mathematics manipulatives is important for the formation of mathematics concepts (Ginsburg, Klein, & Starkey, 1998). Children with advanced fine motor skills manipulate objects in efficient ways and seem to understand spatial relationships and possess better mental representations than children with less advanced fine motor skills (Luo et al., 2007). This phenomenon suggests that actions and representations with mathematics manipulatives allow children to focus cognitively on the underlying mathematical concepts.

There appear to be two explanations for this relationship. First, prekindergarten and lower elementary grades students learn through active manipulation of the objects around them. As they build towers with blocks, they are learning informal geometry, balance, and gravity. As they put together puzzles, they are learning about attributes, matching colors, and shapes (Diamond & Lee, 2011; Lubinski, 2010; Park, Lubinski, & Benbow, 2010). Manipulating blocks and puzzle pieces allows children to exercise and develop their fine motor skills. Many activities that help young children build cognitive skills also involve the use of fine motor skills, suggesting that children who have developed fine motor skills possess the cognitive foundations necessary for academic success.

Neuroimaging techniques provide a second explanation for the relationship between fine motor skills and academic success (Davis, Pitchford, & Limback, 2011; Diamond, 2000) Researchers previously thought that cognitive activities activated only the cognitive areas of the brain and motor activities activated only the motor areas of the brain. Neuroimaging techniques have helped us understand the strong neural connections between cognitive and motor areas of the brain and see how certain motor tasks activate both motor and cognitive areas of the brain (Seitz, 2000). A child who removes a block from a group of three will subtize (i.e., see the total at a glance without counting) the remaining blocks as two. The correlations involved in unconscious addition and subtraction as objects are added or removed is now believed to result in sensorimotor neural connections (Lakoff & Núñez, 2000). These findings suggest that activating fine motor skills activates cognition, thus impacting children's readiness for learning (Leiner, Leiner, & Dow, 1993).

Because desktop manufacturing involves both fine and gross motor skills, exploration of ways in which it might be used to facilitate formation of mathematical concepts, understanding of spatial relationships, and development of mental representations could offer a promising direction for future research. Connections between virtual and physical representations are discussed in the next section.

Connecting Virtual and Physical Representations

Constructing a physical version of a virtual design (or vice versa) engages all three of Bruner's modes of representation. Bruner (1966) postulated three levels of representation: enactive, consisting of physical objects and actions; iconic, which includes visual imagery and diagrams; and symbolic representations involving words and equations. These forms of representation map well to current embodied or grounded theories of cognition that propose that actions performed by the body, visual perceptions, and mental models are interconnected (Barsalou, 2010; Glenberg, 1997). Grounded or embodied theories view the environment and bodily experiences as playing important roles in the development of abstract concepts (Gibson, 1979; Lakoff & Johnson, 1980).

Much educational research points to the benefit of providing students with multiple representations of concepts or phenomena (Goldman, 2003; Hickey, Kindfield, Horwitz, & Christie, 2003; Horwitz, 1995; Horwitz & Christie, 1999; Kozma, 2003). For example, students can learn about rate from looking at a simulation of a car on an observable level moving with a coordinated velocity graph on a symbolic level (Kaput & Schorr, 2008). Students can learn about chemical reactions by having an iconic representation of atoms coordinated with graphs of concentration (Kozma, 2000).

Multiple representations can help students learn by providing complementary information or processes, by constraining interpretations, and by constructing new understanding (Ainsworth, 2006). Multiple representations can provide complementary information in different forms, which can encourage use of different strategies. For example, students may use more self-explanations when solving problems that are diagram based instead of text based (Ainsworth & Loizou, 2003).

Although research points to the benefit of using multiple representations, students have difficulty making connections among representations (Duncan & Reiser, 2007; Johnstone, 1991; Lewis & Wood-Robinson, 2000; Marbach-Ad & Stavy, 2000). Students have difficulty integrating everyday ideas and normative concepts. Successful learning relies on connecting and refining the two worlds (Smith, diSessa, & Roschelle, 1994).

Combining desktop manufacturing with children's engineering can provide a direct link between student designs in a virtual space and the tangible, everyday world. This direct connection can enhance student learning by giving students the ability to manipulate and interact with objects virtually in a CAD environment (de Koning & Tabbers, 2011). Desktop manufacturing provides an opportunity for complementary learning functions with virtual and physical representations. For example, what students design in CAD is produced as an informationally equivalent physical model. Students who may be more facile with computer-based representations can learn from a hands-on equivalent, and students who may understand a physical manipulative can learn from the iconic CAD representation. Students may use different strategies with the hands-on model than the CAD model, such as rapid iteration with CAD and conducting tests with the physical model.

Few studies have examined ways in which connecting virtual and physical representations may impact learning. Researchers are beginning to examine the implications of "bifocal" modeling for engineering (Blikstein & Wilensky, 2007). MaterialSim is a set of models and activities for investigating materials science phenomena such as crystallization, solidification, casting, grain growth, and annealing. The program allows students to connect virtual experiments to real-world outcomes. Students can compare output from the simulation to output from the real world. Blikstein and Wilensky (2010) suggested that materials science students constructing their own models (in this case, coding simulations using NetLogo) and reconciling them with data was particularly beneficial for learning at the college level. At the younger ages, Tseng, Bryant, and Blikstein (2011) have explored the use of tangible interfaces for engineering education. Using *Mechanix*, students construct mechanical systems on a smart screen using manipulative interfaces. Tseng et al. (2011) found that students ages 7–9 were able to use these tangible interfaces to design collaboratively, were supported to try new pieces or new constructions, and were enabled to review and reflect on their designs through digital libraries.

Conclusion

Emerging technologies make affordable, easy-to-use desktop manufacturing systems available to schools. Combining these technologies with children's engineering offers opportunities for students to learn STEM concepts and engineering habits of mind, such as collaboration and optimization. Determination of ways in which these emergent technologies might best advance children's engineering will be important for effective use in schools, which can ultimately contribute to global competitiveness.

At present the conditions under which desktop manufacturing might best be used to extend and advance children's engineering in the classroom are not well understood. However, examples suggest that engineering design projects that involve construction of physical prototypes can lead to deeper understanding of targeted science and mathematics concepts. In particular, desktop manufacturing can benefit mathematical reasoning and problem-solving by enabling students and teachers to explore quantitative, geometric, and spatial concepts and relationships. Desktop manufacturing supports learning through multiple representations by allowing teachers and students to develop graphical, numerical, verbal, and physical representations of mathematics and science concepts that complement, constrain, and construct understanding.

Issues that must be addressed before widespread classroom adoption of desktop manufacturing is feasible include: (a) the technology itself, (b) curricula, and (c) related professional development. Despite recent advances, the technology involved in desktop manufacturing is not yet mature. Consequently, the current use is primarily by enthusiasts and early adopters.

Classroom-tested curricular activities are required before widespread adoption will be practical. CAD software needs to be integrated into the curricula/technology-enhanced learning system. Students need help refining and critiquing their own and others' designs.

Engineering expertise and understanding is required to take advantage of emergent desktop manufacturing capabilities. Many teachers do not fully understand engineering, engineering habits of mind, or design thinking. This expertise is not currently provided in teacher preparation programs. Hence, the current generation of teachers is not well positioned to take advantage of these capabilities.

Future research should explore ways in which children's engineering with desktop manufacturing can augment student learning. Although early efforts with digital fabrication show promise to support children's engineering (Chiu et al., 2012), educational research is very much in an exploratory phase. Future research should investigate conditions under which desktop manufacturing can facilitate learning, and ways in which it can best extend and support related activities such as engineering design projects involving hand fabrication. Finally, future research should investigate design principles for integration of desktop manufacturing with children's engineering and conditions under which it may be used to best advantage.

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55 Supporting Learning with Interactive Surfaces and Spaces

Michael A. Evans and Jochen Rick

Abstract

In recent years, educational research on interactive surfaces such as tablets, tabletops, and whiteboards, and spaces such as smart rooms and 3D sensing systems has grown in quantity, quality, and prominence. Departing from the mouse-and-keyboard form of input, users of these systems manipulate digital information directly with fingers, feet, and body movements, or through a physical intermediary such as token, pen, or other tractable object. Due to their support for natural user interfaces, direct input and multiple access points, these educational technologies provide significant opportunities to support colocated collaborative and kinesthetic learning. As hardware becomes affordable, development environments mature, and public awareness grows, these technologies are likely to see substantial uptake in the classroom. In this chapter, we provide a foothold on the current technology development and empirical literature, highlighting a range of exemplary projects that showcase the potential of interactive surfaces and spaces to support learning across age groups and content domains. We synthesize across the existing work to formulate implications of these technological trends for the design of interactive educational technologies, the impetus for academic research based on such systems, and the advancement of future educational practice.

Keywords

Collocated collaborative learning • Interactive surfaces • Interactive spaces • Kinesthetic learning • Natural user interface

Beyond the Keyboard and Mouse

Desktop computing, which traditionally uses a graphical user interface controlled by keyboard and mouse, was developed in the late 1960s and gained prominence in the 1980s. Though this conventional input and interface configuration is still the default in classrooms, offices, and homes, interactive surfaces and spaces are emerging as a legitimate alternative as tablets (e.g., Apple iPad), tabletops (e.g., SmartTech SMART Table), motion-sensing video game systems (e.g., Microsoft Kinect), and custom-built museum installations (e.g., Horn, Solovey, Crouser, & Jacob, 2009; Kourakis, & Parés, 2010; Steir, & Pierroux, 2011) migrate from the research lab to learning settings. Already, supporting learning with these technologies has become a vital research area in educational technology, the learning sciences, and human–computer interaction (HCI). Over time, hardware will become more capable, available, and affordable, software development environments will mature, and understanding of how to design applications for these technologies will

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grow. Consequently, interactive surfaces and spaces could play an increasingly vital role in educational technology research and in the general support of learning.

This chapter is intended to familiarize readers with the technologies, research in the field, the fundamental benefits to and uses of these technologies for supporting learning, and the implications of this trend for future educational research and practice. First, we introduce the technologies and highlight existing educational research on them. Next, we evaluate the two prominent benefits of interactive surfaces and spaces over desktop computing: support for *direct input* and *multiple access points*, where multiple concurrent interaction points are sensed by the hardware and utilized by the software. Then, we discuss how these features benefit in particular two forms of learning: *colocated collaborative learning* and *kinesthetic learning*. Finally, we summarize the implications this technological trend has for pedagogy and future research in educational technology.

Origins of Interactive Surfaces and Spaces

Revolutions in computing technologies do not often arrive unannounced. While public dissemination and awareness of revolutionary computing might follow normal rates of diffusion and adoption, significant research precedes it. The personal computing revolution of the 1980s was founded on research on graphical user interfaces in the late 1960s and 1970s at places like Xerox PARC. The Internet revolution of the 1990s can be traced directly back to work on ARPANET in the 1960s. The same holds for current work on interactive surfaces and spaces: extensive research has shaped the technology and its use beginning from the late 1990s and continuing today (Buxton, 2011).

Weiser (1999) announced the revolution of *ubiquitous computing*, positing that future computing environments would be composed of a networked system of different-sized interactive surfaces and sensors that would work seamlessly together. In addition, Ishii and Ullmer (1997) indicated that computation was shifting from the desktop in two major directions: (1) the physical environment and (2) onto individual's skin and bodies. They coined the term *tangible user interfaces* (TUIs) to refer to interfaces that users grasp and manipulate, e.g., move, turn, twist, squeeze, combine, to control a digital computing system in contrast to merely pointing-and-clicking. Over time, these research areas have exploded, with annual academic conferences dedicated to these themes, examples including the ACM Conference on Ubiquitous Computing; ACM Conference on Interactive Tabletops and Surfaces; ACM Conference on Tangible, Embedded, and Embodied Interaction, while finding a niche in educational technology and the learning sciences conferences (Evans, Feenstra, Ryon, & McNeill, 2011).

Let us be clear. It is not that these visionaries created the technologies fully formed. Rather, the researchers read technological trends and articulated a compelling notion of how these trends should be employed. Foundational hardware improvements have fueled and been fueled by these visions. Better sensing technologies (faster and higher-resolution image sensors, capacitive touch sensing), advanced processors (faster processors to enable the real-time processing of complex input, cheap low-power processors to embed into small battery-operated devices) and wireless connectivity have led to research and commercial work on interactive surfaces and spaces. Once a hardware foundation was established, software toolkits further stoked research. For instance, reacTIVision provides an open-source, cross-platform computer vision framework for fast and reliable tracking of *fiducial markers*—typically black-and-white visual patterns whose identity, location and orientation can be identified from a camera picture (Jordà, Geiger, Alonso, & Kaltenbrunner, 2007). Most of the examples in the upcoming tangible-based tabletops section have built using this toolkit. The frustrated total internal reflection (FTIR) technique enabled researchers to build their own touch-based tabletops based on shining infrared LEDs into the sides of an acrylic surface that doubled as a display surface for a projected image (Han, 2005). Specialized development environments, such as the research-based DiamondSpin Toolkit (Shen, Vernier, Forlines, & Ringel, 2004) or the commercial iOS Developer Library, can make it easier to handle the specific challenges of these technologies such as the lack of a definitive orientation on tabletops (e.g., text oriented towards me will be upside down for a person seated across from me at the tabletop) or interpreting multiple touch points on tablets (in contrast to a single cursor).

The current crop of interactive surfaces and spaces are based on dramatic improvements in sensing technology and interpretation algorithms. Keyboard and mouse input are simple to interpret in comparison to other types. Tracking an individual's movement in three-dimensional space (e.g., Kinect) or locating the position and orientation of multiple tokens simultaneously (e.g., reacTIVision) requires much more sophisticated processing. Instead of users adjusting to what is easy for a computing system to sense and interpret, these new systems afford what is easy for a user to do. Because these modes of input can be intuitive to use and easy to learn, they are often termed *natural user interfaces* (Wigdor & Wixon, 2011). While there are compelling examples of such benefits (e.g., using a pinch gesture to resize a virtual object), even simple systems rely on standard conventions and guidelines (e.g., a door handle is operated by turning it downwards). For many natural user interfaces, guidelines and standards are still lacking or immature (Norman, 2010). In the following sections, we introduce the established areas for categorizing interactive surfaces and spaces to support learning: tangibles, interactive whiteboards, interactive tabletops, and device ecologies. For each, we describe the technology, provide illustrative examples, summarize existing research, and forecast the future of that technology.

Tangibles

The term tangible user interface was coined and introduced by Ishii and Ullmer (1997) as an extension of the idea of the "grasp and manipulate" interface to make computing truly invisible and ubiquitous. *Tangible user interfaces* (or tangibles) augment the physical world by coupling digital information and everyday physical objects and environments. Tangibles are of significance to education as they have the potential to provide learners an innovative way and a novel form of interacting with physical objects that have been augmented with digital displays and computational power (O'Malley & Fraser, 2004; Price, Rogers, Scaife, Stanton, & Neale, 2003). Proposed benefits to education include learning through action with the use of the tangible interfaces. By playing with physical manipulatives, learners can engage in a self-directed and purposeful environment to build representational mappings to explain symbolic concepts (O'Malley & Fraser, 2004).

Tangibles can be comprised of *construction kits* (electronically enhanced objects that can be interconnected to achieve functionality) or *object tracking systems* (digital systems that can track the location of objects in a space to achieve functionality). Using the Topobo construction kit, a child can assemble a colorful robot with passive and active components (Raffle, Parkes, & Ishii, 2004). She then programs that robot through manipulation: in record mode, she manually moves components; in play mode, the robot reenacts to those motions. In the Mathematical Imagery Trainer, which uses an object tracking system, students ground mathematical notions of proportions in embodied interaction (Abrahamson, & Trninic, 2011). Learners move two tennis balls, attempting to keep their respective heights above the table in the same predefined proportion. If the ratio is maintained, the screen displays green; if the ratio is off, the screen displays red (Fig. 55.1). Thus, she can gain an intuitive understanding of proportions through the movement of tangibles.

Tangibles provide children an innovative way to learn by providing a hands-on system that can be flexibly programmed to provide feedback (Price et al., 2003). The work on tangibles is extensive and a full summary is beyond the scope of this chapter, but can be found elsewhere (Shaer, & Hornecker, 2010; Zaman, Abeele, Markopoulus, & Marshall, 2012). In essence, tangibles provide opportunities for the research and development of educational technologies that combine physical and digital representations that leverage familiar tabletops environments along with advanced computational resources. In regard to potential learning benefits, Zaman et al. (2012) point out that tangibles improve accessibility of the interaction, bi-manual control, and tight coupling of manipulation of physical object and its digital representation. We briefly return to the subject later when we focus on tangible-based interactive tabletops.

Fig. 55.1 In this example, a learner is trying to achieve a ratio of 1:2. In the *left panel*, the screen is red because the tennis balls are raised to about the same height. In the *right panel*, the screen is green because the tennis balls are in the right proportion

Interactive Whiteboards

Standard *interactive whiteboards* (IWBs) project an image onto a large vertical surface; a short-throw, or ultra-short-throw, projector is used to avoid shadows cast by users' heads. A standard IWB connects to a desktop computer, substituting the projected image for the monitor and pen input for the mouse. To enable text entry, software systems usually support an on-screen keyboard. A positive outcome of leveraging existing desktop computing is an increased adoption rate. Desktop computers are cheap and applications for them numerous, available, and affordable. Teachers can simply use software that they are already familiar with. Hence, IWBs have become broadly adopted in classrooms in North America, the UK, and Europe. Adoption has been particularly well funded and substantial in the UK (Moss et al., 2007); consequentially, much of the research reported here is based on the large-scale adoption in this geographical region.

In general, IWBs have furthered whole-class instructor-centered pedagogy (Glover, Miller, Averis, & Door, 2005; Higgins, Beauchamp, & Miller, 2007), with significantly less group work than a traditional classroom (Smith, Hardman, & Higgins, 2006). As with other new technologies, teachers require significant support and experience to become comfortable and proficient (Armstrong et al., 2005). Consequently, an instructor's use changes over time (Beauchamp, 2004). Initially, the IWB is used as a substitute for a conventional whiteboard or as a delivery mechanism for lectures slides. Pedagogically, interactive whiteboards can "reinforce a transmission style of whole class teaching in which the contents of the board multiply and go faster, whilst pupils are increasingly reduced to a largely spectator role" (Moss et al., 2007, p. 8). As teachers gain competence and confidence, they integrate more interactive elements, such as asking questions of students, i.e., the common Initiate-Response-Feedback pattern, and use a wider variety of applications. They spend more time preparing and reusing content. While students are more active in this phase of adoption, the questions tend to be faster paced and the answers briefer than in a conventional classroom (Smith et al., 2006). When teachers feel sufficiently comfortable, they seek out opportunities to actively involve students with the technology. The IWB becomes part of their everyday teaching practice and they would not want to give it up (Beauchamp, 2004; Miller, Glover, & Averis, 2004).

While the experience of the teacher does correlate with more student involvement, it is a difficult goal to achieve. A common initial pattern is for students to present their work to the class; nevertheless, these attempts tend to be unsatisfactory and the practice is soon dropped (Smith et al., 2006). One severe limitation is the reality of one IWB per classroom. While asking the students questions is considered interactive, only one out of many students is interacting with the teacher at any one time. While the IWB can be an appropriate technology for small-group collaboration, this still leaves the vast majority of a typical class to do something else (e.g., Kershner, Mercer, Warwick, & Kleine Staarman, 2010). In summary, the IWB has been shown to be a useful classroom technology for supporting whole-class activities and ill suited for supporting small group work at scale.

A potential negative outcome of adopting desktop computing for IWBs is that innovations in instruction and learning may be hampered. While specialty software can be developed to support more effective forms of teaching (e.g., Miller et al., 2004), most classroom use of IWBs is based on fairly uninspired software, such as digital-ink whiteboard software or PowerPoint. Furthermore, built to emulate conventional mouse-and-keyboard input systems, IWBs are limited to one access point, i.e., one pen can be used at a time, even for systems that provide multiple pens. Thus, though multiple individuals have access to the generous space of the whiteboard, they are limited to sharing a single input device. This can be awkward when, for instance, multiple students have to add their contributions to the whiteboard, a common task for (noninteractive) whiteboard use.

Despite noted drawbacks of the first generation IWBs, next-generation IWB technology is improving: wider display formats (16:10, rather than 4:3) are becoming available, touch input is supported, and multiple access points (usually four simultaneous contact points) are possible with new hardware and realized by specialty software. These foundational improvements may eventually change how IWBs are used in the classroom, particularly for supporting small group interaction. Nonetheless, that potential is not yet documented in current studies, opening a potential research agenda.

Interactive Tabletops

Whereas IWBs are large vertical surfaces, *interactive tabletops* are large horizontal displays that enable interaction. Early research on tabletops used a whiteboard flipped on its side (e.g., Arias, Eden, Fischer, Gorman, & Scharff, 2000; Eden, 2002; Kharrufa, Leat, & Olivier, 2010). This approach is somewhat problematic as IWBs are significantly larger than tabletops. In commercial practice, even small IWBs have four times the surface area of large tabletops. IWBs are designed for displaying content to observers at a distance and can be navigated when horizontal only by walking around. In contrast, users at a tabletop remain somewhat stationary and must navigate the table by limited arm reach (Rick, Harris et al., 2009).

IWBs differ from interactive tabletops in that the latter support multiple user perspectives and multiple concurrent users. As widely adopted desktop operating systems such as Microsoft Windows tend to support neither, interactive tabletops commonly use custom operating systems and development environments. This difference has practical and research implications. Practically, there are few applications for interactive tabletops. Research-wise, it includes designing interfaces that can accommodate these features.

Whereas IWBs are suitable for whole-class learning, tabletops are most compelling for small group work (Eden, 2002; Rick, Rogers, Haig, & Yuill, 2009). Tabletops support awareness of others' actions (Hornecker, Marshall, Dalton, & Rogers, 2008). The horizontal orientation allows users to hover their arms and hands comfortably over the interactive surface, even when not actively seeking explicitly to coordinate actions. As a result, gesture-based communication can often supplement or even supplant verbal communication (Rick, Marshall, & Yuill, 2011), which has been reported to facilitate thinking and understanding (Evans et al., 2011). In contrast, users are more likely to rest their arms between actions when using an IWB due simply to fatigue. Tabletops also support concurrent input and quick transition in who has control. Thanks to these benefits, users are able to engage in more efficient problem solving and peer-supported learning, and groups are able to negotiate conflict to reap potential benefits of colocated collaborative learning (Fleck et al., 2009; Pontual Falcão, & Price, 2009).

While IWBs have been commercially available for a significant time, interactive tabletops have only been so since 2009 with the introduction of the Microsoft Surface. Nevertheless, there is already substantial work on using tabletops to support learning. Dillenbourg and Evans (2011) summarize this work, focusing on the pedagogical considerations. Higgins, Mercier, Burd, and Hatch (2011) summarize this work, focusing on technological considerations in light of instructional design. In terms of opportunities to support learning, Dillenbourg and Evans (2011) indicate that tabletops align well with foundational pedagogical considerations of computer-supported collaborative learning: (1) they support multiple users for interpersonal interaction; (2) the requisite software permits for enhance interdependence among learners, and (3) they encourage multiple perspectives on a shared space. In terms of tabletop technology and instructional design, Higgins et al. (2011) note that the advancement of the field now allows for the generation of design principles to support co-constructive learning as well as promote the longevity of tabletops. In essence, tabletop technology and research on learning with these tabletops has reached a degree of maturity where the focus now can be placed on instructional design, learning, and assessment.

Given the late arrival of commercial systems, most current research is based on proprietary research hardware, such as the DiamondTouch (Dietz, & Leigh, 2001), or homespun systems based on computer vision tracking systems. While IWBs primarily use pen input, tabletops use touch input or the tracking of tangibles tagged with fiducial markers. In the following sections, we divide the summary into these two primary categories.

Touch-Based Tabletops

Multi-touch tabletops can be used to support small-group collaboration in a variety of settings (Scott, Grant, & Mandryk, 2003). Researchers have created applications to support learning in areas of reading (Sluis et al., 2004), time progression (Rick et al., 2010), sustainability (Antle, Bevans, Tanenbaum, Seaborn, & Wang, 2011), and genomics (Shaer et al., 2012). When used for collaboratively highlighting text and taking notes, a multi-touch table was found to have significant advantages over pen-and-paper (Piper, & Hollan, 2009). One learning strategy that has been employed more than once is getting participants to solve a mystery based on a set of textual clues (Kharrufa, Leat et al., 2010; Kharrufa, Olivier, & Leat, 2010). In comparison to doing the same task with paper pieces, it was easier for groups to collaborate using the interactive tabletop. For these tasks, participants can move clues around and resize them to better negotiate the puzzle, e.g., similar clues go together, or more important or active clues are maximized. It was determined in these studies that interactive tabletops afford modes and forms of interaction among colocated peers that enhances the learning experience and outcomes.

Another example is the DigiTile project, where learners were given mathematical challenges to solve on a tabletop (Fig. 55.2). After a 30-min session, the children showed significant differences in their understanding of fractions (Rick Rogers et al., 2009). Rick et al., 2011 concluded that interaction patterns of the children varied dramatically, demonstrating the versatility that interactive tabletops have to support a variety of collaboration styles.

Tangible-Based Tabletops

Tangible-based tabletops are interactive surfaces where the interaction is carried through by positioning and orienting tangible objects on the display surface. The objects are usually tracked through a vision-tracking algorithm. For instance, in the "Physics of Light" project (Pontual Falcão, & Price, 2009; 2011), colored blocks and flashlights have fiducial markers attached to their bottom side. A camera is positioned below the tabletop's surface to track the fiducials—and thereby the objects—on the tabletop. A projector projects a white light beam from the flashlights that can reflect and

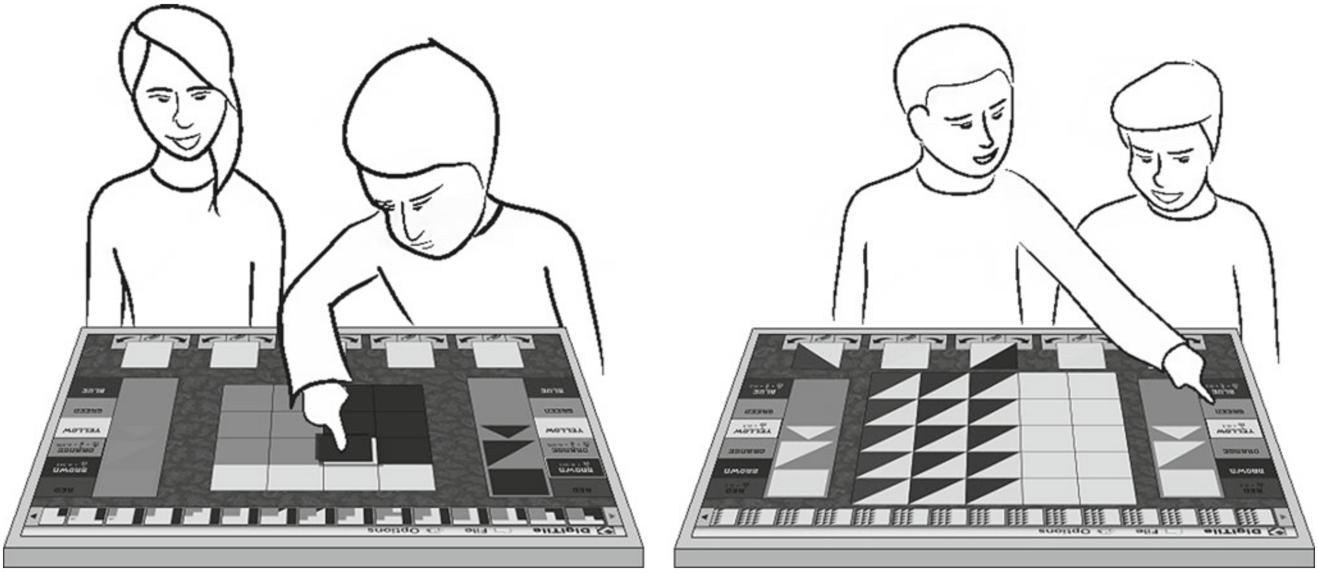

Fig. 55.2 Using DigiTile, students work in pairs to solve various mathematical challenges: (*left*) create a tile that is 3/8 orange and 3/8 brown; (*right*) create a tile that is 1/10 red, 2/10 blue, 3/10 yellow, and 4/10 green

refract off the colored pieces, allowing students to learn about the composition of light.

Tangibles are particularly easy for younger children to maneuver, enabling even young learners to collaborate (Marco, Cerezo, Baldassarri, Mazzone, & Read, 2009). Studies show that the manipulation of physical objects is key in the learning of early childhood education students (Khandelwal & Mazalek, 2007). Using a touch interface with tangible objects that are recognizable by a tabletop, the user can not only integrate tangible objects, but also associate sounds to objects and actions, thus providing "voice feedback and cues coupled with visual feedback on the table's surface" (Khandelwal & Mazalek, 2007, p.192). An example of this is a scaffolding technique used with PreK students where vocal hints are given based on input to guide the learner as needed to an acceptable solution. A more advanced form of this, although leaning more towards the tangibles rather than sound, is the Reac-Table, allowing networking of touch tables which facilitates interactions among many users, each manipulating objects that are not connected by the system (Jordà, Geiger, Alonso, & Kaltenbrunner, 2007).

Another example, the Tangram Tabletop System or "TanTab," bridges between fully intuitive physical manipulation of tangrams, a mathematical manipulative for exploring geometric concepts, and explicit control of the geometric parameters that underlie the manipulation (Evans, 2009). TanTab is an *extended* interactive tabletop system that uses tangrams as tangible user interfaces to mediate geometric learning while supporting group play among PreK students. In TanTab, children transition gradually through three modes from direct manipulation of physical geometric objects (i.e., tangram pieces) to interaction with virtual objects. The system comprises a down-looking camera that captures and tracks physical objects and hand/finger/wand gestures performed on a 30-in. LCD display embedded in a tabletop frame. See Fig. 55.3 for details. The affordances provided by TanTab are grounded in theories of geometric thinking and empirical studies on Prek-2 learners using virtual manipulatives (Evans & Wilkins, 2011; Evans et al., 2011).

The reported benefits accrued from these technologies include affording multimodal learning, leveraging virtual manipulatives for developing mathematical thinking, and supporting peer-assisted learning. Zufferey, Jermann, Lucchi, and Dillenbourg (2009) claim, with work on TinkerSheets, that the combination of tangible blocks, paper sheets that provide simulation parameters, and a top-down projector provided an engaging environment to augment the training of young adults entering technical fields. Tangible-based tabletops, though demonstrating potential to support colocated collaborative learning (Evans & Wilkins, 2011; Evans et al., 2011), require significant effort and time in terms of coordination across computer scientists, domain area experts, learning scientists, and educational technologists. Given that tangible-based tabletops exist in terms of technologies and affordances between interactive tabletops and IWBs, effort is now placed on combining the two to support larger group learning in what can be referred to as an ecology of devices and displays. In the next section we highlight work in this emerging area.

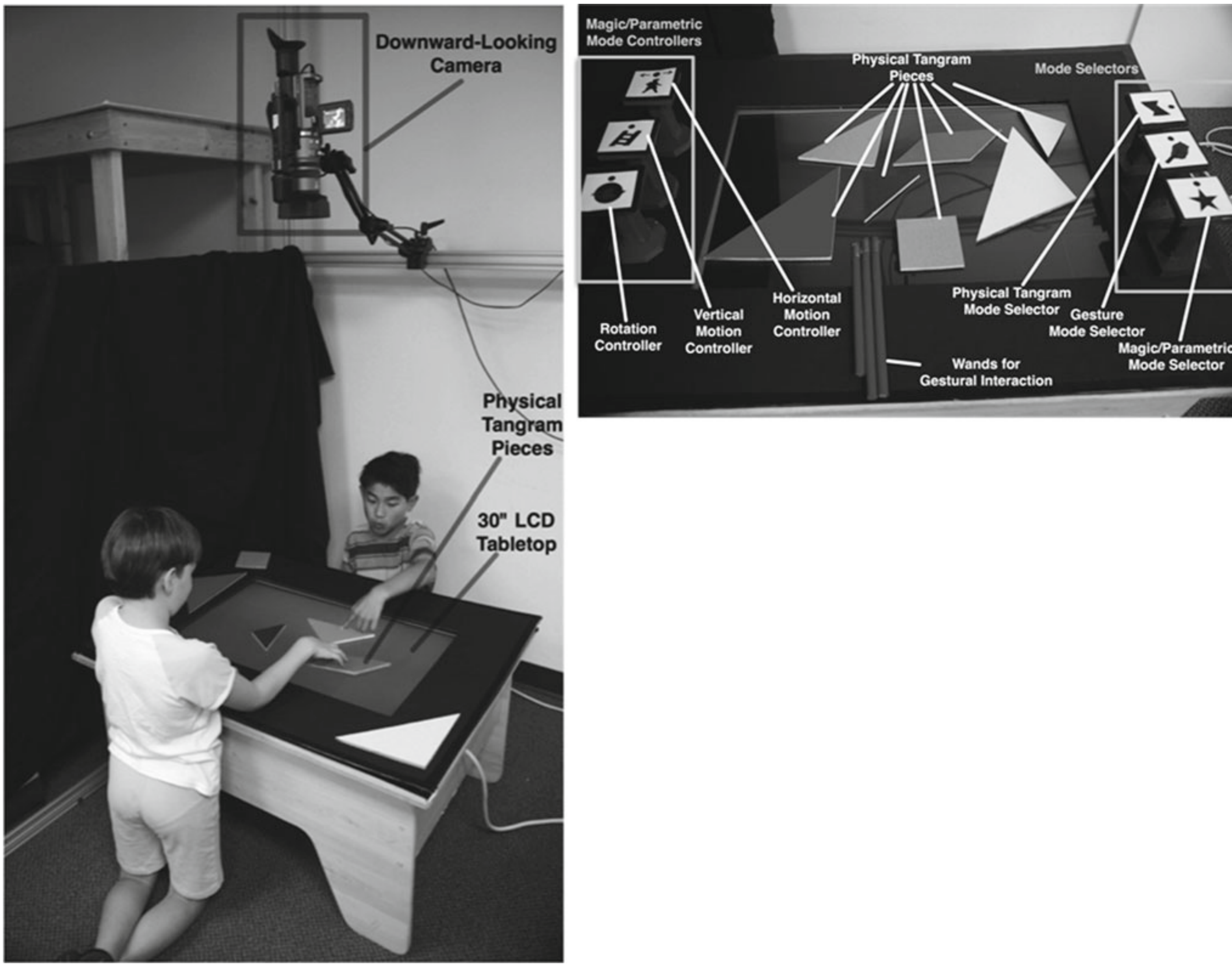

Fig. 55.3 The TanTab System, comprised of a computer vision-tracking camera, LCD monitor, and various tangible user interface controls, was developed to promote mathematical thinking in early childhood education. TanTab allows users to cross modes of operation, from physical mode to gestural mode to parametric mode, each differently supporting the learning and abstraction of mathematical constructs and relationships

Interactive Spaces: Ecologies of Devices and Displays

The technologies covered so far in this chapter only support a small number of active users, usually three or four. While IWBs are usually employed for whole-class activities, only one person—in most cases, the teacher—is active at one time. Tangibles and tabletops do lend themselves more readily to small-group interactions and collaborations. Classrooms, obviously, contain far more students requiring attention and opportunities for active learning. How might interactive surfaces and spaces, when used in combination as *ecologies of devices and displays*, support a larger number of users simultaneously?

The idea of ecologies of devices and displays posits that as computing and communication technologies become ubiquitous, they must also function within ecologies of mutually supporting, interacting, and cooperating (or competing) elements. One approach is to put multiple technologies or multiple instances of the same technologies in one classroom (e.g., Hoppe et al., 2000). Building on Weiser's (1999) vision of ubiquitous computing and our own definition of ecologies of devices and displays, these technologies can then communicate for specific applications (e.g., Lyons, 2007; Roschelle et al., 2007). Alternatively, the affordances of a particular ecology of devices can be investigated (e.g., Lui, Tissenbaum, & Slotta, 2011). In the SynergyNet research project, the classroom features four horizontal tabletops for students, one angled tabletop for the teacher, and a whiteboard to lead whole-class discussion (Higgins et al., 2011). In the NumberNet application, students work in small groups to solve simultaneously mathematical problems. In successive rounds, the results are transferred from one tabletop to

Fig. 55.4 In SMALLab, learners can actively engage a variety of tasks, including (*left*) simulating how chemical particles diffuse and (*right*) exploring the relationship between gravity and projectile flight

another, thereby fostering both in-group and between-group collaborations (Hatch, Higgins, Joyce-Gibbons, & Mercier, 2011). For instance, in a number generating task, the children produce different expressions to arrive at the same result (e.g., 78 = 77 + 1, 78 = 76 + 1 + 1, 78 = 75 + 1 + 1 + 1). By rotating results around the tabletops, children can build on the innovation of their peers.

Another approach is to scale the interactive space to include the whole class. In the RoomQuake project, the entire room is transformed into an earthquake simulation based on a series of interconnected wall-mounted flat-panel computers and speakers (Moher, 2006). When a quake hits, the children must work together to find the fault lines. In the WallCology project, wall displays simulate windows inserted into the classroom walls, where simulated life forms live (Moher, Uphoff, Bhatt, Silva, & Malcolm, 2008). Classrooms of children collaborate to track the creatures and understand what conditions allowed them to prosper. The SMALLab environment takes a more high-tech approach, supersizing the interactive space. A large image is projected onto the floor. To control applications, users maneuver tangibles that can be quickly and precisely tracked in three-dimensional space (Fig. 55.4). A variety of learning activities, such as layering a sediment cake for earth sciences, have been created for the system (Birchfield & Megowan-Romanowicz, 2009). SMALLab is large enough for an entire class: several students can interact simultaneously, the others can observe their actions, and the teacher can lead active discussion.

Direct Input

A distinct benefit of interactive surfaces is support for direct input. In comparison to moving a mouse to control a cursor, the cognitive distance between intent and execution is shortened when using direct input, i.e., the user's physical input action directly corresponds to her intention on the display. The advance is a direct coupling of input and output without an offset or indirect mapping. In situations with multiple participants, a potential learning benefit is that hand, arm, and body movements are visible. Consequently, an instructor can transition easily from pointing to an interface element for explanation to manipulating that interface element directly. As a result, IWBs that use direct input have been shown to improve the instructor's presentation methods, motivate students, and further enhance learning overall (Glover et al., 2005; Higgins et al., 2007).

Direct input is particularly beneficial to younger children, who have a harder time bridging the additional cognitive distance between physical actions and cursor movement on the screen while lacking the dexterity to properly control a mouse. This impediment can lead to frustration and inevitable abandonment of the activity. Several popular YouTube videos show preverbal children successfully operating touch-based handhelds or tabletops. One tangible-based tabletop project demonstrated how the manipulation of physical objects could be key to learning for PreK students. In their study, Khandelwal and Mazalek (2007), had children position tangible objects with associated sounds, thus providing voice feedback and cues coupled with visual feedback on the table's surface.

Multiple Access Points

Interactive surfaces and spaces have the additional benefit of being able to support multiple access points (Church, Hazlewood, & Rogers, 2006). Tangibles almost exclusively involve manipulating or combining multiple pieces. Interactive tabletops track multiple touch points, multiple tangible pieces, or both. Though conventional IWBs have been an exception as indicated above, recent IWB technology increasingly supports multiple access points.

For a single user, this has several benefits. First, it can enable a richer set of gestures to control the interface, such as using two fingers to scroll or a pinch gesture to zoom on a multi-touch system. Second, it allows the user to easily switch which hand they use. Such bimanual interaction has been shown to be more efficient (Forlines, Wigdor, Shen, & Balakrishnan, 2007). Third, both hands can be used simultaneously. For example, in the Hands-On Math project, users position and scale virtual paper with the left hand while entering equations with the pen in the right hand (Zeleznik, Bragdon, Adeputra, & Ko, 2010).

Furthermore, the multiple access points can be distributed among multiple users. In comparison to devices with a single access point, such as a pen on an older IWB or a mouse-and-keyboard on a desktop computer, concurrent input or swift transition between which user has focus has been shown to lead to inequitable interaction (Evans, & Wilkins, 2011; Harris et al., 2009; Rick, Harris et al., 2009). It should be noted that, with the exceptions of a few research systems (Dietz & Leigh, 2001; Martínez, Collins, Kay, & Yacef, 2011), these systems do not track which user is associated with each specific access point. This has implications for usability and functionality. For instance, a concept mapping application on an interactive tabletop cannot automatically connect a user's keyboard with the textual node they are trying to edit. In some learning tasks, it is useful to enforce collaboration by allocating different responsibilities to different users or by enforcing turn taking (Kerawalla, Pearce, Yuill, Luckin, & Harris, 2008; Piper, O'Brien, Morris, & Winograd, 2006). This point derives from the finding that learners, especially PreK and elementary-aged, do not inherently exhibit or understand collaboration and coordination in learning (Evans & Wilkins, 2011). Therefore, it is feasible that future commercial interactive surfaces and spaces will correct this deficiency, while current systems must be used in ways to avoid or negotiate this limitation.

Colocated Collaborative Learning

There is an established computer-supported collaborative learning (CSCL) research community with an eponymous biannual conference and international journal. A foundational tenet of that community is that collaboration is a preferred method to promote learning and that computer technology can support that learning. Until recently, the community has been dominated with research on Internet-based distance learning. Interactive surfaces and spaces are changing this trend by providing new opportunities to support colocated collaborative learning (Dillenbourg & Evans, 2011).

While there are notable exceptions (e.g., Roschelle, 1992), desktop machines are not particularly well suited for colocated collaboration that promotes kinesthetic learning. True, there have been innovative uses of networked desktops for distance and synchronous learning in the fields of medicine and engineering (e.g., Kochsmann 1995). Nevertheless, desktop (or "personal") computers have been designed for a single user and normally feature only a single keyboard and a single mouse, severely limiting either smooth transitions or colocated collaborative efforts (Evans & Wilkins, 2011). In contrast, interactive surfaces and spaces are designed inherently as *shareable interfaces*—interfaces that support more than one user and facilitate interaction and communication among them (Rick, Rogers et al., 2009).

As summarized in the previous section, multiple access points support multiple users. The value to learning of supporting multiple users has been demonstrated by multiple mice systems (Inkpen, Booth, Klawe, & Upitis, 1995; Inkpen, Ho-Ching, Kuederle, Scott, & Shoemaker, 1999; Nussbaum et al., 2009; Stewart, Bederson, & Druin, 1999). The direct input of interactive surfaces provides useful support in awareness of others' actions (Hornecker et al., 2008). Hand and arm movements are particularly noticeable, enabling peripheral awareness of partners' actions (Rick et al., 2011). In addition, the physical actions can act as powerful "communicative modality" (Roth, 2001) to complement or supplement verbal communication; this most readily benefit young children, who find it difficult to express their thoughts, and novices, who have yet to develop sophisticated vocabularies in the target domain.

Of course, the affordances of a specific technology affect how colocated collaboration is supported: vertical displays are more appropriate for multiple presenters, while horizontal displays lend themselves to small-group work (Rogers, Lim, Hazlewood, & Marshall, 2009).

Kinesthetic Learning

Direct input interfaces, whether touching the interactive surface or manipulating tangible pieces, also lend themselves to *kinesthetic learning*—the learner physically interacts with the learning experience. The value of such learning is that abstractions can grow out of these bodily activities and that understanding and thinking are then represented through perceptual motor activities (Nemirovsky, 2005). For instance, when controlling the HarmonySpace musical environment on an interactive floor, a user can dance to add both a rhythmic and performance element to their interaction (Holland et al., 2009). From Piaget onwards, the sensorimotor system is considered to be a fundamental component and driver of cognitive development. A user study demonstrated a 19 % increase in spatial memory for information controlled with a touchscreen, which provides direct kinesthetic cues, compared to a standard mouse interface (Tan, Pausch, Stefanucci, & Proffitt, 2002). Finally, Evans et al. (2011) demonstrated that nonverbal communication, as expressed through gesture and posture, are integral components to the development of geometric thinking in PreK students. Working with virtual manipulatives on a multi-touch tabletop, small groups of girls and boys coordinated verbal and nonverbal actions to build understandings of fundamental geometric operations such as translations.

Implications for Educational Practice

As interactive surfaces and spaces continue to find a place in classrooms and other learning settings, we are cautiously optimistic that they could transform educational practice. As this chapter demonstrates, these technologies are particularly suited for supporting active learning, whether in whole-class activities or small group work. Hence, it will be increasingly possible for students to take an active part in whole-class activities. For instance, the affordances provided by device and display ecologies such as those provided in Wallcology can facilitate the sharing of information between students to a public space to engage the entire class in an activity. The evolution of IWBs is another case in point that illustrates the benefit of these types of affordances. Traditional whiteboards are easy to use for group tasks of multiple students writing on the board at the same time. Older IWB technology actually impeded these activities by supporting only one access point. Newer IWBs will once again allow for such activities, perhaps even enhancing them by enabling additional features, including archiving contributions, magnifying contributions to facilitate whole-class discussion, recombining multimedia records, and replaying actions to be used for reflection activities.

In a standard classroom, it can be difficult for a teacher to orchestrate and manage small group work. Groups clamor for attention, ignoring the needs of others. Monitoring the progress of multiple groups is challenging. Interactive surfaces and spaces could assist. The systems could provide real-time feedback to groups on the learning task, making it less likely that groups will need assistance or permission from the teacher to make progress. They can also provide feedback on the collaborative process, enabling groups to reflect on their interactions (Bachour, Kaplan, & Dillenbourg, 2010). They also offer teachers unique opportunities to orchestrate or script the collaboration, inside groups and between (Dillenbourg & Jermann, 2010). If the system could recognize who makes what contributions, then it could provide incentives to collaborate, such as enabling particular features only when students coordinate (Benford et al., 2000).

Implications for Educational Research

In this chapter, we have given an overview of the current research on using interactive surfaces and spaces to support learning. While that research is already strong enough to show the potential of this new technology to transform learning, there is still much to understand about how such technologies could be integrated into classrooms (Laurillard, 2009). To make effective use of these new tools requires an understanding of how to design learning environments and pedagogical approaches that take full advantage of what they have to offer. Thus, what is needed is research to understand how these new technologies influence the individual learner, group collaboration, and whole-classroom orchestration (e.g., Jamil, O'Hara, Perry, Karnik, & Subramanian, 2011). Just because these interfaces are more enjoyable to use does not mean that they are inherently more effective (e.g., Do-Lenh, Jermann, Cuendet, Zufferey, & Dillenbourg, 2010).

When considering an entire classroom, additional research issues arise, such as the organization of the physical space, supporting the teacher in orchestrating activities, and designing for the practical constraints of the classroom. As yet, little work has been done in this direction (Higgins et al., 2011). The base technologies may be well understood, but serious work will be needed to integrate that base technology into practical learning contexts.

New technologies are arriving and older technologies are maturing. Currently, tablets are being widely adopted in the home and commercial settings. There is already steep interest in bringing these into the classroom, even if current efforts are limited to digital textbook initiatives (Lim, Song, & Lee, 2012; Nelson, 2008). As interactive surfaces and spaces mature, technological progress will lead to additional educational opportunities. Educational technology research needs to bridge the gap between the two. In this chapter, we have given an overview of the existing work, but also pointed to limitations in existing research and opportunities for future research. Ultimately, much work—research, development, distribution, etc.—must be done before the implications for educational practice can be realized.

Conclusion

As we write this chapter, the ubiquity of smartphones, tablet computers, IWBs, and large LCD displays is reaching a saturation point due to lower cost production and market demand. Contributing to this phenomenon is the imminent release of software systems, most notably Microsoft 8 and Apple iOS 6, which have been developed from the ground up as multi-touch environments that deploy across a host of devices. We are not suggesting that these hardware and software developments should dictate educational research and practice. What we have proposed in this chapter is that hardware and software are approaching levels of interactivity and usability that may better serve the learning theories and pedagogies that underlie our work—positions that value colocated collaborative learning, verbal and nonverbal interaction among peers, and kinesthetic learning. As we have pointed out, the limits of desktop computing and the default single input mode have constrained how we can research and deploy educational technologies that rely on the highly constrained communication and computational resources provided by extant hardware and software. In this chapter, we have gone into some detail to describe the technology only because we feel it important to understand the obstacles overcome by the investigators and their work reported. Given the sense among researchers in the community that interactive surfaces and spaces have reached a point of stability, the time is now to focus on the affordances of these technologies to support learning (Dillenbourg & Evans, 2011; Higgins et al., 2011; Zaman et al., 2012). Interactive surfaces and spaces have the potential to lead a paradigm shift in how we envision and design educational technologies to support learning, particularly where colocation, kinesthetic learning, and closer coupling of the physical objects and digital representations are valued pedagogically. With this understanding, we intend that the next generation of educational technologists and educational researchers can take full advantage of interactive surfaces and spaces to support learning, rightfully placing primary focus on understanding learning and improving practice.

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Smart Toy Based Learning

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Abstract

This chapter examines the general characteristics of and related recent research on smart toys. Smart toys can be defined as new forms of toys featuring both tangible objects and electronic components that facilitate two-way child–smart toy interactions to carry out purposeful tasks. In this chapter, smart toy based learning projects are discussed and the characteristics of smart toys as cognitive tools to facilitate learning are analyzed. This chapter also covers the relationship between smart toys and children's developmental stages—with a particular focus on motivation—in order to understand smart toys' potential effects on children.

Keywords

Toy • Smart toy • Cognitive tool

Introduction

Play holds an important role in children's cognitive, social, and behavioral development. According to Boucher and Amery (2009), play helps children to learn, develop, gain confidence, and manage experiences through exploration, creativity, entertainment, and socialization. Similarly, Levin and Rosenquest (2001) argue that play helps children learn to control their actions, interact with people, and explore the world. Children's play is often mediated by toys. Toys are objects that encourage children's expression, fantasy, interest, exploration, construction, education, cognitive development, and sex-role learning (Axline, 1974; Peretti & Sydney, 1984). Playing with toys is crucial to a child's life and this play supports learning and development (Butterworth & Harris, 1994). In this context, children's toy preferences are of great importance in terms of not only fun but also with respect to developmental and cognitive stages.

Technology-based toys are among children's most preferred options in today's world. With rapid growths in technology, related toys have become widespread in the market. World toy sales grew by nearly 5 % in 2010 to 83.3 billion US dollars (The NPD Group Inc, 2011). According to the Toy Industry Association, Inc. (2007), electronic toys were the largest growth category in the industry, with a 17 % increase. The same report indicated that electronic toys with educational purposes consisted of 60 % of total purchased electronic toys.

A popular type of technology-based toy is the smart toy. Smart toys include tangible objects alongside electronic components that facilitate two-way child–smart toy interaction to carry out a purposeful task. In this chapter, purposeful tasks refer to behavioral and cognitive tasks that children conduct as they play with smart toys. Smart toys promise to provide an interactive environment in which children develop cognitive, social, and behavioral abilities by means of the toys' dynamic structure.

Although several smart toy projects appear in the literature, a limited number study these toys from educational

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and developmental perspectives. Additionally, the common characteristics of these toys and their foci on the developmental stages and motivation of children have not been covered adequately. Therefore, the purpose of this chapter is to provide general characteristics of smart toys by referring to specific examples while presenting the dynamics of smart toy based learning in accordance with children's developmental needs and inner motivation conditions. This chapter also discusses smart toy based learning in the light of learning through interaction and analyzes smart toys as cognitive tools. In all, this chapter presents six topics: (1) Key characteristics of smart toys; (2) Smart toy projects; (3) The relationship between smart toys and developmental periods of children; (4) Smart toys from the perspective of intrinsic motivation; (5) Smart toys as cognitive tools; and (6) Future implications.

Key Characteristics of Smart Toys

Smart toys exist today in a variety of forms based on the ways in which children interact with them and the sorts of purposeful tasks they initiate. Purposeful tasks are the main function that distinguishes smart toys from their counterparts. For instance, a toy mobile phone simply plays tones when buttons are pushed, but no further action is demanded of the child. While such classic electronic or digital toys use technological features only to increase attraction to the toy, smart toys allow for mutual interaction and encourage purposeful tasks. These smart toys can be categorized based on the kinds of tasks initiated, namely, behavioral tasks or cognitive tasks. Smart toys featuring behavioral tasks aim to enhance behavioral skills of children. For instance, with one smart toy, the Furby, children can hone behavioral skills by caring for and treating the toy like a real, live creature. Similarly, with Fisher Price's Learning Kitchen, children can develop simple behaviors, such as opening and closing the refrigerator. On the other hand, smart toys prompting cognitive tasks mainly emphasize on children's cognitive skills. For instance, children can practice storytelling and reflection while playing with a smart toy such as StoryMat (Ryokai & Cassell, 1999). Similarly, Fisher Price's Learning Lantern is intended to teach numbers, counting, opposites, animals, and greetings by providing lively sing alongs, musical tones, and interactive dancing lights. In addition, the LeapFrog Fridge Phonics Magnetic Letter Set smart toy is designed to teach letter names and phonics by talking and singing a song about the selected letter.

The other categorizations of smart toys are based on interactions, namely, smart toys that interact with computers or smart toys that are self-contained. An example of a smart toy that interacts with computers is Rosebud (Glos & Cassell, 1997), which includes stuffed animals integrated with a computer that identifies each animal's internal transmitter and presents a dialogue box for the child to create a story (see Fig. 56.1).

Fig. 56.1 A child playing with Rosebud (Glos & Cassell, 1997)

Similarly, with StoryTech (Kara, Aydin, & Cagiltay, 2012a), when a child puts a plush toy or background card on a receiver panel, the related character or picture appears in a Flash animation on the screen. The aim of this smart toy is for children to create their own imaginative stories (see Fig. 56.2).

In contrast, self-contained smart toys can be considered as a unique device with integrated digital features. These self-contained smart toys include play sets, play spaces, or environments with interactive objects and characters or may include digitally combined objects or characters within their structure rather than requiring an external computer. For instance, Sifteo, aka Siftables (Merrill, Kalanithi, & Maes, 2007), features physical blocks with integrated electronic chips. Children produce different word and image combinations using Sifteo (see Fig. 56.3).

Two-way child–toy interactions are another significant characteristic of smart toys. According to Price and Rogers (2004), interacting in digitally enhanced physical spaces has two key components: (1) raising the awareness of children about their activities, and (2) providing children with richer experiences by combining physical and virtual realities. In smart toy play, child–toy interaction is also important in terms of technological components and instructional activities. StoryTech (Kara et al., 2012a) is another example of this kind of interaction.

In most smart toys interaction is facilitated with electronic sensors in the toys so children can build richer interactions, either directly or mediated by computers (Luckin, Connolly, Plowman, & Airey, 2003). Resnick (1998) pointed out that orchestration and coordination of interactions among playthings is also a large part of children's play and learning. According to Roussou (2004), many educational technologists support the idea that interactivity is a necessity in

Fig. 56.2 Children playing with StoryTech (Kara et al., 2012a)

Fig. 56.3 An example of application with Sifteo (Hunter, Kalanithi & Merrill, 2010)

learning, and the author emphasized further that meaningful tasks lead children to take learning more seriously. McVee, Dunsmore, and Gavelek (2005) stated that interaction between material and activity has deep implications for learning and cognition. The authors also pointed out that interaction with materials or tools helps learners build knowledge relationships. In smart toy play, learning through interaction can be defined as learning several concepts or skills combined with purposeful tasks that are accomplished by interacting with fun technological and instructional components. For instance, with StoryTech (Kara et al., 2012a, 2012b), children can improve creativity and imagination through storytelling by interacting with plush toys and multimedia features of the computer environment. With curlybot (Frei, Su, Mikhak, & Ishii, 2000), children practice computational and mathematical thinking through free play with a two-wheeled vehicle smart toy that measures, records, and reports its movements.

Smart Toy Projects

Several smart toy projects appear in the literature. This section introduces those projects by providing details about specific characteristics, working mechanisms, and related research.

Glos and Cassell's (1997) Rosebud was designed to help children write stories about stuffed animals integrated with a computer. Based on the above categorization of smart toys, Rosebud interacts with an external computer and initiates a cognitive task, specifically storytelling. The stuffed animal has an infrared transmitter that sends a unique signal to the computer, which recognizes the stuffed animal by this signal. MIT Media Laboratory researchers tested Rosebud with six children ranging from 7 to 12. The children produced 11 stories, and the authors concluded that the mixed media interface provided richer and dynamic interaction.

Ryokai and Cassell's (1999) StoryMat provides a play space in which children could record and replay their own stories. StoryMat is a self-contained smart toy that does not require interaction with an external computer. It initiates a cognitive task, specifically storytelling. StoryMat has a soft surface featuring several applied figures on which the child moves a small stuffed animal with an ultrasonic transmitter, while the child's narration and the stuffed animal movements are recorded. When the stuffed animal returns to the same place on the surface, narrations are replayed. In a study by Cassell and Ryokai (2001), the members of the Gesture and Narrative Language Group in the MIT Media Lab described their user study with 36 children between the ages of 5 and 8. Children were randomly assigned to either the StoryMat group or the control group. The authors concluded that the children using StoryMat produced more imaginative stories than peers playing with a passive toy. They also pointed out that the ability to produce imaginative objects in a real environment is an important indicator of cognitive development.

Frei et al.'s (2000) Curlybot is a two-wheeled vehicle that measures, records, and plays back its exact movement on any flat surface. Within the categorization of smart toys, Curlybot is a self-contained smart toy requiring no external computers. In addition, Curlybot initiates cognitive tasks, specifically those that are mathematical and computational. Curlybot's two wheels, which are controlled by a microprocessor, not only move forward and backward but also rotate freely. For recording movements, the smart toy includes a memory chip. The child records the movements of curlybot by pressing a button that lights up a red or green indicator. Researchers from the Tangible Media group in the MIT Media Laboratory conducted an informal user study with 81 children. The study showed that children ages four and above playing with Curlybot engaged in computational and mathematical concepts in a more creative way.

Piper and Ishii's (2002) Pegblocks is an educational toy showing basic physics principles to elementary school students. Children manipulate wooden toys connected to each other via electrical cables to observe kinetic energy changes. Based on the smart toy categorization, Pegblocks is a self-contained smart toy that initiates cognitive tasks such as observing and understanding kinetic energy changes. Pegblocks is a set of five wooden blocks. Each block consists of nine pegs combined with electric motors, converting the kinetic energy of the child's hand into electrical energy. Researchers from the Tangible Media Group in the MIT Media Laboratory informally observed children playing with Pegblocks and concluded that they allowed children to see and understand the relationship between electrical and kinetic energy.

Vaucelle and Jehan's (2002) Dolltalk is a computational toy that records children's gestures and speech and plays back their voices. Dolltalk is a self-contained smart toy that initiates cognitive tasks, specifically, linguistic expressions and storytelling. Dolltalk includes a platform with tag sensors, two speakers, one microphone, and two stuffed animals with sensors. When the child removes the two stuffed animals from the platform, recording begins. When the two stuffed animals are placed on the platform again, playback of the narration begins. Researchers from the MIT Media Laboratory conducted a user study with 12 children at an elementary school and concluded that children generally enjoyed their interaction with Dolltalk by frequently repeating the playback.

Fontijn and Mendels' (2005) StoryToy is an environment featuring stuffed farm animals that tell stories and react to each other. Within the above categorization, StoryToy is a self-contained smart toy. It initiates the cognitive task of storytelling. Each plush character has a motion sensor connected to a wireless transmitter that advances play. For instance, StoryToy proposes three modes—free play, reactive play, and story play—based on the location of the duck character. All sensor events are uploaded to the computer via receiver and translated into audio responses by Java. These responses are then sent through a wireless speaker. The researchers from the Philips Research Company and Eindhoven University of Technology conducted their study with children between 2 and 6. The researchers concluded that older children (4–6) considered more complex dialogues enjoyable, but it was hard to follow dialogues of younger children (2–3).

Lampe and Hinske's (2007) Augmented Knight's Castle is a smart toy playset enriching the pretend play of children by providing sound effects and verbal reactions from toys. The Augmented Knight's Castle is a self-contained smart toy that initiates cognitive tasks through fantasy play and imagination. RFID technology detects the position of objects in the playset. Since the Augmented Knight's Castle smart toy is set in the Middle Ages, the objects provide relevant sound effects, background music, and verbal commentary in accordance with the information sensed by the RFID hardware. Hinske, Lampe, Yuill, Price, and Langheinrich (2010) conducted a user study of the smart toy with 103 children ranging from 6 to 10. The authors also conducted interviews with seven teachers to explore their opinions about the smart toy. The findings revealed that it provided significant learning opportunities about Middle Ages, such as clothing, festival, music, and literature for children and increased retention of what they learned after short play sessions.

Merrill et al.'s (2007) Sifteo allows children to interact with electronic blocks to produce different knowledge combinations. Children select electronic blocks in accordance with their desires and create their own patterns. Sifteo is a self-contained smart toy. As explained above, it initiates cognitive tasks through thinking, imagination, and knowledge creation. Sifteo has mainly five components, namely, color LCD screen, accelerometer, infrared transceivers, rechargeable battery, and RF radio. A user's physical manipulations are sensed and considered as input to the system. Visual feedback is displayed on the LCD screen.

Kara et al.'s (2012a) StoryTech allows children to create their own stories in a mixed reality environment by placing plush toys and background cards on a receiver panel connected to a computer. Based on the categorization, StoryTech is a smart toy that requires external computer interaction. In addition, it initiates the cognitive task of storytelling. StoryTech includes three components, namely, story objects (stuffed animals and background cards), the computer, and the receiver panel. RFID tags give unique codes to each story objects. When the child puts the object on the receiver panel, these codes are transmitted to the computer, and the virtual representation of the story object appears on the computer screen. StoryTech incorporates two phases of play: scaffolding and storytelling. In scaffolding, children only place the rabbit or turtle characters on the receiver panel to continue the story told by the narrator. The aim of this section is to prepare children ready for storytelling. Next, children are expected to produce their own stories by using the story objects. Kara, Aydin, and Cagiltay (2012b) conducted a user study with 90 children ranging in age from 4 to 6. For the experimental study, the researchers created experimental groups playing with StoryTech and control groups playing with a passive toy. Based on the results, 5- and 6-year-old children playing with StoryTech produced more complex stories than the control group children. Additionally, the 6-year-old children were the most effective users of StoryTech in collaborative play.

These smart toy projects have several common characteristics. These studies mostly focused on the attitudes and responses of the children rather than their learning outcomes. The input of their teachers was not emphasized during design and development or during the study. Further, these research activities were primarily small-scale user studies.

Smart Toys and Developmental Stages of Children

The relationship between the characteristics of smart toys and the developmental stages of children needs to be analyzed to develop effective smart toy learning environments. Determining the developmental periods of children is important because smart toys need to be developed in accordance with relevant characteristics. A child at age 2 may play with a toy in a completely different manner than at age 5 or 6, if the child wants to play with the same toys at all after a certain age (Kudrowitz & Wallace, 2009). Piaget (1964) separated children's intellectual development into four stages: (1) sensory-motor or preverbal (first 18 months), (2) preoperational representation (2–7), (3) concrete operations (7–11), and (4) formal or hypothetic-deductive operations (after 11). Smart toys may have different characteristics for each stage.

Sensory-Motor Stage

According to Piaget (1962), simple reflexes, actions, and movements are the main activities of children in the sensory-motor stage. Language is not present in this stage, and object permanence is not developed. At this stage, traditional toys such as stuffed animals, dolls, and colorful objects are generally used for developing simple reflexes. Children may also use smart toys with behavioral purposes. For instance, Fisher Price's Learning Kitchen is intended to allow children to learn through everyday experiences and develop simple reflexes such as opening and closing a refrigerator, flipping a light switch, and stirring soup with accompanying music, sounds, and lights. Similarly, Furby allows children to control a virtual character, practicing behavioral tasks by caring for and treating it like a real creature. In addition, Fisher Price's Learning Music Player is designed to enable children to learn and develop basic actions such as skip, rewind, and pause, as well as manipulating volume. A child can listen to songs and watch dancing characters on the screen by pressing buttons (see Fig. 56.4). Compared with traditional toys, these smart toys allow children to develop simple reflexes while also learning simple actions through purposeful tasks.

Fig. 56.4 Learning music player (Fisher Price)

Preoperational Stage

According to Piaget (1962), symbolic functioning and language acquisition are the main characteristics of the preoperational stage. In addition, he explains the significance of language and symbolic functions:

> It becomes possible to invoke objects which are not present perceptually, to reconstruct the past, or to make projects, plans for the future, to think of objects not present but very distant in space (p. 38).

Therefore, cognitive processes are mostly emphasized in this stage, though behavioral processes can also play an important role at first. Hence, smart toys with both behavioral and cognitive purposes are highly suitable for children in this stage. For instance, Fisher Price's Smart Fit Park is designed to allow children to carry out behavioral tasks such as walking, jumping, and running, and enable children to gain cognitive skills with interactive learning activities such as letter identification, counting, subtraction, and spelling.

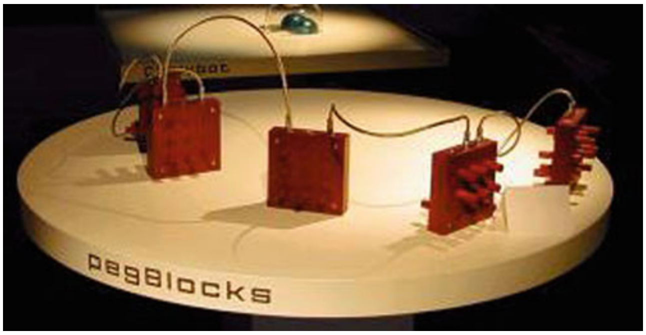

Fig. 56.5 Pegblocks (Piper & Ishii, 2002)

Creativity and imagination should be emphasized for children in the preoperational stage. StoryMat can enhance children's creativity and imagination by providing a play space where children tell stories using stuffed animals, then listen to playback of their recorded stories. Similar storytelling smart toys are generally suitable for children in this stage because these children learn to think, reflect, and use their imaginations to create stories (Ryokai & Cassell, 1999). Curlybot is also suitable for young children to learn mathematical and computational thinking (Frei et al., 2000).

According to Ryokai and Cassell (1999), children begin engaging in more social play by age 4. Thus, using smart toys for collaborative purposes should be implemented from this age forward. These researchers' StoryMat toy, for example, can be used for collaborative storytelling, as children in peer groups can tell stories by interpreting a playmate's actions with the stuffed animals.

Concrete Operations Stage

According to Piaget (1962), the concrete operations developmental stage involves children's ability to engage in calculations, rational relations, and numerical activities. This is also the stage at which children become capable of classifying objects according to similarities and differences and serializing according to size and weight. Pegblocks, which allows children to manipulate wooden toys connected via electrical cables to learn basic physics principles, may be suitable for children at this developmental stage (Piper & Ishii, 2002) (see Fig. 56.5).

Similarly, Sifteo may be suitable for children at the concrete operations stage as it provides "sensing, graphical display, and wireless communication, which can be manipulated as a group to interact with digital information and media" (Merrill et al., 2007, p. 75).

Formal Operations Stage

According to Piaget (1962), children can present reasoning skills based on hypotheses or propositions in the formal operations stage. Smart toys with advanced cognitive purposes may be best for these children. At this stage, children begin to demonstrate a preference for computer-based applications rather than physical toys. Lego Mindstorms robotics kits, developed at the MIT Media Lab, may be more suitable for children at the formal operations stage: "Lego robotics is comprised of building materials (regular blocks, gears, pulleys and axels) and programming software with an effective graphical interface for developing robotic applications" (Alimisis et al., 2007, p. 2). This toy may enhance creativity, imagination, and problem solving capabilities in children (Mauch, 2001).

As seen in this section, knowing children's developmental stages is important when selecting the appropriate smart toy. These stages also have to be taken into consideration during the design and development of such toys. The factors that motivate children to play with these toys are also significant.

Smart Toys from the Perspective of Intrinsic Motivation

The potential motivational power of toys may explain their importance in the process of cognitive development. In smart toys specifically, technological components facilitate two-way child–toy interactions to carry out a purposeful task with a goal of learning. Petersson and Brooks (2006) emphasized that play is closely related to intrinsic motivation. Malone and Lepper (1987) further stated that learning experiences should be intrinsically motivated and define toys as objects guided by internal goals. Thus, intrinsic motivation must be defined, and its relationship with smart toy based activities must be explored. Malone and Lepper (1987) categorized four intrinsic motivation components with regard to learning experiences: (a) challenge, (b) curiosity, (c) control, and (d) fantasy.

Challenge

According to Malone and Lepper (1987), activities should challenge learners in order to motivate them intrinsically. Generally, toys enable children to gain skills by challenging them. Smart toys that provoke behavioral or cognitive tasks may provide possibilities for challenging and motivating children. For instance, with Rosebud, children type stories about a selected stuffed animal (Glos & Cassell, 1997). Thinking about the stuffed animal and creating a suitable story can be considered challenging for children based on age. Some smart toys require more complex cognitive tasks and present more advanced challenges. For instance, children may be given different Sifteo blocks and be expected to solve basic mathematical problems (Merrill et al., 2007).

Curiosity

Malone and Lepper (1987) considered curiosity to be the most effective component in motivating learners intrinsically. Several smart toys provide open-ended features that allow children to explore new facets of play and may increase curiosity. Since smart toys with cognitive purposes lead children to construct knowledge patterns through stories, combinations, and calculations based on children's own selections, open-ended characteristics can be easily linked to their curiosity. For instance, Sifteo blocks enable children to reach different combinations each time, maintaining the curiosity of children. Similarly, with Furby, children may feed the toy, then wait for Furby's audio response, letting the child know whether to continue feeding it. The open-ended features of several storytelling smart toys can also enhance curiosity. With StoryTech (Kara et al., 2012a), for instance, children can create different stories based on each plush toy or background card. As Petersson and Brooks (2006) emphasize, open-ended features that include collaborative play increase children's motivation to learn. With these features, children share their activity with other children, enhancing each other's learning experiences.

Control

According to Malone and Lepper (1987), activities should give a powerful sense of control to learners to provide a successful learning experience. With some smart toys, children take control of the toy itself to conduct purposeful tasks. For instance, Furby allows children to control a virtual character while practicing behavioral tasks, caring for it like a real pet. Taking care of Furby is completely in the hands of children, who keep Furby healthy and happy according to their decisions. Similarly, with Curlybot (Frei et al., 2000), children control an electronic vehicle and enhance mathematical thinking by recording and playing back the coordinates of the vehicle's movements. As another example, in StoryTech, children control the virtual environment and characters that appear on the screen by selecting desired cards and toys to produce their own stories (Kara et al., 2012a).

Fantasy

Fantasy is also an important dimension in children's play. In fact, all toy activity is rooted in fantasy. Children create an imaginary world and act in this environment as if they were in the real world. According to Cassell and Ryokai (2001), "Fantasy play allows children to explore different possibilities in their life without the risk of failure and frustration from unexpected events" (p. 172). Smart toys with multimedia components attract the attention of children in an environment where they can engage in purposeful events, such as behavioral and cognitive tasks. In this environment, children carry out fantasy play as active players. For instance, children can tell their own stories by using stuffed farm animals, and reacting to each other as they play in the StoryToy (Fontijn & Mendels, 2005) fantasy environment. Based on the StoryTech user study with 90 children, the age 5 and 6 groups especially produced imaginative stories (Kara et al., 2012b).

Smart Toys as Cognitive Tools

Smart toy projects provide different sorts of scaffolds to facilitate children's knowledge construction. Hannafin, Land, and Oliver (1999) listed four main types of scaffolds: (a) conceptual, (b) metacognitive, (c) procedural, and (d) strategic. According to the authors, "Conceptual scaffolding can be designed to help learners reason through complex or fuzzy problems, as well as for concepts where known misconceptions are prevalent" (p. 132). For instance, with StoryMat conceptual scaffolding is implemented through providing recorded narrations to children, aiding them in telling their own stories (Ryokai & Cassell, 1999). Similarly, in StoryTech narrations describing the environment and objects based on the selected background card trigger children to continue storytelling in accordance with their choices (Kara et al., 2012a). Metacognitive scaffolding guides learners to think about and reflect on their own learning (Hannafin et al., 1999). For instance, children can think about knowledge representations that they produced with Sifteo blocks (Merrill et al., 2007) or think about kinetic energy changes with Pegblocks (Piper & Ishii, 2002). According to Hannafin et al. (1999), procedural scaffolding guides learners to use existing resources and tools. Smart toys, in general, have specific functions making the toy easy to use for play. These functions can be considered procedural scaffolds. For instance, in StoryToy (Fontijn & Mendels, 2005), play modes can be changed easily in accordance with the location of the duck character in the smart toy environment. Strategic scaffolding emphasizes reaching needed information and existing resources, and building relationships between current knowledge and new knowledge and experiences (Hannafin et al., 1999). For example, in StoryTech (Kara et al., 2012a), before presenting storytelling, strategic scaffolding allows children to understand the system and be ready for storytelling. As another example, the Augmented Knight's Castle (Lampe & Hinske, 2007) provides alternative approaches to enhance children's knowledge about the Middle Ages, as the objects provide relevant sound effects, background music and verbal commentaries.

Cognitive tools are intelligent resources that help construct knowledge through interaction with learners (Jonassen, 1992; Kim & Reeves, 2007). Based on this definition, cognitive tools support learning experiences (Joolingen, 1999). Furthermore, Liu and Bera (2005) emphasized that technologies can be considered cognitive tools if they provide effective learning environments by supporting learning experiences. Based on this perspective, smart toys can also be considered cognitive tools since they help children construct their own learning. For instance, Piper and Ishii's Pegblocks (2002) allows children to learn basic physics principles by providing an interactive environment supported by technological features. Similarly, with a storytelling smart toy, a child produces an original story with the help of virtual content and plush toys (Kara et al., 2012a). Smart storytelling toys serve as cognitive tools because they teach storytelling to children in an interactive way. Children must select the toys or background cards to tell their stories using the accompanying Flash animation.

Learner control is another important characteristic of cognitive tools (Jonassen, 1992). Rather than teacher directed or technology driven learning, smart toys provide an interactive environment for children to use technology to conduct cognitive tasks. Further, Kim and Reeves (2007) mentioned the importance of flexibility and open-ended characteristics of cognitive tools. Sifteo prompts children to interact with electronic blocks to produce different combinations (Merrill et al., 2007). As a cognitive tool, Sifteo provides different learning experiences with each play. Cognitive tools are based on a constructivist paradigm where learners construct their own experiences by actively engaging with these tools (Jonassen, 1992; Kim & Reeves, 2007).

Conclusions

This chapter introduces the general characteristics of smart toys by referring to specific examples in the literature and presented the dynamics of smart toy based learning in relation to children's developmental needs and motivation conditions. Smart toys are new forms of toys that incorporate tangible objects and electronic chips to provide two-way interactions leading to purposeful tasks with behavioral or cognitive merit. In smart toy play, interaction is used for instructional purposes within an authentic play environment rather than only for child attraction, so interaction assumes the main role in learning. The consistency between the attributes of smart toys and the developmental characteristics of children needs to be analyzed in depth to assist in the effective development of smart toy based learning. Additionally, smart toys should be analyzed from a developmental perspective to reflect suitable age-related options. As Piaget's developmental stages are mostly emphasized in the literature, the characteristics of smart toys should be appropriately associated with them: sensory-motor, preoperational, concrete operations, and formal operations. The relationship between motivation and play is also emphasized in the literature. Smart toys' characteristics should be analyzed to understand children's inner motivations. Malone and Lepper (1987)'s classification of intrinsic motivation is still of great importance for play, so smart toys need to be developed according to its components: challenge, curiosity, control, and fantasy. Smart toys can be used by children to gain both behavioral and cognitive skills. In addition, these technologies can be considered cognitive tools, assisting children construct their own learning experiences.

Many smart toy projects have been conducted by computer science researchers from the MIT Media Lab. Although the smart toys were developed for pedagogical purposes, early childhood scholars' or teachers' contributions have been limited. Most early childhood education curricula refer to information and communication technologies and programmable toys (Plowman & Stephen, 2003), but smart toy practices in the literature generally focus on specific purposes, like storytelling or pretending. Existing smart toy projects have not offered applications for formal early educational environments specifically aligned to curricula. Also, researchers developing new toy technologies for young children have thus far conducted mostly small-scale user studies. Although there are still questions in the literature about how best to integrate new technologies in young children's learning environments, the design and development phases of new smart toy technologies have not been emphasized sufficiently. Thus, we believe that young children's and teachers' perceptions about the design and development process should play a significant role in generating new principles and revealing participants' preferences.

Although smart toys have several advantages due to their capabilities, these technologies also have their limitations. In individual play, smart toys may decrease socialization, leading children to play with the toy more than each other. Additionally, these technologies may make children dependent on the constant, instant feedback and interactions in smart toy play. To decrease potential risks, children should be guided by parent or teachers in play.

Although this chapter provides general characteristics of smart toys, the relationship of smart toys to children's developmental stages and motivation, smart toy based learning in light of learning through interaction, and smart toys as cognitive tools, several topics were not covered, such as design and development issues in smart toy based learning environments. Hence, this topic should be considered in future studies. Additionally, studies exploring the experiences of children when playing with smart toys and regarding the integration of technologies such as multitouch and tablet technology in smart toys should be conducted. New smart toy studies should be carried out for children with disabilities, as well. With the advent of new technology, smart toy based applications will become widespread, and children will have more opportunities to use these powerful toys effectively. This chapter aims to encourage more researchers, designers, developers, and instructional technologists to carry out smart toy based research activities.

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e-Books for Educational Uses

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Ann-Louise Davidson and Saul Carliner

Abstract

An e-book is a publication in an electronic format that users can read with an electronic device such as an e-book reader, a tablet, a computer, or a smartphone. Although research in this domain is fairly new and little of it has been published in the educational technology literature to date, that which has been published reveals issues important to educational technologists. Some of these studies have focused on hardware, including ones for the development of electronic ink and paper. Other studies have explored specific applications of e-books in various environments of interest to educators. Libraries have studied various programs to provide e-books to patrons, the challenges in administering these programs and related reactions. Although interest exists, participants in these studies often still prefer traditional printed books. In classrooms, researchers have explored different applications of e-books to traditional learning activities. Other research has explored uses of e-books in learning contexts outside of the classroom, the impact of digital publications on the market for books and periodicals, consumer perceptions and acceptance of e-books and unique issues of copyright and intellectual property arising from digital texts. Several other areas of research contribute to our understanding about e-books, such as research on tablet computing, software and processes related standards for publishing content digitally, and provide initial guidance in designing and developing e-books.

Keywords

e-Books • Electronic books • Digital texts • Textbooks • Usability

Introduction

The Horizon reports in 2010 and 2011 suggested that e-books are one of the six most important trends affecting higher education (Johnson, Levine, Smith, & Stone, 2010; Johnson, Smith, Willis, Levine, & Haywood, 2011). Although it does not explicitly name e-books, the 2011 Horizon report on technology in K-12 contexts (Johnson, Adams, & Haywood, 2011) predicted the rise of two related technologies affecting e-books: open content (which covers open textbooks, which are often distributed online) and personal learning environments (which include a variety of resources tailored to learners' needs, including networks with other people and, more germane to this discussion, resources for learning, such as e-books). That e-books would be predicted to play such a pivotal role in education was difficult to imagine just a few years earlier, when e-book advocate Gall (2005) tried to dispel the myth that e-books presented a new idea that had already failed.

E-books are the most recent in a long history of publishing revolutions that also affect education, revolutions like writing systems of writing to the invention of the printing

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press (Baber, Bradley, & Childress, 2008; Lewin, 2008). Because it has the potential to go beyond merely publishing the written word, but also incorporating audio, full-motion video, and animation sequences (Wonderfactory Inc., 2009), e-books also have the potential to blur the line between textbook and instruction, especially online instruction. As of the writing of this chapter, the digital transformation of books and periodicals is still a work in progress, providing only partial clarity on the resulting forms that these publications will take when they become fully digital. The only thing that is clear is that e-books are expected to have a profound effect on education (Johnson et al., 2010, 2011).

This chapter presents current research relevant to e-book use in educational contexts. Because the field is just emerging as this Handbook is being written, the first part of this chapter provides an overview of the current state of e-book technology and the anticipated applications of this technology in education. The second part of this chapter summarizes the nascent body of empirical research on e-books. Note that much of this research has been conducted outside of educational technology, but it has applications and insights for our field. At the end of this synthesis of the existing literature, we offer a model to shed light on the various research avenues of e-books in education and we mention several research opportunities emerging from the literature as well.

The Current State of e-Book Technology

An e-book is a publication in a digital format that users can read with an electronic device such as an e-book reader, a tablet, a computer or a phone. Although the name e-book suggests that the publications are books, for the purpose of this discussion, e-book is a broader term that encompasses any type of publication, including books, periodicals, reports, and references. Although the technical definition of e-books refers to publications read on digital devices, in the vernacular, the term has also come to encompass some of the devices on which people read those books. This section describes the components central to the use of e-books: (1) e-book hardware, the devices for reading the publications; (2) e-book software, which renders content on the screen; and (3) e-book content, which includes text, graphic, audio and video.

e-Book Hardware. The device on which people read electronic publications is called an *e-book reader*. Any device that can recognize the file format in which the book was produced can be considered an e-book reader. Several types of devices serve as e-book readers, including:

- Computers, both desktop and laptop. The advantage of these devices is that they offer the largest screen sizes and an easy way of annotating pages. The primary disadvantage of these devices are their size and bulk—even laptop and netbook computers are considered cumbersome devices, and their screens can only be read well under certain conditions.
- Mobile devices, such as smart phones and music players, like the iPod®. The primary advantage of these devices is their portability; the primary disadvantage is their tiny screen sizes, which makes reading difficult for some.
- Tablets, such as the iPad® and Samsung Galaxy®. These devices provide larger screens than smart phones and music players and almost as many capabilities as computers—without their bulky size. The screen quality, however, often fails to provide a comfortable brightness for reading under certain conditions.
- Purpose-built devices, such as the Kindle® and Nook®, also called e-book readers. These technologies have a screen size similar to many tablets and use a display technology called *digital ink* to ensure the sharpest contrast and easiest reading under a variety of lighting situations. The disadvantages of these devices, however, are that most can only display books and periodicals; they have few, if any, additional capabilities.

e-Book Software. Specialized software renders digital content for reading on the screens of the devices described above, especially e-book readers and tablets, like the iPad. In nearly all instances, the software itself can work on many or all of these platforms, but each prefers to display content in its own format. Specific software includes software iBooks® from the Apple, Kindle from Amazon, Nook from Barnes & Noble, and Acrobat®, which displays content in the long-popular portable data format (PDF). Different software can render documents in different file formats on the screen. Among the most popular file formats are PDF, ePub, MOBI, AZW, TXT, HTML, and DOC.

e-Book Content. The third component of e-books is the content with which people interact. This content includes text, graphics, audio, and video. Most e-book hardware has the capability of displaying text and audio, and some also has the ability to provide an interactive experience with the content, including educational content. Rockley (2011) incorporates these capabilities into her definitions of different types of e-book content: a basic e-book is one that "includes text, images, table of contents, but no additional functionality" an enhanced-book is one that "includes audio, video, and internal and external links" and an e-book app is "software that looks and acts like a printed book, but provides an interactive experience" (Rockley, 2011, direct oral quote). She emphatically adds that "a PDF is not an e-book" (Rockley, 2011, direct oral quote). In practice, however, some e-book providers like Barnes & Noble have had much success selling PDFs for their e-book readers (Peters, 2011), and the dominant types of e-book content are digital versions of print publications, including books, periodicals, reports, references, brochures, and similar types of materials. However, businesses like Apple hope that authors of content specifically intended for publication as e-books not only include text and graphics, but also reused and re-purposed video and audio content, such as news stories, documentaries, as well as video and audio content specially produced for e-books.

Several authors have proposed specific applications of e-books in educational contexts. The first is as textbooks (Lewin, 2008; Wieder, 2011) for courses at all levels. Some of these textbooks are merely less costly digital versions of printed texts. Electronic versions of books can cost between 30 and 60 % less than printed ones, significantly reducing costs for students who must purchase their own textbooks like university students as well as school systems, like the State of California, which provide textbooks for all students in the system. To accelerate this process, Apple launched a major push in January 2012 to encourage instructors to prepare and publish textbooks through its iTunes® store (Apple, 2012). The second educational application of e-books combine features of textbooks and how-to videos (Rockley, 2011), such as an electronic users guide for a car that includes brief video sequences demonstrating simple car repairs. The third proposed educational application is as a research tool, especially as a means of easily and quickly locating literature on a given field for a paper or to locate resources for a webquest activity. A fourth proposed application of e-books is to provide online instruction integrated with the content of the digital textbook. This is similar to the second use, but would include exercises and tests. Such a use of e-books—while technically feasible—goes beyond informing and provides instruction and feedback; it is e-learning on an e-book device.

The next section explores insights from the empirical research on the likely success of these applications under real-world conditions.

Research on e-Books in Educational Contexts

This section of the chapter summarizes the research on e-books, specifically focusing on four areas of particular interest: research on the hardware used for e-books, on the applications of e-books, on attitudes towards e-books, on issues of intellectual property arising from digitizing books, and research from other areas of educational technology and professional communication and publishing. But first, it provides some perspective on the research.

About the Research on e-Books

Despite enthusiasm for e-books, the extent of research is actually limited, especially in the field of educational technology. For example, between 2009 and the first quarter of 2012, *Educational Technology Research and Development* published only two articles on the subject (Huang, Liang, Su, & Chen, 2012; Lim, Song, & Lee, 2012). The *British Journal of Educational Technology* published no articles on the subject.

Relevant research does exist outside of our field, however, in other branches of education, library science, and fields associated with publishing, such as professional and technical communication. Additional relevant though non-peer-reviewed research comes from industry associations in publishing and technology. We identified relevant studies through a search of the ERIC and Academic Search Premier, using the keyword e-book, ebook, electronic book, online books, and research.

Research on Hardware Used for e-Books

One area of research on electronic books has focused on the devices used to read them. Although people can read e-books on a variety of devices now—personal and laptop computers, tablets, iPods, smart phones, and purpose-built e-book readers—our search of the literature suggests that much research has focused on purpose-built e-book readers E-book readers differ from the other devices. They use a different technology (electronic paper and electronic ink) that more closely mimics the features of paper than is possible with traditional computer screens.

Despite the ability of users to read electronic texts on other devices, research continues on purpose-built electronic books because some researchers and publishers believe it offers a reading experience that is closer to traditional books than is possible with other types of devices. Much of this research focuses on electronic paper (or e-paper), a type of screen used to read electronic texts using e-ink, especially newspapers (Graham-Rowe, 2007). Ideally, electronic paper visually resembles a newspaper as that was one of the first applications for which it was intended (eInk Corporation, 2012), but features of electronic paper are integrated into the screens of e-book devices. In his review of research and development in this area, Graham-Rowe (2007) comments that electronic paper is a type of display that resembles a real paper. It uses less energy than the LCD technology commonly used for the screens of computers, tablets, iPods, and smart phones. In addition, electronic paper offers better brightness and contrast than LCD screens. As noted in some of the advertisements for the Kindle—a device used for reading textbooks—this glare-free screen makes it possible to read e-books at the beach, where the glare from the sun renders the screens of LCD displays all but unreadable. As of 2007, electronic paper could not yet display color (Graham-Rowe, 2007), a challenge that researchers started to overcome by 2009 (Kroeker, 2009). By 2010, technological development led to color versions of e-book readers like the Kindle and Nook, which extends the capabilities of e-book content, including e-textbooks and similar educational materials.

Research on Applications of e-Books

As discussed in this section, many studies have explored specific applications of e-books in various environments of interest to educators: in libraries, in classrooms, and among publishers. The following sections explore the applications studied in each of these situations.

e-Books in Libraries. School and university libraries have explored various ways to provide e-books to patrons, the challenges in administering these programs and the reactions to them. Some studies have reported on efforts by university libraries to increase the accessibility of e-books by lending e-book devices to patrons. Patrons in these pilot programs generally had positive reactions to these efforts. For example, in a case study of lending e-books through the library at the Technical University of Catalonia, Clavero, Codina, Pérez, and Serrat-Brustenga (2009) reported that participants appreciated the convenience of the service. Other school and university library projects have focused on offering electronic content to patrons, including books, journals, reports, dissertations, and similar types of texts. By digitizing books and other texts and making them available online through the Web, libraries hope to make these materials more accessible to patrons. Estelle and Woodward (2009) reported that patrons found these digital materials to be more accessible than printed ones.

Studies have differed, however, in their conclusions about who makes the most use of e-books. For example, Anuradha and Usha (2006) concluded that students are more likely to use e-books than faculty and staff. Similarly, Schoch, Teoh, and Kropman (2006) found that students had either positive or indifferent attitudes towards e-books; they did not hold negative views. Nariani (2009) found that students were more aware of e-books and related services than instructors. Shelburne (2009) added that students are enthusiastic about e-books because of their practicality. However, the eBrary study (Shelburne, 2009) contradicted some of these findings, reporting that a higher percentage of faculty had used e-books (55 %) than students (50 %).

Chu (2003) identified barriers to further use of e-books by patrons, including the difficulty of reading them online and the need in many instances for special equipment to do so. Shelburne (2009) noted that some of these issues are probably temporary ones; technology under development should address them.

e-Books in the Classroom. Researchers have explored a variety of ways e-books might be applied to traditional learning activities, both directly in the classroom as well as other types of contexts in which learning occurs. Some of the studies have focused on students, others have focused on instructors, and some have focused on the design process.

Studies Focused on Students: Most activities focus on the implementation challenges and results of using e-books in colleges and universities. Some of the earliest studies explored the availability of e-books on the study habits of university students. For example, Williams and Dittmer (2009) reported on a 2003 study of nursing students who had access to e-books through handheld devices. The researchers found that some students used both digital information returned by online searches as well as more conventional printed materials. Those students who used digital materials strengthened their information retrieval skills, increased their use of digital information resources, and showed a preference for e-books over print materials.

Waycott, Jones, and Scanlon (2005) explored several uses of personal digital assistants (PDAs) in different learning contexts, including the use of PDAs as e-book readers (which is why it is of interest here). One use was in a university-based distance education environment, where researchers found that students had difficulty reading materials and encountered difficulties with navigation, and reported a preference for printed texts. A second use was in a workplace learning context, where researchers found that workers used the PDAs to perform tasks *other* than learning. A third use was in a museum context, where researchers explored the use of PDAs in informal learning: more specifically, as an aid in interpreting exhibitions. In the museum context, researchers found that the multimedia capabilities enhanced the visit but could not emulate the verbal communication that often occurs among visitors to museums, thus limiting its effectiveness in learning.

Many of the studies that have been conducted to date have isolated various characteristics of e-books that affect their use in the classroom. Some characteristics confirm advantages that e-book proponents had earlier proposed. For example, instructors for distance education sections found that using digital materials simplified distribution to distance learners, who are often in several locations and many of them out of reach by traditional delivery services like postal services (Williams & Dittmer, 2009). Lower cost, too, is a benefit. In their study of an initiative to publish and integrate an e-book into a university-based accounting course, Schoch et al. (2006) noted that the online text was less expensive than a comparable printed one.

Several studies also found several practical issues arising with the use of e-books. Schoch et al. (2006) found that some students had some reservations about using e-books. Other students experienced problems with readability and screen issues, difficulty with—and slow speed of—turning pages, an inability to take notes and highlight passages of interest, and problems with Internet connections to the books. Nariani (2009) reported similar issues, finding that students and instructors had problems reading from the screen and that students still preferred printing materials, writing on the printouts, and sharing comments with others.

Shepperd, Grace, and Koch (2008) found that students who used e-books reported studying less for class each week than those who used printed books, although actual grades did not differ between the two groups. Other studies have explored the use of e-books in the primary school context. For example, Korat, Shamir, and Arbiv (2011) studied the impact of e-books on the emergent literacy of 5- and 6-year-old children found that it supported the development of phonological awareness and emergent word writing when assisted by adults.

Studies Focused on Instructors: In addition to studies with students, some of the research on the use of e-books has explored the willingness of instructors to integrate e-books in their courses and the extent to which they do so. Corbeil and Valdes-Corbeil (2007) noted that, despite their use of mobile technologies outside of the classroom (including e-books and other e-texts), many instructors had not integrated e-books into the classroom. Carlock and Perry (2008) reached a similar conclusion, adding that some faculty who tried using e-books in class reported negative experiences, such as a loss of access to the server containing a textbook e-book the day before an exam and the fact that students could only access the textbook through the server.

Other researchers found that instructors used e-books for research and class preparation (Rowlands, Nicholas, Jamali, & Huntington, 2007) and that they integrate sections of e-books into the readings or link to them as references (Anuradha & Usha, 2006). In these situations, faculty perceptions of e-books are similar to those of students (Chu, 2003; Ismail & Zainab, 2005).

Carlock and Perry (2008) found that the extent to which instructors integrate e-books depends on the discipline. Instructors in history and design integrate e-books the most. Other factors affecting the likelihood that instructors would adopt e-books include age, rank, and past experience.

Studies Focused on the Process for Designing e-Books for the Classroom

Two other studies in the literature to date have explored ways to design usable e-books for the classroom. Huang et al. (2012) explored an e-textbook system with elementary school students and found that the students found the system usable, though patterns of usage by elementary school students differed from those of students at other levels, such as the extent of jumping among sections within the text. When comparing performance on the e-book system and printed books, Huang et al. (2012) found no significant difference, meaning students performed equally well with both types of books.

Reflecting on their experience designing an e-textbook for schools and that employed several usability evaluation methods, Lim et al. (2012) proposed nine design elements affecting the usability of e-books: "agreement with user expectations, consistency, convenience of operation, minimization of memory load through screen design, error prevention, advice and help information, feedback, aesthetic satisfaction, and user control" (p. 170).

Table 57.1 summarizes this nascent body of research on e-books presented in this section and presents an emerging list of issues that affect the success of e-textbooks.

e-Books in Other Contexts

e-Books and Publishers

News accounts (such as Streitfeld, 2012) suggest that publishers now see that e-books could have a significant impact on the publishing industry. Although different parts of the publishing industry are affected differently, some of the changes directly affecting educational publishing include a focus on open source textbooks by government education agencies and research publications by researchers, sometimes at the expense of established publishers (Lewin, 2009), an emphasis on self-publishing by Apple and other online publishers (once again at the expense of established publishers) (Apple, 2012; Tugend, 2011), changes to editorial practices and production processes to encompass e-book publication, and a reduction in the sales of books and other media. Some of the most visible to the academic community are the closing of university presses (Howard, 2012).

However, as recently as 2007, publishers did not anticipate any immediate concerns. In a 2007 interview-based study of American and British publishers, Towle, Dearnley, and McKnight (2007) found that publishers did not foresee the impact of e-books—yet. Participants felt that the technology for e-books at the time was still in its infancy. When the technology did become ready, some of the issues they anticipated included the right to publish content in digital format and the costs of doing so. Publishers also expressed concern whether readers would spend extended periods of time reading screens. Last, publishers were concerned about customers' perceptions of e-books, specifically wondering how customers would accept digital texts, an issue that later research has validated.

Table 57.1 Issues affecting the success of e-textbooks

Category	Specific issues affecting the success of e-textbooks
Price	• Comparison to printed text
Formats	• Ability to print electronic texts and read them offline • Readability on the screen – Contrast and brightness of the screen – Readability under different lighting conditions (such as natural sunlight) – Fatigue from prolonged viewing
Support for different types of uses	• Conducting research with e-texts • Providing entire texts • Linking to specific articles and book chapters
Note-taking ability	• Ability to highlight text • Ability to annotate text
Features for special learning needs	• Sound capabilities to help young children with language learning • Visual capabilities and interactivity to help young children verify language learning
Navigation	• Clarity of the navigation scheme to users • Scheme for referencing specific passages in the e-book so others can find them • Ability to easily jump to different parts of the e-book
Distribution of e-books	• Persistent link to the Internet (for resources read online or referred to online) • Quality of links (that is, a link in a course continues to work when students reach that point in the course) • Ease of distribution to distance students • Number of pages students can read in a given online session (some publishers restricted this)
Usage patterns	• Tendency of students using e-books to spend less time on class preparation
Attitudes towards e-books	• For newer users, willingness to forgo relationship with printed books • Past experiences that shape current impressions of e-books

Research on Attitudes Towards e-Books

Because issues about acceptance has arisen in other areas of research on e-books, one area of research about e-books has exclusively focused on acceptance by readers. The studies began in the early 2000s.

Some early studies explored whether consumers would be interested in reading e-books (Henke, 2003) and found a general openness to the idea among participants. Other early studies were conducted by libraries and explored both perceived acceptance of e-books and actual usage of them. Several studies found slow acceptance and low usage, except for electronic journals (Levine-Clark, 2006; Lonsdale & Armstrong, 2001).

More recent studies have had similar findings. For example, Nariani (2009) concluded that e-books had not yet been widely used. In a specific pilot of the Kindle at Reed College, Marmarelli and Ringle (2009) concluded that "students and faculty in Reed's Kindle study were unanimous in reporting that the Kindle DX—in its current incarnation—was unable to meet their academic needs" (p. 11). According to the authors, the Kindle's limited note-taking capability, concerns about digital rights, and file formats that are incompatible with other readers, meant that students might not be able to read all of the assigned readings for a course. Furthermore, Marmarelli and Ringle (2009) predicted that, even once these technical problems are resolved, the adoption of e-books on campus would more likely follow a cell-phone model in which students choose their own device and devices lack proprietary file formats, rather than a computer model, in which institutions sanction a particular device, make sure that it reads all content that would be distributed, and require students to purchase the preferred devices and models.

Research on Issues of Intellectual Property Arising from Digitizing Books

Rao (2003) noted that the digital content of e-books raises significant concerns about digital rights management. Having content in proprietary digital formats might make it inaccessible to those who do not have the software to read it, but it might also prevent future generations from using that content.

The popular press has also reported on other issues of rights that have arisen with e-books. Because of the ability to easily cut and paste text, someone might create a new original work consisting exclusively of repurposed content from other authors (Kennedy, 2010), much like hip-hop musicians create new songs from bits and pieces of other songs. Another concern is that authors of older printed books might prevent or limit publishers from publishing digital versions of their works, as the estate of author William Styron has done (Rich, 2009). As a result, some older works might be delayed or never become available in a digital format.

Limits on digital rights prevent users from exchanging electronic texts like printed ones, which could limit dissemination of works. For example, although users can read the digital materials they purchased on several of their own devices such as purchasing a Kindle book and reading it on a Kindle device or on an iPad or computer using Kindle software, only users of Nook can lend those books to others to read on their own devices.

Research from Professional Communication and Publishing

In addition to these areas of direct study, several other areas of research contribute to our understanding of e-books, and provide guidance in designing and developing them.

Some of the research focuses on the software and related standards for publishing content digitally. Some of the research effort focuses on the design of standard formats for digital texts, so the content easily works as intended on several different types of devices. Rao (2003) proposed an open reader initiative, although, as of this publication, device manufacturers still favor closed formats. No single format dominates nor does a single format exist that all devices can use.

Other software such as specialized content management systems let publishers go through a single process to create an e-book while producing content in a variety of formats for a variety of reading devices (Rockley, 2012). This process of producing content once and publishing it on many different platforms is called *single-sourcing* in the publishing industry. Other content management systems let publishers produce material "on the fly" so publishers can tailor e-book content to the profiles of their readers. To do so, authors write topic-based prose and the system assembles the product when presenting the content to readers online, a process called *dynamic publishing*. Between the implementation of electronic work flows from these content management systems and the preparation of individual topics rather than complete books, these systems have affected the processes and work products of people who produce content (Hart-Davidson, Bernhardt, McLeod, Rife, & Grabill, 2008; Rockley, 2012). Emphasis has shifted from creating entire documents (like a user's guide) to writing individual topics; emphasis has also focused on reducing the time needed to formally publish content.

Other research has focused on the end product of e-books. Some research has focused on emerging genres of content used in e-books, such as Frequently Asked Questions and online help (Carliner, 2009). Other research focuses on conventions of designing content for viewing online (such as van der Geest & Spyridakis, 2000) and writing content to be read online (Redish, 2007). Much of this research primarily focuses on the computer screen but some of it focuses on the screens of mobile devices. And other studies focus on the ways that readers view and process information online.

Some research has generally found that reading accuracy and speed on a computer screen are degraded from the similar experience in print (Price & Price, 2002) and that readers tend to scan more and only read in-depth the content of interest (Redish, 2007). Yet studies conducted with e-book readers have found comparable patterns among readers of printed and e-books (Levine-Clark, 2006).

Suggestions for Future Research: Emerging Framework for Considering the Production and Use of e-Books

Although the research presented in this section explored isolated aspects of the production and use of e-books, these activities do not occur in isolation. Rather, they occur in a system of activity that transforms ideas into publishable content for use in learning contexts. Some aspects of this process are similar to those for printed texts; others are unique to e-books. Figure 57.1 presents a model of this system and suggests the transformation that content that goes through in the process of becoming an e-book. These steps align with the categories of research just presented.

Consider this example of a transformation process. When writing a book that will be published electronically, an author makes decisions regarding content. One pertains to length of the book. Some e-books are shorter than books, but the primary constraint of the book—the number of pages—is no longer an issue with e-books as the number of pages, which is often used to calculate printing costs, plays a less significant role in publishing costs. Indeed, the length of pages on e-books varies, from 100 to 250 words (Ford, 2011) and, depending on the size of type a reader chooses, the length of a page presented to one reader might significantly differ from that presented to a second. Authors expect readers to access the content through a different medium than the traditional paper version of books, and recognize that the book that readers see might differ from the one that the author visualized when preparing the text. This corresponds to a content-production-decision transformation. Future research might explore how freedom from the restrictions of pages and page counts affects the content choices of authors.

Moreover, when the editors fit the content of e-books on the software that will format the e-book for various devices, another set of decisions is made. This formatting process is called "rendering" and corresponds to a content-production-decision-software transformation. Authors and publishers have complete control over rendering of printed texts; because e-book devices let users choose type size and other characteristics and, because devices differ, authors and publishers have less control over rendering of e-books. Future research might explore how this loss of control over the rendering process affects decision making among authors.

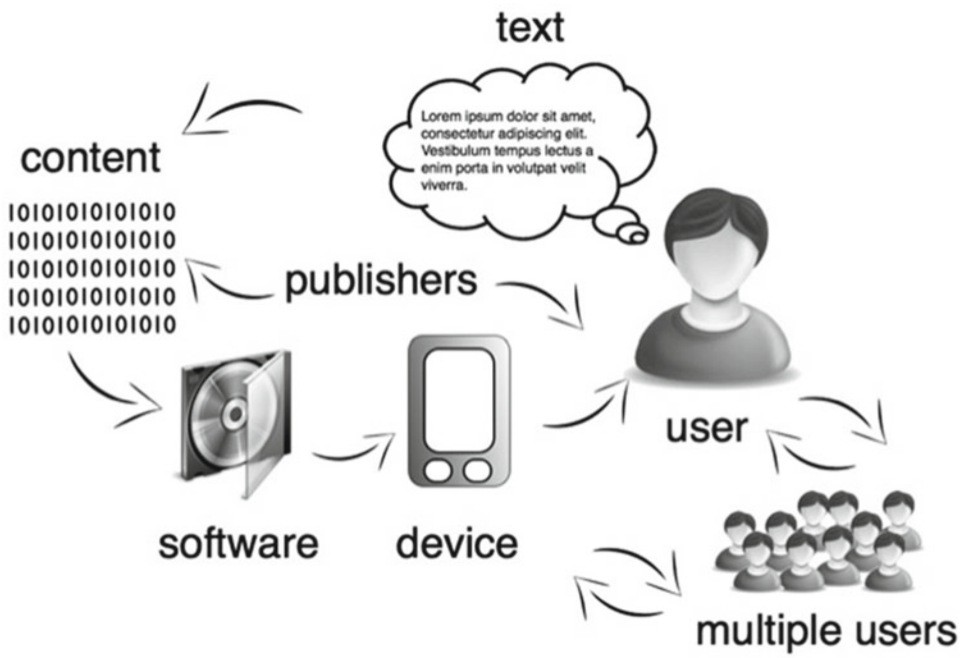

Fig. 57.1 The system of e-books

Once the content has been rendered into the publishing software, it is distributed and downloaded to various devices. The device affordances also play a role depending on the software they use to read the e-books and the physical capabilities (affordances) of the e-readers. This corresponds to a content-production-decision-software-device transformation.

Once the e-book is uploaded to an e-reader, users can read it and grasp the ideas that are being conveyed by the author of the book. This corresponds to a content-production-decision-software-device-user transformation. However, we must look at this transformation more deeply because user particularities are more complex than that. First, users can pick up any e-reader and think that this is how e-books are read. Second, users can be more critical and require various functions of the e-reader or require a particular access to the e-book that demands certain affordances from the e-reader. Or users can bypass the e-reader and access the e-book from another device such as a computer. Future research should explore the impacts of these different user interfaces on the reading experience, specifically considering issues such as the types of features that users want, how they use them, and whether users felt that the e-book device presented the content as users expected.

Moreover, we must remember that e-books are a marketable commodity and publishers are in the middle of this system. Fundamentally, they are the ones who give the users (readers) access to the content. Future research should explore the impact of e-books on the publishing industry and how they affect the work processes of individual publishers. For example, Estelle and Woodward (2009) suggested that researchers study the formats and structures of e-books themselves and also suggested that researchers explore various business issues in publishing e-books. They suggested exploring user behaviors to help identify appropriate business models for publishing e-books and the different segments of the e-book market. Such research would open new avenues for educational technology, which has traditionally focused on educational products and their production, and not as much on the marketing and financial aspects of those products.

And speaking of users, they are at the end of this system. Future research might explore the impact of e-books on users. For example, Levine-Clark (2006) suggested conducting research into the habits of people who read e-books. The author recommended research identifying which types of books people read electronically and which ones they read in print, as well as usage patterns of electronic books.

Related to reading habits, an issue strikingly absent from the research on e-book is studies about the use of the annotation capabilities that many devices now have and the possibility of adding exercises in textbooks. This is where general interest e-books and educational e-books might differ. Knowledge about how to best use interaction in educational e-books and how readers might better construe the meaning of the content if they are able to comment and share their comments, highlight passages and share their highlighted passages remains embryonic because up until now, this area of research remains largely unexplored. Future research might explore these types of interactions about knowledge construction and e-dialogue about e-content through e-readers.

Most significantly, researchers need to continue exploring proof-of-concept projects that define what e-books are and how they integrate with other learning activities, the impact of e-books of all types on learning (especially those produced as proof-of-concept projects), improvements to the technology and interface of e-books so users can have the most satisfying experience with them, and the impact of e-books on the work of instructors, librarians, and publishing professionals. Such studies would explore what happens when books go digital and the physical space devoted to them might no longer be necessary.

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Situated Learning in Virtual Worlds and Immersive Simulations

58

Lisa Dawley and Chris Dede

Abstract

Virtual worlds and immersive simulations are designed to create a compelling, collaborative, and participatory experience for the user, and often contain a variety of features not possible in the real world to enhance users' engagement and learning. Over the past several years, an increasing number of immersive virtual environment experiences have become available for both educational and entertainment purposes. Participants in entertainment experiences now number hundreds of millions, yet adoption in educational settings has been limited thus far. In this chapter, we review examples of virtual worlds and immersive simulations that are designed, or adapted, to support situated learning experiences, analyze their use for a variety of educational purposes, explore theoretical foundations, identify learning affordances and limitations, and examine instructional design considerations.

Keywords

Virtual worlds • Simulations • Situated learning • Immersive technologies

Introduction

In the past several years, we have seen growing interest in the use of virtual worlds (VW) such as *Whyville* and *Minecraft*, and immersive simulations such as *SimCity* and *Quest Atlantis*, to support learning in new and innovative ways. Due to recent technological advances, an explosive growth has occurred in these types of technologies for both entertainment and, on a much smaller scale, educational purposes, with over a billion user accounts in hundreds of VWs as of 2012. As schools and educators seek to reengage and motivate students, prevent high dropout rates, overcome issues of educational access, and provide more authentic learning and assessment opportunities, immersive environments offer unique and engaging environments to support situated learning.

Situated learning occurs when a student experiences and applies learning in a specific environment or setting that has its own social, physical and cultural contexts. Learners are often required to solve problems in the setting and then contribute their insights to improve the environment, thus building a bond with the community sharing the context and moving the learner from the periphery to engage at the center of the community (Schuh & Barab, 2008). For example, a student who manages a store can gain valuable knowledge and skills in business operations, customer relations, and marketing in an authentic way that one could not attain by reading a textbook and writing a paper. His/her work then becomes one important contribution to the continuing success of the store and those affiliated with it.

Immersive technologies provide alternative environments for situated learning, because an almost endless variety of virtual contexts are available, or can be created, that give users a sense of "being there," (Gibson, 2010; Slater, 2009) and thus, the ability to apply learning in a plausible, unique

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context. The immersive sensation is achieved through the use of sensory inputs (graphics, sounds, visual perceptions of moving through the environment; the ability to touch objects, maps providing geo-location clues), a variety of social communication layers (Warburton, 2009); avatar personalization; choice and autonomy in the storyline; the ability to design and build aspects of the environment itself; and by providing feedback mechanisms that help learners visualize their own progress in the environment (Dede, 2012).

A virtual world is an immersive environment in which a participant's avatar, a representation of the self in some form, interacts with digital agents, artifacts, and contexts. VWs are typically multiplayer; offer communication options such as chat, IM, and messaging; and may contain game or role-playing elements. *Whyville* is a well-known example of an educational VW where preteens gather online to socialize and play games. Content creation is possible in some VWs, such as *Minecraft* or *Kitely,* allowing users to make their own objects and media, and providing teachers and instructional designers the opportunity to incorporate a large variety of learning options in the environment, such as role-plays or scavenger hunts.

A subset of VWs, *immersive simulations,* use the above features to create model-based environments that simplify or enhance reality while retaining the validity of what needs to be learned. Some may facilitate learning through repetitive practice in a heavily contextualized environment integrating game and pedagogical elements (Aldrich, 2005). For example, *Spore* is a popular immersive game marketed as a simulation—unfortunately with numerous scientific inaccuracies—where users can design and redesign creatures as they grow through five stages of evolution. The player observes the direct impact his/her creatures have on the ecosystem and can modify the designs accordingly.

In this chapter, we review examples of VWs and immersive simulations that are designed or adapted to support situated learning experiences, analyze their use for a variety of educational purposes, explore theoretical foundations, identify learning affordances and limitations, and examine instructional design considerations. This chapter does not review research on heavily game-based or massive multiplayer online (MMO) environments, such as *Star Wars: The Old Republic*, or *World of Warcraft*, as those topics are covered elsewhere in this handbook.

Examples of Simulations and Virtual Worlds Designed for Learning

The below scenario provides an example of situated learning with fifth grade students using *Past/Present: 1906*, an immersive role-play simulation that looks much like a video game:

> Louisa and James are 5th graders who are ready to begin their history unit on the industrial revolution. They sit together at a laptop, log into the simulation, and play as Anna Caruso, an immigrant textile mill worker during turn-of-the-century America. As Louisa and James work together to move Anna's avatar down the streets of Eureka Falls, they encounter her family members, the newspaper boy, co-workers in the factory, and other characters in the simulation. These characters provide important background information, help create a holistic storyline, and offer Louisa and James the ability to interact, analyze, and problem solve by choosing responses to options in the storyline (*see* Fig. 58.1).

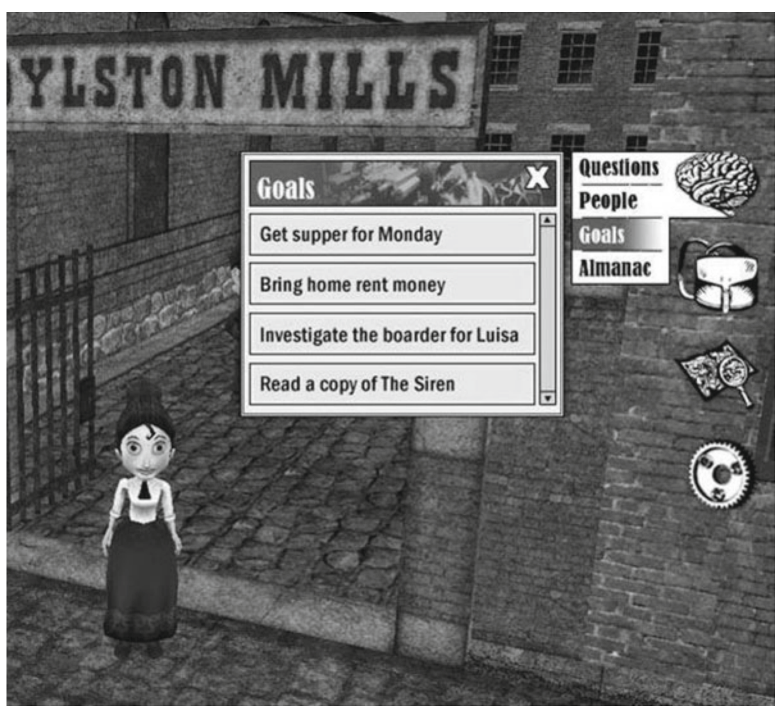

Fig. 58.1 Avatar Anna Caruso in *Past/Present: 1906*, an historical role-playing simulation

Anna has a job running looms in the textile mill. Her job is designed as a game inside the simulation, where Louisa and James will have to run Anna back and forth between the looms to keep them operating at an efficient pace. Based on their performance on the looms, Anna's salary will vary each day, and Louisa and James are then faced with making ongoing decisions about how to best earn and spend money to meet the needs of Anna's family.

This type of situated embodiment allows Louis and James to experience life as Anna in a time period and setting that no longer exists, and attain a variety of educational objectives. By decision-making as the character Anna, they make choices that have an eventual impact on outcomes in the simulation, gaining insights about that historical period and about comparable issues today.

In Table 58.1, below, we see a representative sample of research-based VWs and simulations, and VW content authoring environments used for education.

The wide variety of immersive environments illustrated above might leave a teacher or instructional designer wondering what specific environments are appropriate for their students and the learning goals they need to meet. As these environments continue to expand in type and variety, a good starting point is to ask how the intentionality of design will help meet desired learning outcomes, and what affordances and limitations will shape the design.

Intentionality of Design: Entertainment or Education?

What makes an immersive technology "educational?" VWs and simulations can be as complex as the physical world itself, incorporating varying degrees of virtuality, design intent, contexts, and layers of technology (Warburton, 2009), all influencing the nature of the immersive experience.

Table 58.1 Examples of educational VWs and simulations

Name	Ages	Description
Active Worlds Educational Universe	Varies	A shell for constructing and hosting VWs in which users create 3D educational institutions, learning content, and explore new paradigms in social learning http://www.activeworlds.com/edu/awedu.asp
America's Army	13+	An immersive game-based simulation created by the US Army, players are bound by rules of engagement (ROE) and grow in experience as they navigate challenges in teamwork-based, multiplayer, force versus force operations. The simulation demonstrates values of loyalty, duty, respect, selfless service, honor, integrity and personal courage http://www.americasarmy.com
Blue Mars	18+	A shell for constructing VWs in which users create 3D content; its emphasis is on high quality graphics and scaling capability http://www.bluemarsonline.com/
EcoMUVE	12–14	A middle grades, 1 month, ecosystems science curriculum based on two immersive virtual ecosystems, for learning science concepts, inquiry, and complex causality http://ecomuve.gse.harvard.edu
Idea Seeker Universe	8–13	Players come together to chat, explore, and can participate in scientific expeditions and projects, learning to grow food in realistic timelines http://www.kidscom.com/
Jibe	Varies	Players can host a VW on the OpenSim or Unity 3D platform; educational projects include language learning, scientific visualizations, walkthrough tours, distance learning http://reactiongrid.com/
JumpStart	3–12	Immersive early childhood educational games and activities played using an avatar known as a "jumpie." http://www.jumpstart.com/
Past/Present: 1906	12–14	Players assume the role of an immigrant textile mill worker in 1906, face challenges, and play games to earn money to live http://muzzylane.com/project/pastpresent
Quest Atlantis	9–15	3D multiuser environment to immerse learners in rich narrative, role playing, and in educational tasks http://atlantis.crlt.indiana.edu/
Real Lives	14–18	Players interact in this life simulation game that enables them to live one of billions of lives in any country in the world http://www.educationalsimulations.com/
River City	12–14	Interactive simulation for middle grades science students to learn scientific inquiry and twenty-first century skills http://muve.gse.harvard.edu/rivercityproject/
Second Life	13-adult	A shell for constructing VWs in which players can socialize, connect using voice and text chat, and participate in or create 3D educational sims such as EdTech Island, Jokaydia, and SciLands http://secondlife.com
SimSchool	18+	Players assume the role of a teacher managing a class of students in this interactive classroom simulator http://www.simschool.org/
Whyville	13–17	Players come together as citizens to learn, play, earn "clams" through educational activities, and have fun http://www.whyville.net/smmk/nice

Researchers have attempted to develop a variety of taxonomies to provide definitions or parameters of VWs and other immersive environments to assist instructional designers and researchers in their work, not without some debate due to rapid technological development and cross-functionality between emerging technologies (Bell, 2008; Richter & Dawley, 2010).

Because context is a critical aspect of situated learning, understanding the design intentionality of the platform is an important first step: Is the immersive technology designed for entertainment, education, or socialization purposes? Is it collaborative or competitive? Are the learning outcomes structured and explicit, or informal and tacit?

Some immersive simulations, such *Past/Present: 1906, Quest Atlantis,* and *NASA's Moonbase Alpha,* are designed to achieve specific educational purposes and goals. For example, in *Moonbase Alpha*, players are situated in a hypothetical lunar outpost as a crewmember, and have to participate in realistic mission challenges. Strengths of these types of environments include some level of assurance that curriculum is appropriately addressed according to standards, student safety is protected, the environment can be customized, and development is based on theoretical and empirical frameworks. Critics of these environments argue that, when education is the main focus as opposed to fun or socializing, motivation and engagement can decrease for the user (Akilli, 2008): the "chocolate covered broccoli" issue.

Other online worlds, such as *Idea Seeker Universe* or *JumpStart,* may be designed for social or entertainment purposes with a given age group, but they also integrate educational activities for their players, such as a virtual visit to the Chicago Museum, or reading storybooks with an adopted pet. The main characteristic of these environments is that an emphasis on "fun" comes first, and learning often happens as a by-product of interaction in the space, or has to be directed by the teacher (e.g., "Today you'll be growing vegetables in the virtual garden to get ingredients to make salsa.") These types of environments can be harder to integrate into a traditional school environment due to concerns with student safety resulting from exposure to unknown online players, design intent that only partially meets educational goals, and inability to customize the design (National Research Council, 2011).

Finally, hundreds of educational organizations have established learning communities or simulations in commercial content creation VWs, such as the AECT educator community in *Second Life*, or teachers who participate in the Massively Minecraft guild in *Minecraft.* In these VWs, the technology provides an authoring shell where the design intent is left open and leveraged by instructional developers and others who wish to create their own virtual environments. Adult learning and teacher training are popular educational activities in content creation worlds. An obvious strength of these worlds is the openness of the design possibilities—what your mind can imagine, your fingers can create. However, the newly christened are often left wondering where to begin, "Do I design a role play, a simulation, or a "mirror world" that looks like a real place? What types of learning activities and assessments should I include? How will students find those activities and get feedback on their accomplishments? What objects should I build into the environment?"

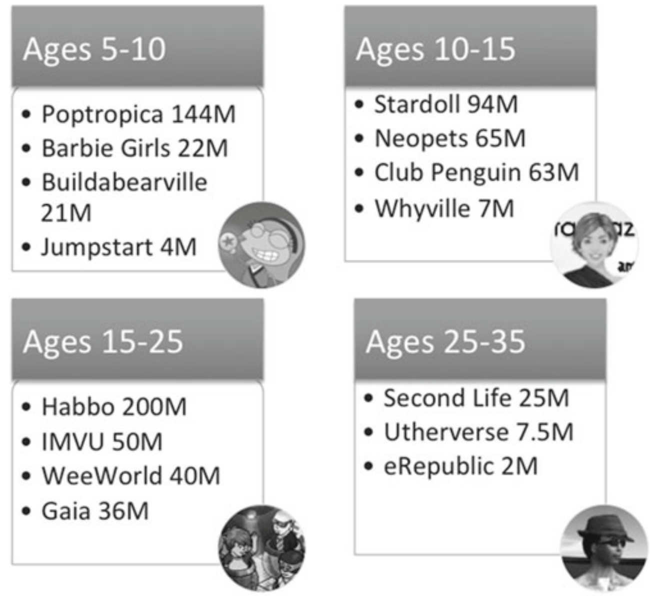

Fig. 58.2 Top inhabited VWs by age, in millions of users, adapted using data from KZero Inc. (2011)

Some projects have used the strategy of allowing K-12 students to become the builders of the world itself, thus translating their learning into 3D. However, content creation worlds have experienced a higher adoption rate in higher education and organizational training, literally using the space as a 3D learning environment supporting distance education. As a result, many colleges and businesses use the platforms to support in-world conferencing, meetings, and workshops.

Growth and Use Trends by Age

As of 2012, there are estimated to be over 900 VWs, thousands of online simulations, and millions of users around the globe. This number was almost double over the prior year (deFreitas, Rebolledo-Mendez, Liarokapis, Majoulas, & Poulovassilis, 2010; KZero Inc., 2011). A majority of VWs in the education sector cluster around the 10–15 year old age group, with over 500,000,000 registered user accounts (KZero Inc., 2011). No education-specific VWs are noted for those over 20 years old. This conclusion is misleading, because the VWs commonly used for learning by adults, such as *Second Life* or *Active Worlds*, are authoring shells that were built with an open design intent. Figure 58.2 illustrates the top inhabited VWs and simulations by age group.

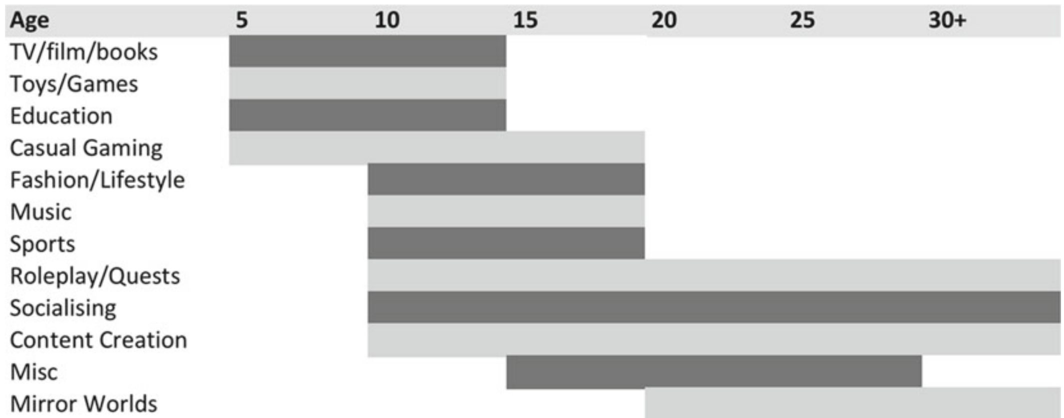

Fig. 58.3 Types of VWs by age range, adapted using data from KZero Inc. (2011)

By displaying KZero Inc. (2011) data on an age timeline below (Fig. 58.3), we are better able to see types of VW usage trends by market sectors.

Younger children are engaging in VWs that focus around games, toys, films, TV, and education, such as Disney's *Pixie Hollow* or DreamWork's *KungFu Panda World*. Tweens and teens are using VWs for casual gaming, fashion, music and sports, such as *NFL RushZone* or *GoSupermodel*. Two highly researched VW environments, *Second Life* and *ActiveWorlds*, are designated as "content creation" worlds, appealing to older teens and adults. Note that mirror worlds, such as *Google Earth*, provide a blend of VW and augmented reality (discussed in another chapter in this handbook) that appeals to a particularly adult audience. Understanding these types of immersive learning preferences and design considerations for a given age group is important for instructional developers and researchers. This knowledge can aid in determining whether to leverage existing VWs in various educational or entertainment sectors, or instead to design a new virtual world setting in a content creation shell such as *ActiveWorlds* or *InWorldz*.

Theoretical Foundations

As a cognitive tool or pedagogical approach, immersive technologies align well with situated and constructivist learning theory (Vygotsky, 1978), as these position the learner within an imaginary or real-world context (i.e., simulated physical environment). The immersive interface and associated content guides, scaffolds, and facilitates participatory and metacognitive learning processes such as authentic inquiry, active observation, peer coaching, reciprocal teaching and legitimate peripheral participation based on multiple modes of representation (Dunleavy, Dede, & Mitchell, 2009; Palincsar, 1998).

These technologies and their resulting contexts are often designed to promote situated embodiment (Barab, Zuiker et al., 2007), giving the learner a sense of projection into the context, as well as a meaningful role, goals, and an ability to take actions that result in significant consequences. Although immersive technologies are not inherently games, these types of situated embodiment are often purposely designed around game-like fantasy environments using rich narratives that are created to give players choice and purpose in their actions, and to promote generalizations across contexts. For example, Barab, Gresalfi, and Ingram-Goble (2010) drew upon transformational play theory to inform their design of *Quest Atlantis*, inviting players to become active decision makers whose choices create meaningful cycles of social impact on both the player and the game as it unfolds.

For older teen and adult learners in particular, Siemens' (2005) theory of connectivism also helps to explain the appeal of educational VWs and immersive simulations. By emphasizing the existence of knowledge that resides outside the person via connective nodes, learning becomes a process of connecting information, which relies on a variety of strategies in decision and meaning making. Some immersive environments provide a technological infrastructure, including data feeds and social network communication mechanisms, to assist players in making linkages among these data sources.

The online, multiplayer of aspects of immersive technology, combined with game-like narratives that emphasize socio-technical structures, are often grounded in critical/transformation studies that examine age, gender, and culture differences, and underscore the need for ethical action in globally relevant concerns, such as global warming, genocide, and poverty (Barab, Dodge, Thomas, Jackson, & Tuzun, 2007; Kafai, 2010).

Theories about motivation from social psychology describe various reasons why participants might become highly engaged in a VW or immersive simulation and might be motivated to frequently seek out this experience. Aspects of a videogame experience that promote intrinsic motivation include intrapersonal factors such as challenge, control, fantasy, and curiosity as well as interpersonal factors such as competition, cooperation, and recognition (Bartle, 2003). The challenge dimension of engagement is heightened when a participant achieves a state of flow through facing challenges that are difficult, but surmountable at their current level of skill (Csikszentmihalyi, 1988). Other generic, intrinsic factors that heighten motivation include the perceived instrumental value of an activity (Brophy, 1999), perceived personal competence in accomplishing the goals of an activity (Dweck, 2002), and autonomy in making choices within an activity (Ryan & Deci, 2000). Lepper and Henderlong (2000) described various ways that extrinsic incentives used to promote participating in an activity, but unrelated to the intrinsic nature of the experience, can undercut learning and intrinsic motivation, if overdone. Both they and Habgood and Ainsworth (2011) suggested strategies for ensuring that educational experiences such as games culminate in participants having strong intrinsic motivation. Przybylski, Rigby, and Ryan (2010) summarized these dimensions of motivation as applied to videogames.

Learning Affordances and Limitations

Research on the design, use, and impact of VWs and immersive simulations in education goes back over a decade. However, the ways in which VWs are effective as learning environments is still unclear, as much of the research is descriptive, relying on self-report data (Hew & Cheung, 2010), rather than theoretically based and experimental.

Virtual worlds can be used to create learning spaces that are applicable to almost all disciplines, subjects, or areas of study (Johnson, Levine, & Smith, 2007). In their meta-analysis of 470 studies, Hew and Cheung (2010) identified three uses of VWs in K-12 and higher education environments: (1) communication spaces, (2) simulation of physical spaces, and (3) experiential spaces. Their research suggested that K-12 students like using VWs because they can fly and move around freely in a 3D space, meet new people, and experience virtual field trips and simulations. Similarly, adult learners and teachers have reported great enthusiasm when learning in immersive spaces (Dickey, 2011).

Learning affordances and limitations in immersive environments will vary depending on the interplay between the technology's design intent, functionality, and the needs of the learner (Dickey, 2011). This section presents findings from research emphasizing teaching and learning affordances and limitations of these environments, as well as design mechanics, including: identity exploration, communication and collaboration, spatial simulation, experiential spaces, and assessment.

Identity Exploration Through Virtual Embodiment

The experience of situated embodiment lies at the heart of immersive experiences in which one feels psychologically present in a context that is not where the person is physically located (Winn, 2003). In VWs and immersive simulations, situated embodiment is based on the willing suspension of disbelief (Dede, 2009). Motivational factors that encourage this mental state include empowering the participant in an experience to initiate actions that have novel, intriguing consequences, invoking powerful semantic associations and cultural archetypes via the content of an experience, and sensory immersion through extensive visual and auditory stimuli. Situated embodiment in virtual environments and immersive simulations offers the potential for identity exploration, in which a participant plays a role different than the one portrayed by that person in everyday life. Laurel (1993) and Murray (1997) described design strategies that can enhance participants' identity exploration, such as providing options to modify the avatar's appearance, gender or clothing; creating role-play opportunities in historical or fantasy-based settings; and experiential learning opportunities to be someone other than yourself and reflect on the experience. However, freedom to play with identity can cause confusion, and users must learn to manage their reputation when using avatars in professional contexts such as teacher, or that are associated with their institution or organization (Warburton, 2009).

Communication and Collaboration Spaces

Many VWs and simulations provide opportunities for social interactions between individuals, and among members of communities, as well as more limited interactions with objects and with agents who are scripted by the computer (Warburton, 2009). Typically, the user creates an avatar that may or may not have an identified role in the world, providing the user a vehicle for situated embodiment in the setting and a sense of "being in the world" (Barab, Zuiker et al., 2007). Avatars can communicate nonverbally using gestures, appearance, and avatar postures, as well as verbally through the use of text-based chat, IM, voice chat, and group communication tools. Social cues in the VW, such as eye-gaze while talking, are governed by the same norms as those in the physical world (Yee, Bailenson, Urbanek, Chang, & Merget, 2007).

Because the communication space is virtual and multi-player, it provides an alternative delivery format for distance education students (deFreitas et al., 2010). The opportunity to interact with users from around the world in a shared immersive setting can promote cultural sensitivity and awareness of global issues. Through the use of translation technology available in some VWs, language barriers can be overcome, increasing communication options.

Dawley (2009) lists over 15 in-world and out-of-world communication mechanisms available in VWs. In-world communication mechanisms can include private messaging, group chat, newsletters, global chat, and the like. Out-of-world communication mechanisms are tools that can be accessed while in a virtual world, but are hosted elsewhere on the Internet, such as Twitter, blogs, Web sites, and even calling someone's mobile phone while logged in as an avatar. When leveraged effectively, these communication options can support increased engagement and motivation, group action, individual transformation, and shared meaning-making opportunities. Community presence to induce a sense of belonging and group purpose is another affordance supported through communication mechanisms such as groups, guilds, and clans (Warburton, 2009). Subcultures such as goths, furries, griefers, educators, and superheroes can create strong identity affiliations, promoting persistence in the VW space. However, if guidance is not provided for the user, communities can be hard to locate and learning the norms for participation takes time.

Social network knowledge construction (SNKC) is a pedagogical model for VW learning (Dawley, 2009). SNKC takes advantage of the various social network communication mechanisms that are available to older participants in VWs, leading learners through a five-stage process: identify, lurk, contribute, create, and lead. Learners begin as neophytes, working through the cycle to eventually become mentor/leader on a given topic. SNKC begins with learners identifying relevant social networks in and around the VW that will support their inquiries in a given course of study. They learn to lurk and recognize cultural norms and rules for participation. Eventually, they begin to offer small contributions of information or their time to the network. As they gain experience and credibility in the network—or "avatar capital" (Castronova, 2006)—they shift into positions where they have the opportunity to create their own work, buildings, exhibits, and the like. Finally, the cycle completes with the learner taking leadership, either of a network by mentoring neophytes, or by managing a group, thus supporting an ongoing viral cycle with a new set of neophyte learners.

Spatial Simulation

Immersive technologies are effective when learners need practice with repetitive tasks where it may not be possible or realistic to repeat these tasks in real life, such as practicing take off and landings in a plane simulator, or practicing administering medications to a patient in a simulated hospital setting. Spatial simulation is one of the fundamental affordances of VW environments (Hew & Cheung, 2010). This is the context in which "being there" occurs. Spatial simulation involves the ability to recreate authentic content and culture, as well as the creation of content that may be historically unavailable, imaginary, futuristic, or too expensive to produce in real life (Warburton, 2009). In role-play simulations such as *simSchool* or a nursing simulation in *Second Life*, the spatial simulation is central as a pre-training experience for neophytes, familiarizing them with the physical space, tools, and structure of their future workplace prior to assuming their duties in the physical world.

Experiential Learning

In experiential learning, avatars learn by doing: "acting" on the world, observing the results of their actions, and testing their hypotheses (Hew & Cheung, 2010). In medical and school simulation scenarios, for example, learners can conduct repetitive tasks in the environment (such as sanitary protocols), take risks, and try alternative strategies at no cost and without fear of harming the students or patients (Gibson, Aldrich, & Presnsky, 2007). Participants are able to experience learning first-hand, as opposed to viewing a video or reading a text about student management or patient care.

Educational activities in VWs emphasize experience and exploration over recall strategies. The participant experience is choreographed to emphasize learner control, engagement, learner-generated content, and peer-based learning that may, or may not, be based in a narrative storyline (deFreitas et al., 2010). Educational activities can be rich and varied, including role-play and simulation, walk-through tutorials, displays and showcases, historical recreations, artistic performances, machinima (animated video) production, scavenger hunts, immersive language instruction, and writing and book production (Dawley, 2009; Warburton, 2009). The ability to design, build, and own content in the VW is a noted powerful motivator (Warburton, 2009).

Assessment

A final affordance of VW lies in opportunities for assessment. Clarke-Midura and Dede (2010) suggested that virtual performance assessments provide new vehicles for innovative observation and sophisticated analysis of complex student performances. They outlined the quandary associated with using national tests that do not align with the content they are supposed to be measuring, and suggested that immersive environments excel as tools for observation of authentic student behaviors, choices, and performance on tasks. For example, they illustrated a learner who logs into a virtual Alaskan ecosystem, encounters kelp depletion, and begins to collect and analyze data to identify the problem. This type of assessment is difficult to conduct using traditional paper-and-pencil, item-based assessments, which neither richly evoke constructs to be measured nor provide a detailed stream of evidence about what the learner does and does not know. In contrast, in an immersive environment, the assessment is rich and performances are detailed, yet assessment is unobtrusive because players leave "information trails" (Loh, 2007) as they move through the virtual space, interact with objects, and chat. These behaviors can be recorded in data streams for analysis using data and text mining techniques (Dede, 2009) In learning environments, as opposed to assessment, feedback can made available in real-time for the participant to enable progressive improvement (Dede, 2012).

Additional Limitations

Teachers and instructional designers are often uncertain about what immersive environments are suitable for their students and how to design immersive learning. Also, cost, the time required to learn a new technology, student safety and privacy issues, and institutional barriers to adoption all pose challenges (Dawley, 2009).

Dissatisfaction with VWs and simulations often revolves around technical problems with equipment, Internet connectivity, scalability of the platforms, and institutional firewalls, as well as prohibition of the use of VWs in public computers (deFreitas et al., 2010; Hew & Cheung, 2010; Warburton, 2009). Users also express concerns regarding the need for fast typing and the requirement to quickly formulate responses in chat communication. Of particular concern for K-12 learners are issues of student safety and data privacy issues (Dawley, 2009). Other challenges include:

1. *Collaboration*: Trust, eye contact, and virtual presence are all important components to build effective collaboration. Asynchronous communication mechanisms such as a discussion forum or wiki are required to promote ongoing persistence for group activities, especially when users live in multiple time zones. Collaboration may need purposeful scaffolding.
2. *Time*: Simple tasks, such as speaking, walking, or changing clothes, can take a long time to learn to do efficiently. Instructors must learn design and technical management skills.
3. *Economics*: VWs and simulations may be based on varying forms of business models, often requiring the user to either purchase a premium level of service, or participate in inworld activities or "jobs" that will generate revenue for the vendor.
4. *Standards*: Lack of open design standards creates issues for developers who want to integrate other technologies and resources.
5. *Persistence and social discovery*: Unlike other social networks such as Facebook™, most VWs hide the user's larger social network, keeping them at the center of the network, unable to see friends of friends. While the VW is persistent, the avatar maintains persistence only when logged in.

Unique Affordances for Instructional Design

Smart, Cascio, and Paffendorf (2007) outlined infrastructure similarities common to all VWs:

- Persistent in-world environment
- Shared, multiplayer space
- Virtual embodiment using an avatar
- Interactions between avatars and objects
- Real time actions, interactions, and reactions
- Similarities to the real world, such as topography, movement, and physics

However, because VWs and simulations vary greatly in their design and functionality, some researchers have developed typologies to identify the range of design options (Messinger, Stroulia, & Lyons, 2008). deFreitas et al. (2010) proposed the *Four Dimensional Framework* for considering the design and development of VWs:

1. The learner (their profile, role, and competencies)
2. The pedagogical models used (associative, cognitive, and social/situative)
3. The representation used (fidelity, interactivity, and immersion)
4. The context (environment, access to learning, supporting resources) where learning occurs

This framework provides a way to consider various effective instructional design strategies for VW and simulations, as shown in Table 58.2.

For those interested in creating their own virtual world or simulation, the less technologically savvy builder can first learn to build in existing content creation worlds such as *Active Worlds*, *Jibe*, *Second Life* or *Minecraft*. Builders are often self-taught using YouTube™ videos, or learn by taking in-world workshops, often hosted at no cost to players.

There are several popular companies such as *Kitely*, *ReactionGrid*, and *InWorldz* that host virtual worlds using the OpenSim platform. The benefit of OpenSim is that one can create his/her own virtual world without programming knowledge, and environments can be restricted to specific

Table 58.2 VW and simulation instructional design strategies

Framework dimension	Instructional design strategy	Research study
Learner	Create roles that let learners meld their identity with the game role	Barab, Zuiker et al. (2007)
Pedagogical models	Rich narrative activities establish the need for embedded formalisms and embodied participation	Barab, Zuiker et al. (2007)
Pedagogical models	Apply formalisms to problems close at hand, then proximal, then those that are more distal	Barab, Zuiker et al. (2007)
Learner	Game is responsive to player's decisions, both game and player change as the game progresses	Barab, Zuiker et al. (2007)
Representation	Culturally, ethically sensitive designs should provide options in outcomes, with the preferred outcome providing the most favorable results	Barab, Dodge et al. (2007)
Pedagogical models	Integrate progressive use of in-world and out-of-world social network communication mechanisms to support active knowledge construction, persistence, and a shift from neophyte to mentor	Dawley (2009)
Learner	Match the design of the VW or sim to the needs and competencies of the learners	deFreitas et al. (2010)
Context	Use in-world observations and downloaded data streams to triangulate assessment of complex learning	Clarke-Midura and Dede (2010)
Representation	Use spoken text vs. printed-text as a feedback mechanism in simulation design to promote decision-making performance	Fiorella, Vogel-Walcutt, and Schatz (2011)
Pedagogical models	Use a case study as the basis for a simulation design	Kahn (2007)
Learner	Compare alternative strategies for learning to see what works for whom and when	Ketelhut, Nelson, Clarke, and Dede (2010)
Context	Embed guidance unobtrusively and make usage optional	Nelson (2007)
Representation	Manage sensory complexity and cognitive load; design for a middle ground including a combination of relevant visual information and immersive elements (such as sidewalks, streetlamps) without creating cognitive overload	Nelson and Erlandson (2008)
Representation	Address three layers of presence (physical, communication, status) to create a strong immersive experience	Warburton (2009)
Context	Consider access to newer technology, bandwidth, firewalls as part of the design	Warburton (2009)
Representation	Leverage avatar opportunities for interaction among each other and objects	Warburton (2009)
Pedagogical models	Provide avatar space, training, and authentic reasons for constructing in 3D	Warburton (2009)

users, a feature that can be very important for younger users and schools districts worried about student privacy. Users such as Linda Kellie at http://lindakellie.com provide free downloadable OpenSim content so new builders do not have to create everything from scratch.

For those with programming experience, *Unity 3D* is a popular game engine used in simulation design, and *ReactionGrid* is a company that can provide hosting of a Unity simulation.

Design-Based Research

Because of the emergent nature of these technologies, many designers/researchers are using design-based research methodologies, working in iterative cycles of needs analysis, design, data collection and analysis, and generation back to theory that informs the design (Dede, 2005; Design-Based Research Collective, 2003). Design-based research is a mixed methods approach that tests and refines "educational designs based on theoretical principles derived from prior research" (Collins, Joseph, & Bielaczyc, 2004, p. 18). Less emphasis is placed on generating truths that would apply across all VWs or all simulations; rather, research data is used to inform the ongoing development of specific interventions or technologies, as well as their guiding theoretical frameworks.

Although VW and simulations lend themselves to traditional research methods, it is noteworthy that these technologies have evolved in ways that now provide scholars the opportunity to collect and analyze data to support the research-design process. It is typical, and often desirable, for researchers to use mixed methods strategies for understanding mixed realities (Feldon & Kafai, 2008). The cloud-based architecture of these technologies provides the opportunity to capture user activity behavior and logs, including chat dialogues, interactions with items, time and date stamps of events, avatar trail tracking through the virtual space, IP logins, geo-spatial locations, and more. This user activity can be downloaded and "cleaned" in a data mining process, with results often viewable using graphic visualizations. For example, Fig. 58.4 below illustrates a heat-map showing avatar activity over a 1 week period on a simulation in Second Life. Each dot on the heat map represents one minute of avatar tracking in a particular zone of the VW.

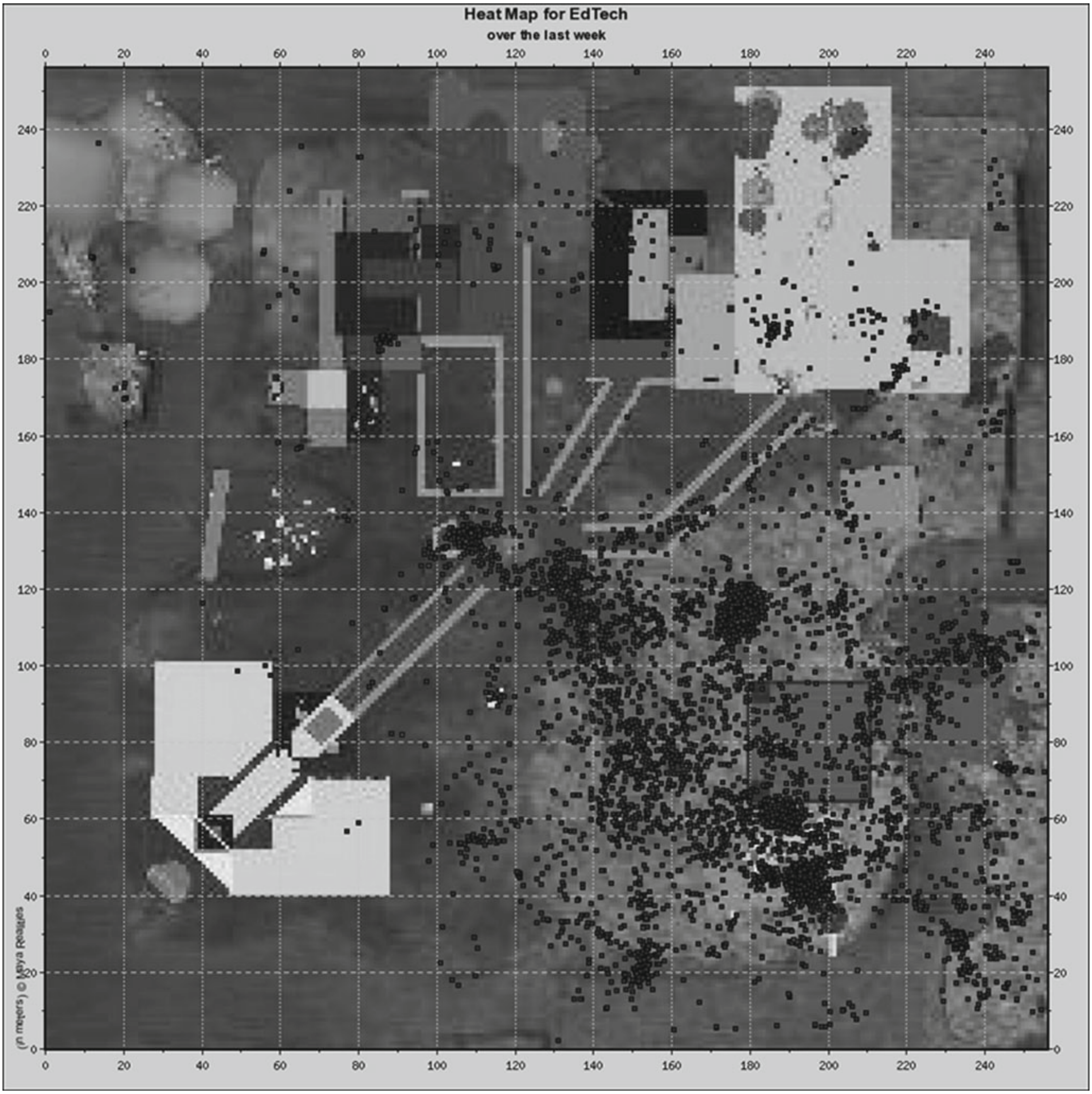

Fig. 58.4 Heat map illustrating user activity in a VW

In much the same way that a Web designer might use site statistics to inform decisions about Web site design, this specific form of visual data can be useful to instructional designers who seek to understand the use of space in immersive environments and where design changes may be needed in the environment.

The intentionality of the VW design often frames the design-research process (Richter & Dawley, 2010). For example, Kafai's (2010) work in *Whyville*, a social VW for preteens, explores the nature of the social interaction among gender, and the resulting implications for instructional management. This type of research on "what do kids learn in informal VWs" produces different types of results than educational design-based research in a specific VW developed to achieve distinct learning goals (Barab, Gresalfi, Dodge, & Ingram-Goble, 2010; Clarke-Midura & Dede, 2010). In the former, the research is done to answer a larger global research question. In the latter, research is collected to inform the design itself.

Conclusions

The body of research on VWs and immersive simulations has grown substantially, with hundreds of education-related studies published over the last 5 years. Researchers have documented that situated learning in VWs can be an important and engaging component in an educational program for various reasons and purposes. Transfer of learning from the VW or simulation to other contexts does occur and can be purposefully designed by using rich narratives and contexts, and by giving the user decision-making roles that impact the environment. Ownership and leadership in the learning process can be supported through the careful integration and leveraging of social network communication mechanisms associated with a VW. However, there are definite limitations to the use of these technologies in education, including issues of access, technical problems, appropriateness, and needing to match learning goals to design intent.

Scholars are still determining the full extent to which VWs and simulations can support learning. VW projects developed using a mixed-methods design-based research approach, and supported with observation, data mining, and text mining from user activity logs, are providing strong evidence of what is learned and the extent to which the knowledge can be used or applied. However, a large amount of published research still relies on user self-reporting as a main data collection strategy.

New technology developments show continued promise for the use of VWs and simulations. Immersive technologies are experiencing huge commercial growth, with new market sectors and uses appearing as the technologies themselves evolve. As commercial opportunities continue to grow, so will engagement for educational purposes. Trends in immersive technology growth include more cross-platform development between VWs and entertainment (TV, movies, books, and toys), spaces for visual artists and celebrities, content creation and science fiction for adults, and additional social network integration across platforms (KZero Inc., 2011). Open-source viewers, advanced visualization and haptic devices, and developing consensus over open standards and specifications may support better interoperability in the near future to provide more personalized learning experiences and allow avatar-users to cross platforms (deFreitas et al., 2010; Warburton, 2009).

As enrollments in online education increase, and the emphasis on blended schooling continues to expand, immersive technologies will play an important and growing role to augment the virtual learning experience. These developments have implications for educational professionals: teachers need training in pedagogical and technical skills; instructional designers require professional development in the appropriate use and application of immersive technologies; design-based researchers need training in mixed-methods data collection and strategies for data mining; and network administrators will have to work to overcome technical limitations of bandwidth, access, firewalls, and outdated computers.

Many areas are ripe for future research in educational immersive technologies. As our emphasis in education shifts away from the memorization of decontextualized facts and toward the personalized learning experiences to develop human beings who can problem-solve across a variety of scenarios, immersive environments may support this objective. As design studies begin to shift away from randomized controlled trials toward the use of mixed-methods design research integrating observation and data mining, our understanding of the learner evolves, as well as our understanding of how to build a better learning system.

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59 Augmented Reality Teaching and Learning

Matt Dunleavy and Chris Dede

Abstract

This literature review focuses on augmented realities (AR) for learning that utilize *mobile*, *context-aware* technologies (e.g., smartphones, tablets), which enable participants to interact with digital information embedded within the physical environment. We summarize research findings about AR in formal and informal learning environments (i.e., schools, universities, museums, parks, zoos, etc.), with an emphasis on the affordances and limitations associated with AR as it relates to teaching, learning, and instructional design. As a cognitive tool and pedagogical approach, AR is primarily aligned with situated and constructivist learning theory, as it positions the learner within a real-world physical and social context while guiding, scaffolding and facilitating participatory and metacognitive learning processes such as authentic inquiry, active observation, peer coaching, reciprocal teaching and legitimate peripheral participation with multiple modes of representation.

Keywords

Augmented reality • Mobile learning • Context-aware • Location-based

Introduction

This literature review focuses on augmented realities (AR) for learning that utilize *mobile*, *context-aware* technologies (e.g., smartphones, tablets), which enable participants to interact with digital information embedded within the physical environment. We summarize research findings about AR in formal and informal learning environments (i.e., schools, universities, museums, parks, zoos, etc.), with an emphasis on the affordances and limitations associated with AR as it relates to teaching, learning, and instructional design.

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There are two forms of AR currently available to educators: (1) location-aware and (2) vision-based. Location-aware AR presents digital media to learners as they move through a physical area with a GPS-enabled smartphone or similar mobile device (Figs. 59.1 and 59.2). The media (i.e., text, graphics, audio, video, 3D models) augment the physical environment with narrative, navigation, and/or academic information relevant to the location. In contrast, vision-based AR presents digital media to learners after they point the camera in their mobile device at an object (e.g., QR code, 2D target). The following scenario provides a contextualized example of both forms of AR:

> As the 7th grade life science student passes by an oak tree in her school playground, software leveraging GPS plays a video on her smartphone describing the various habitats and animals that are found near the tree (location-aware). At the end of the video, the student is prompted to point her phone's video camera at a placard at the base of the tree, which triggers a 3-dimensional model illustrating the anatomical structure of the oak (vision-based).

The potential power of AR as a learning tool is its ability "to enable students to see the world around them in new

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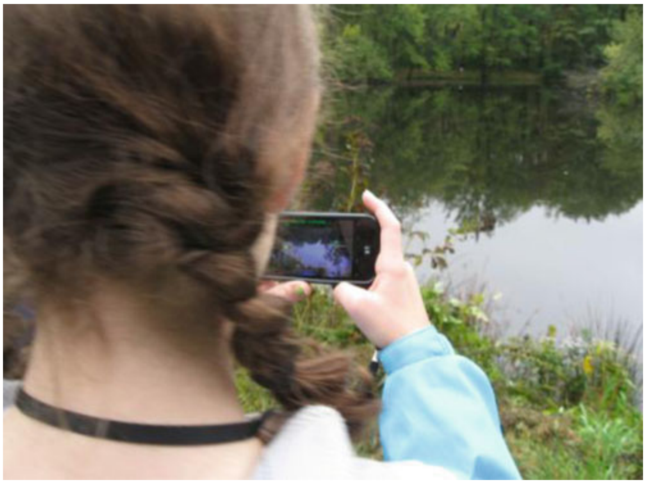

Fig. 59.1 Students collecting data

Fig. 59.2 Students analyzing data

ways and engage with realistic issues in a context with which the students are already connected" (Klopfer & Sheldon, 2010, p. 86). These two forms of AR (i.e., location-aware and vision-based) leverage several smartphone capabilities (i.e., GPS, camera, object recognition and tracking) to create "immersive" learning experiences within the physical environment, providing educators with a novel and potentially transformative tool for teaching and learning (Azuma et al., 2001; Dede, 2009; Johnson, Smith, Willis, Levine, & Haywood, 2011). Immersion is the subjective impression that one is participating in a comprehensive, realistic experience (Dede, 2009). Interactive media now enable various degrees of digital immersion. The more a virtual immersive experience is based on design strategies that combine actional, symbolic, and sensory factors, the greater the participant's suspension of disbelief that she or he is "inside" a digitally enhanced setting. Studies have shown that immersion in a digital environment can enhance education in at least three ways: by allowing multiple perspectives, situated learning, and transfer.

Furthermore, these two forms of AR both leverage the affordance of context sensitivity, which enables the mobile device to "know" where it is in the physical world and to present digital content to the user that is relevant to that location (Klopfer, Squire, & Jenkins, 2002). This review primarily focuses on location-aware AR played outdoors in the physical environment; while vision-based AR holds enormous potential for educators, there are few current studies on this version of AR. Research on related immersive media suggests ways in which vision-based AR could be powerful. For example, using the medium of sensorily immersive virtual reality, Project ScienceSpace contrasted egocentric rather than exocentric frames of reference (Salzman, Dede, Loftin, & Chen, 1999). The "exocentric" frame of reference provides a view of an object, space, or phenomenon from the outside, while the "egocentric" frame of reference provides a view from within the object, space, or phenomenon. The exocentric and the egocentric perspectives were found to have different strengths for learning, and the "bicentric" perspective alternating between egocentric and exocentric views was shown to be particularly powerful.

Theoretical Foundation for AR

The assertion that AR could provide enhanced learning experiences is grounded in two interdependent theoretical frameworks: (1) situated learning theory and (2) constructivist learning theory.

Situated learning theory posits that all learning takes place within a specific context and the quality of the learning is a result of interactions among the people, places, objects, processes, and culture within and relative to that given context (Brown, Collins, & Duguid, 1989). Within these contexts, learning is a co-constructed, participatory process in which all learners are "transformed through their actions and relations in the world" (Driscoll, 2000, p. 157). Situated learning builds upon and extends other learning theories such as social learning theory and social development theory, which posit that the level of learning is dependent upon the quality of the social interaction within the learning context (Bandura, 1977; Vygotsky, 1978).

Situated learning through immersive interfaces is important in part because of the crucial issue of transfer (Dede, 2008, 2009). Transfer is defined as the application of knowledge learned in one situation to another situation and is demonstrated if instruction on a learning task leads to improved performance on a transfer task, ideally a skilled performance in a real-world setting (Mestre, 2002). Researchers differentiate between two ways of measuring transfer: sequestered problem-solving and preparations for future learning

(Schwartz, Sears, & Bransford, 2005). Sequestered problem-solving tends to focus on direct applications that do not provide an opportunity for students to utilize resources in their environment (as they would in the real world); standardized tests are an example of this (Cobb, Yackel, & Wood, 1992). Giving students presentational instruction that demonstrates solving standard problems, then testing their ability to solve similar problems involves near-transfer: applying the knowledge learned in a situation to a similar context with somewhat different surface features.

When evaluation is based on the success of learning as a preparation for future learning, researchers measure transfer by focusing on extended performances where students "learn how to learn" in a rich environment and then solve related problems in real-world contexts. With conventional instruction and problem-solving, attaining preparation for future learning requires far-transfer: applying knowledge learned in a situation to a quite different context whose underlying semantics are associated, but distinct (Perkins & Salomon, 1992). One of the major criticisms of instruction today is the low rate of far-transfer generated by presentational instruction. Even students who excel in educational settings often are unable to apply what they have learned to similar real-world contexts. The potential advantage of immersive interfaces for situated learning is that their simulation of real-world problems and contexts means that students must attain only near-transfer to achieve preparation for future learning. Flight and surgical simulators demonstrate near-transfer of psychomotor skills from digital simulations to real-world settings; research on the extent to which AR can foster transfer is an important frontier for the field (Gallagher & Sullivan, 2011; Hays, Jacobs, Prince, & Salas, 1992).

Constructivist/Interpretivist theories of learning assume that meaning is imposed by the individual rather than existing in the world independently (Dede, 2008). People construct new knowledge and understandings based on what they already know and believe, which is shaped by their developmental level, their prior experiences, and their sociocultural background and context (Bruner, 1966; Vygotsky, 1978). Knowledge is embedded in the setting in which it is used; learning involves mastering authentic tasks in meaningful, realistic situations (Lave & Wenger, 1991). Learners build personal interpretations of reality based on experiences and interactions with others, creating novel and situation-specific understandings. Instructional design approaches based on Constructivist theories include anchored instruction (Cognition and Technology Group at Vanderbilt, 1993), case-based learning (Kolodner, 2001), cognitive flexibility theory (Spiro, Feltovich, Jackson, & Coulson, 1991), collaborative learning (Barron, 2000), microworlds and simulations (White, 1993), mindtools (Jonassen, 2005), and situated learning in communities of practice (Lave & Wenger, 1991).

Instruction can foster learning by providing rich, loosely structured experiences and guidance (such as apprenticeships, coaching, and mentoring) that encourage meaning-making without imposing a fixed set of knowledge and skills (Lave & Wenger, 1991). Constructivist learning theory outlines five conditions most likely to enhance learning: (1) Embed learning within relevant environments, (2) Make social negotiation integral to the learning experience, (3) Provide multiple perspectives and multiple modes of representation, (4) Provide self-directed and active learning opportunities, and (5) Support and facilitate metacognitive strategies within the experience (Bruner, 1966; Cunningham, 1992; Driscoll, 2000; Piaget, 1969; Vygotsky, 1978).

As a cognitive tool or pedagogical approach, AR aligns well with situated and constructivist learning theory as it positions the learner within a real-world physical and social context, while guiding, scaffolding and facilitating participatory and metacognitive learning processes such as authentic inquiry, active observation, peer coaching, reciprocal teaching and legitimate peripheral participation with multiple modes of representation (Dunleavy, Dede, & Mitchell, 2009; Klopfer & Sheldon, 2010; Palincsar, 1998; Squire, 2010).

Augmented Reality Learning Research Teams and Experiences

Although AR has begun to gain popular attention over the last year (Johnson et al., 2011; Li, 2010), relatively few research and development teams are actively exploring how mobile, context-aware AR could be used to enhance K-20 teaching and learning. The majority of the findings presented in this review are studies from four research groups: (1) the MIT Scheller Teacher Education Program; (2) the Augmented Reality and Interactive Storytelling (ARIS) Group at the University of Wisconsin at Madison; (3) the immersive learning group at the Harvard Graduate School of Education; and (4) the Radford Outdoor Augmented Reality (ROAR) project at Radford University. While the majority of the findings presented in this review are drawn from these four labs, European teams (e.g., Futurelab, INVENTIO-project, Studierstube) are making significant contributions to the field as well, and their research was also incorporated in this review. Among all these research and development teams, they have developed and presented substantial findings on at least seventeen distinct AR experiences and simulations (Table 59.1).

All of these AR development teams are using some form of design-based research (DBR) approach to explore the feasibility and practicality of using AR in the K-12 environment for teaching and learning (Dieterle, Dede, & Schrier, 2007; Dunleavy & Simmons, 2011; Klopfer & Squire, 2008; Squire, 2010). DBR is a mixed methods approach that tests

Table 59.1 Augmented reality experiences

Name	Genre	Scenario
Science		
Outbreak at MIT	Inquiry-based simulation	Users investigate a disease outbreak and attempt to contain it (Design Team: MIT)
Environmental detectives	Inquiry-based simulation	Users investigate the source of a chemical spill to determine causal factors and environmental effects (Design Team: MIT)
TimeLab 2100	Inquiry-based simulation	Users travel back in time to change the devastating effects of climate change (Design Team: MIT)
Outbreak at RU	Inquiry-based simulation	Users investigate a disease outbreak and develop an antidote to stop it (Design Team: RU, NSF Grant: DRL-0822302) Web site:http://gameslab.radford.edu/ROAR/games/outbreak.html
Savannah	Inquiry-based simulation	Users explore the African savannah as a pride of lions to learn about the ecosystem and behavior of animals (Design Team: FutureLab). Web site: http://202.129.0.151/Teleport/FutureLab/savannah.htm
Gray anatomy	Inquiry-based simulation	Users investigate the causes behind why a whale has beached itself (Design Team: Harvard)
Mad City Mystery	Inquiry-based simulation	Users investigate a murder mystery involving environmental toxins (Design Team: UW-M)
Sick at South Beach	Inquiry-based simulation	Users investigate why a group of kids are sick after spending the day at the beach (Design Team: UW-M)
Lake Wingra	Inquiry-based simulation	Users explore the area around Lake Wingra to investigate if the lake is healthy (Design Team: UW-M)
EcoMobile	Inquiry-based simulation	Users explore a pond to determine the types of causal dynamics it exhibits (Design Team: Harvard, NSF Grant: DRL-1118530). Web site: http://ecomobile.gse.harvard.edu
History		
Dow day	Historical reenactment	Users "experience" a series of anti-Dow chemical protests that took place on the University of Wisconsin at Madison campus in October of 1967 (Design Team: UW-M). Web site: http://arisgames.org/featured/dow-day/
Greenbush	Inquiry-based simulation	Users explore a historic neighborhood to learn how urban planning impacts communities (Design Team: UW-M)
Buffalo hunt	Inquiry-based simulation	Users explore the American plains in the 1800s as an American Indian tribe to find buffalo herds (Design Team: RU). Web site: http://gameslab.radford.edu/ROAR/games/buffalo-hunt.html
Reliving the revolution	Inquiry-based simulation	Users explore the Lexington, MA revolutionary war battlefield to determine who fired the first shot (Design Team: Karen Schrier, MIT)
Museums and zoos		
Mobile augmented reality quest (MARQ)	Treasure hunt	Users worked in teams to solve puzzles related to the various museum exhibits (Design Team: Christian Doppler Laboratory). Web site: http://handheldar.icg.tugraz.at/marq.php
Zoo scene investigators	Inquiry-based simulation	Users explore the zoo to learn about the illegal wildlife trade (Design Team: MIT/Futurelab)
Other		
Hip Hop Tycoon	Inquiry-based economics simulation	Users attempt to set up a hip-hop store to sell music related merchandise in their neighborhoods (Design Team: UW-M)
Mentira	Inquiry-based language simulation	Users investigate a murder mystery requiring Spanish language skills (Design Team: University of New Mexico). Web site: http://www.mentira.org/
Alien contact!	Inquiry-based Math/English simulation	Users investigate an alien landing site to determine the intent of the extraterrestrial visitors (Design Team: Harvard). Web site: http://isites.harvard.edu/icb/icb.do?keyword=harp

and refines "educational designs based on theoretical principles derived from prior research" (Collins, Joseph, & Bielaczyc, 2004, p. 18). As applied to AR development, this formative research uses an approach of progressive refinement where AR designs that have been informed by learning theory frameworks as well as video game design principles (e.g., immersive narrative, role play, puzzles) are field tested in real world contexts with typical users to determine which design elements work well in practice and which elements need to be revised and retested (O'Shea, Dede, & Cherian, 2011). This iterative research and development process is similar to the rapid prototyping methods used in software engineering (Tripp & Bichelmeyer, 1990). Although DBR is challenging to conduct (Dede, 2004, 2005), it is the most appropriate approach to determine the design principles that leverage the affordances of this emergent and nascent pedagogical and technological tool, as well as insights about theory and heuristics about practical usage (Design-Based Research Collective, 2003; Squire, 2005).

K-20 Augmented Reality Literature Review

As a result of the DBR approach, the majority of the findings resulting from AR research and evaluation presented in this review pertain to the actual design of the units and how these designs are aligned with both theoretical constructs and unique AR affordances. Although the majority of the findings focus on design, we begin the review with unique affordances and limitations AR currently presents to educators, as well as the most frequently reported learner outcomes as found in the literature at this stage in AR's development.

Affordances

The most frequently reported affordance of AR is the ability to present to a group of learners multiple incomplete, yet complementary perspectives on a problem situated within a physical space (Dunleavy et al., 2009; Facer et al., 2004; Klopfer & Squire, 2008; Perry et al., 2008; Squire, 2010; Squire et al., 2007). This affordance is a direct result of the 1-to-1 device-to-student ratio provided within most AR learning environments, in which each student is interacting with a GPS-enabled device to participate in the activity. This unique affordance enables educators to incorporate collaborative pedagogical techniques and experience design approaches such as jigsaw and differentiated role play, which lend themselves well to inquiry-based activities requiring argumentation (Klopfer, 2008; Morrison et al., 2009; Squire, 2010).

By embedding these multiple perspectives within the environment and contextualizing them within a problem-based narrative, AR also affords educators the ability to leverage physical space as an additional layer of content for students to observe, manipulate and analyze (Perry et al., 2008; Squire et al., 2007). In other words, augmenting the physical environment with digital information transforms that environment into a venue for multiple, otherwise unrealized learning opportunities (Facer et al., 2004; Klopfer, 2008; Klopfer & Squire, 2008; Liestol, 2011; Morrison et al., 2009; Schmalstieg & Wagner, 2007; Squire et al., 2007).

The ability to access outside resources (i.e., Internet) and additional software on the devices to solve the given problem more effectively is another unique affordance of AR, which utilizes Wifi or data service-enabled handhelds (Klopfer & Squire, 2008). In addition, students may leverage the technologies provided by the handhelds in unanticipated, yet superior ways relative to how the designers had planned (e.g., using the video recording feature on the handheld to make video field notes instead of taking handwritten notes) (Perry et al., 2008).

Finally, across studies research reports that AR implementations result in substantial student motivation. As documented in the literature, student and teachers report high engagement as a result of using the handhelds, adopting roles, negotiating meaning within active, inquiry-based compelling narratives, solving authentic problems, and physically exercising (Dunleavy & Simmons, 2011; Dunleavy et al., 2009; Facer et al., 2004; Klopfer & Squire, 2008; Perry et al., 2008; Schmalstieg & Wagner, 2007; Squire, 2010; Squire et al., 2007).

Limitations

The most frequently reported limitation of AR in its current state of development is student cognitive overload. Across studies, researchers report that students are often overwhelmed with the complexity of the activities (Dunleavy et al., 2009), the scientific inquiry process and navigation (Klopfer & Squire, 2008), or making decisions as a team (Perry et al., 2008). Managing the level of complexity is a key instructional issue, and AR experience designers have attempted to decrease the cognitive load by: (1) creating an simplified experience structure initially and increasing complexity as the experience progresses (Perry et al., 2008); (2) scaffolding each experience explicitly at every step to achieve the desired experience/learning behavior (Klopfer & Squire, 2008); (3) limiting characters and items encountered by students to ~6 per hour (O'Shea, Mitchell, Johnston, & Dede, 2009); and (4) replacing text with subtitled audio (O'Shea et al., 2009; Perry et al., 2008).

Another limitation reported in the literature is the challenge of integrating and managing the overall AR experience from the designers' and teachers' perspectives. The first aspect of this limitation is cultural. The standards-driven efficiency culture and context of school systems are not well aligned with AR, which is best suited for exploratory, inquiry based activities. These are time consuming, more difficult to manage than presentational instruction, and focused on learning objectives (e.g., collaborative problem solving), which do not easily transfer to an achievement test (Clarke-Midura, Dede, & Norton, 2011; Facer et al., 2004; Klopfer & Squire, 2008). Difficulties such as these are comparable to the challenges classroom teachers face in conducting field trips.

The second aspect of this limitation is managerial. At this stage of development, AR integration necessitates a minimum of two to three facilitators to ensure proper implementation without any technical errors (Dunleavy & Simmons, 2011; Dunleavy et al., 2009). In addition, a successful AR implementation is highly dependent upon a skilled teacher to introduce and facilitate key points of the experience (O'Shea et al., 2009; Perry et al., 2008).

Finally, there are limitations with the current state of the art in location-aware and mobile technologies. Most of the technical problems experienced within AR implementations involve GPS error (Dunleavy et al., 2009; Facer et al., 2004; Perry et al., 2008). While GPS technology continues to evolve at a rapid pace, at present it simultaneously enables and limits AR implementations.

Although cognitive overload can be overcome with better design, and the evolution of the technology will remove the current technical challenges, the integration and managerial limitations detailed above present obstacles to the scalability of AR, comparable to the challenges faced by classroom teachers conducting field trips.

Design

The majority of the findings related to designing AR experiences, simulations and stories fall within four major categories: (1) location; (2) narrative; (3) roles; and (4) experience mechanics. While these findings are categorized for organizational and readability purposes, all of these areas overlap in various capacities and are interdependent (e.g., interplay among location, narrative and roles).

Location. The choice of venue or location is one of the most critical design decisions reported in the literature. As the use of the physical environment is a major aspect of the AR affordances, the choice of the location has multiple cascading effects on learning objectives, environment interaction, portability of the AR, and overall player experience.

There are two types of AR experiences in terms of location: (1) place-dependent and (2) place independent (Dunleavy, 2010; Klopfer, 2008; Squire et al., 2007). Place-dependent experiences are designed around a specific location and leverage the history, geography and physical structure of that location within the AR experience. These place dependent experiences are also referred to as highly localized (Klopfer, 2008), location-specific (Klopfer & Sheldon, 2010), and place-based (Squire, 2010). Place-independent experiences are designed to be highly portable and do not leverage any specific location; instead, they are designed to be used within any physical space that has sufficient size. These place-independent experiences are also referred to as lightly localized, space-based, and place-agnostic (Klopfer, 2008).

There are many pros and cons related to the choice between place-dependent and place-independent AR experiences, but the three major issues most frequently reported in the literature pertain to the authenticity of environment interaction and portability (Dunleavy, 2010; Klopfer, 2008; Squire et al., 2007). As AR is inherently a spatial medium, aligning the learning objectives with the potential interactions the users have with the surrounding environment is a critical factor to consider (Rosenbaum, Klopfer, & Perry, 2007). If authentic environmental observation and interaction are part of the learning objectives, then a place-dependent model is optimal, as the designers can scaffold experiences that require the users to observe and manipulate the physical environment (e.g., sampling water, observing topography, collecting leaf samples) to accomplish a specific experience-based task.

However, what is gained in authentic environmental interaction comes at a cost to the experience's portability and utility to other locations (Dunleavy, 2010; Klopfer, 2008). In other words, the more aligned an AR experience is to a specific environment, the less portable it is to other locations, which significantly decreases the experience's scalability. On the other end of the spectrum is a place-independent experience, which, once designed, is highly portable (i.e., can be played anywhere), but does not have a significant amount of authentic interaction with the environment (Klopfer & Sheldon, 2010).

Regardless of the choice of venue, AR experience development is a complex instructional design process, and this factor also needs to be considered when analyzing the trade-offs between place-dependent and place-independent models (Perry et al., 2008). These trade-offs are highly significant not only to specific experience design, but also to the field in general, so extensive research is needed to thoroughly explore this design dynamic (Dunleavy, 2010; Klopfer, 2008; Klopfer & Sheldon, 2010).

A related issue reported in the literature is the interaction between the location and the users' prior relationship with or perception of that location (Perry et al., 2008; Squire et al., 2007). One approach posited as an emerging best practice for AR design is to identify and design around *contested spaces* (Squire et al., 2007). By choosing a space that has a preexisting conflict or compelling narrative, the experience has a narrative "hook" and potentially gives the player more "agency" or sense of control within the experience (Squire et al., 2007). This approach also has the potential to make the AR experience and the location therein more meaningful by connecting the physical space with issues that are relevant to the lives of the users (Klopfer & Sheldon, 2010). Finally, choosing a location that students know conceptually or physically (e.g., a zoo) may provide familiar mental and physical models, thereby decreasing some of the inherent complexity and subsequent cognitive load for the participating users (Perry et al., 2008).

Narrative. The choice of narrative or story is another critical design decision reported in the literature. Similar to the choice of location, the choice of the driving narrative, which provides the structure and rationale for the AR experience, has a profound impact on the quality of the experience (Klopfer and Squire, 2008; Perry et al., 2008).

As previously discussed, designers can build AR experiences to facilitate interactive storytelling in which users need to collect pieces of a story (e.g., new stories, interviews, photographs, videos, etc.) distributed across and embedded within a physical environment. Designer must provide ways that users can subsequently construct these story "pieces" into a synthesized whole, to give the participants a complete view of the problem or narrative (Squire et al., 2007).

Similar to the spectrum possible within location choice, AR researchers report pros and cons of designing a fantastic narrative (e.g., being a pride of lions on the African Savannah) versus a lightly fictionalized narrative (e.g., being a scientist researching a chemical spill) (Facer et al., 2004; Klopfer & Squire, 2008). Facer et al. (2004) argue that the attempt to recreate a different physical reality (e.g., African savannah) on top of a real physical space (e.g., school playground) may be creating a potentially problematic disconnect between a highly fictionalized narrative and the real landscape. This assertion is reinforced within AR designs of authentic simulations, for which the objective is to "create games that could address important disciplinary practices in realistic ways" (Klopfer, 2008, p. 95).

Roles. As discussed above, one of AR's affordances is to present multiple incomplete, yet complimentary perspectives on a problem. This ability enables designers to create differentiated role-based AR experiences that use a combination of jigsaw pedagogy and interdependent roles to give students a complete picture of problem or experience space (Squire, 2010). According to Squire (2010), these fictionalized roles (1) invite students to apply preexisting personal experience to the problem solving process, (2) provide a context for argumentation, (3) create a sense of responsibility among the students who are "experts" in their domain, and (4) enable an active problem solver identity amongst students. In addition, the roles can be used to scaffold and model collaborative research roles, which closely approximate authentic scientific practices (Klopfer & Sheldon, 2010; Kamarainen et al., 2012; Rosenbaum et al., 2007; Squire & Jan, 2007; Squire et al., 2007). While the potential benefits of using role differentiation within AR experiences are clearly stated across the literature, several studies also emphasized the importance of explicitly designing and scaffolding this behavior within the experience (Perry et al., 2008; Squire & Jan, 2007).

Experience Mechanics. While the vast majority of the findings reported in the literature pertained to location, narrative and role, many other specific findings were also reported. These are categorized under experience mechanics, as most of them address particular strategies to enhance the AR experience design for teaching and learning.

The interplay between competition and collaboration is one of more frequently reported aspects of AR experience design. Across studies, researchers reported the need to structure the AR experience in a way that prevents the students' natural inclination to "race" through the experience in an effort to "beat" their classmates by being the first ones to finish (Dunleavy, 2010; Dunleavy et al., 2009; Klopfer and Squire, 2008). One specific solution was to design a nonlinear path with an entry point "gatekeeper" that triggered all the remaining digital objects that students needed to encounter (O'Shea et al., 2009). The students then choose their own paths and are therefore less likely to see themselves as ahead or behind their classmates.

Another experience mechanic finding reported in the literature is the tension between users focusing on the handheld and users interacting with their environment. Several studies documented the students becoming fixated on the handhelds rather than interacting with environment (Dunleavy & Simmons, 2011; Dunleavy et al., 2009; Perry et al., 2008; Squire, 2010). Designs should utilize the handheld to foster interaction with the context rather than to present extensive information independent of context.

Finally, the majority of AR designers have purposefully developed open-ended, inquiry-based experiences, which require argumentation, but do not have a closed "win state" or correct answer. Across studies, students reported that this design model was frustrating and that they desired to have a definitive answer rather than an open-ended scenario (Dunleavy et al., 2009; Klopfer & Squire, 2008; O'Shea et al., 2009; Squire, 2010). This is a challenge inherent in all forms of authentic inquiry-based instruction.

Development Platforms

All of the preceding affordances and limitations are dependent upon the available technology and the appropriate design. As the technology has evolved, so too have the tools developers have to design AR experiences to reach their educational objectives, as have the capabilities available to achieve a quality user experience. In our judgment, based on the current stage of devices, the state of the art in design, and educational objectives aligned with the affordances at present of AR, the ideal development platform would contain the following features:

- *Brower-based editor*. Designers create custom AR experiences using an editing Web site interface that enables them to embed an interactive layer of digital information into any outdoor physical location of their choosing without programming skills.

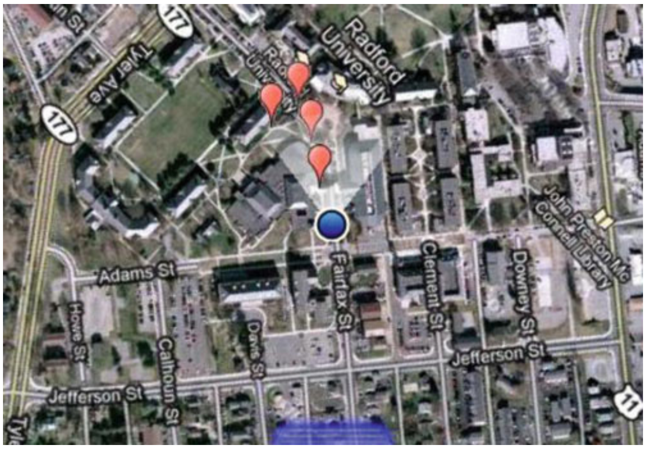

Fig. 59.3 Overhead view

Fig. 59.4 Live view

- *Digital Objects* & *Multimedia embedding* (*i.e.*, *text*, *audio*, *graphics*) (*DO*). Designers can overlay the physical environment with interactive multimedia objects, items, and characters.
- *Location-based functions* (*i.e.*, *GPS and compass*) (*LB*). App users trigger and experience location-specific narrative, navigation, and/or academic information when they come within relative proximity to the location.
- *Overhead and Live View*. App users toggle back and forth between an overhead, satellite view (e.g., Google Maps) and a live-view that uses the handheld's camera to display interactive media on top of the video image. The ability to use both will facilitate navigation (Overhead) (Fig. 59.3), immersion, (live-view), and authentic environment–player interaction (live-view) (Fig. 59.4).
- *User archive*. During the AR experience, App users have access via filter-driven archive or library to all digital objects they have encountered throughout experiences. This function allows participants to have on-demand access to all the information related to an AR experience, negating the need to remember the details or carry additional materials to record the information.
- *YouTube/Vimeo Embed*. Designers are able to embed YouTube or Vimeo videos into their AR experiences by simply copying and pasting the video's URL into the appropriate editor field. This enables designers to leverage all of the existing video content available on the YouTube and Vimeo libraries, thereby significantly reducing the media management and hosting requirements.
- *Roles*. Designers can assign and differentiate between different participant roles, enabling individualized and/or team-based experiences. This function mirrors popular video experience-based design elements in which each user has unique skills and information, thereby making that person valuable and necessary to team-based problem solving.
- *Dynamic Triggers*. Triggering and anti-triggering describe a feature whereby designers can enable and make visible digital objects in the AR environment, or disable and make invisible digital objects, dependent upon user input and/or movement. This allows for dynamic and cascading events within the AR experience.
- *Embedded Assessment*. Designers can embed assessments within their AR experience in multiple formats (e.g., alphanumeric keypads for fill in the blank and sentence completion, and multiple choice). The use of embedded assessments allows AR designers to more closely align their in-experience assessment to their educational objectives (e.g., learning about the Lincoln Memorial) while maintaining the immersive nature of the AR experience. Furthermore, the use of embedded assessments can provide a check on user comprehension, while also providing the experience designers with a control mechanism on user movement (Figs. 59.5 and 59.6).
- *Data Collection*. App users will be able to capture and store data during the AR experience. This data will include photos and audio, which can geo-tagged and stored either on the smartphone or the server. In addition, researchers could use this data collection function for assessment and evaluation purposes.
- *Device-to-Device Communication* (*D2D*). App users will experience a single shared AR world with other users, in which changes in one user's experience will generalize to other users' experiences. For example, if a user picks up a digital item within an experience, this item will disappear for all other users within the same experience.
- *QR Code Embed* (*QR*). Designers can embed QR codes into an AR experience to act as markers or targets for triggering various media (e.g., videos, Web sites, 3D models, etc.).
- *Vision-Based 3D Model Embed* (*3D*). Designers can embed vision-based or visual recognition AR to trigger interactive 3D models.

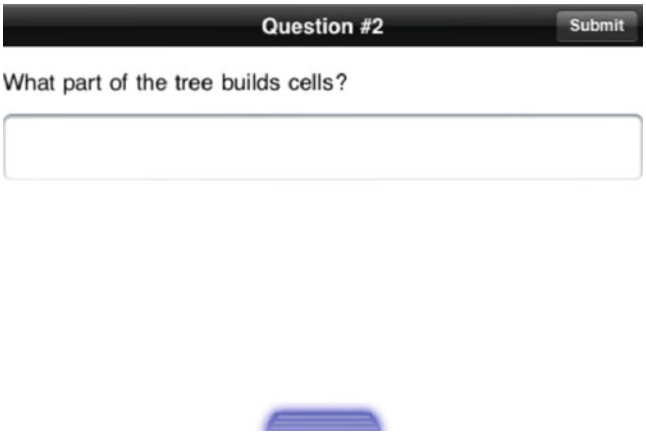

Fig. 59.5 Question prompt

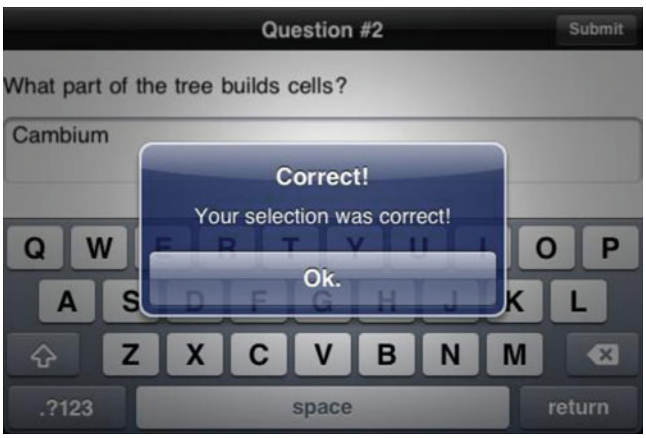

Fig. 59.6 Feedback

- *Social Networking* (*SN*). Designers can leverage social networking tools (e.g., Twitter, Facebook, Google +, etc.) as a mechanic within the AR experience or as a way to share content and/or AR experiences.

While there are several AR browsers (e.g., Layar, Junaio, Wikitude) and programming-based AR development tools (e.g., ARToolKit, ARchitect, metaio Mobile SDK) emerging across the field, there are relatively few stand-alone AR development platforms that enable educators and instructional designers to create custom AR *without* programming skills. This is a key and fundamental requirement of any development platform that will be used by a diverse and often nontechnical audience of educators and instructional designers who nonetheless want to leverage the potential of AR in their students' learning environment. With this adoption and scaling requirement in mind, the following AR development tools provide the majority of the previously outlined functions while not requiring programming or server hosting from the user:

ARIS (http://arisgames.org/): is a "user-friendly, open-source platform for creating and playing mobile games, tours and interactive stories." ARIS was developed out of an ongoing research project from the University of Wisconsin at Madison's Game Learning and Society Group (Gagnon, 2010).

buildAR (http://buildar.com/): enables designers to embed Points of Interest (POIs) into the physical environment, to manage this content via their Content Management System (CMS), and to publish these experiences to the Layar and Junaio browsers.

FreshAiR (http://playfreshair.com/): enables designers to embed and experience a dynamic and interactive layer of digital information into any outdoor environment. FreshAiR was developed through a National Science Foundation (DRL-0822302) grant from Radford University's GAMeS Lab.

Hoppola Augmentation (http://www.hoppala-agency.com/): enables designers to create a layer of location-based content and publish this to Layar, Junaio and Wikitude.

TaleBlazer (http://education.mit.edu/projects/taleblazer): uses a visual block-based scripting platform to create interactive, location-based experiences. TaleBlazer was developed out of the MIT Scheller Teacher Education Program (STEP).

7Scenes (http://7scenes.com/): is a "mobile storytelling platform" that enables designers to create location-based experiences. 7Scenes was developed out of research from the Waag Society in The Netherlands.

Table 59.2 illustrates the availability of each function in AR development platforms as of January 4, 2012. The functions listed are not comprehensive and some of these platforms contain additional functions that do not fall within the listed categories. The reader is encouraged to explore each of these platforms to understand the complete range of functionality.

Conclusions

In 2012, approximately 197 million AR-capable phones will be shipped throughout the globe, doubling the amount shipped in 2010 (Gauntt, 2009). As this trend continues and AR-capable phones become more prevalent, instructional designers and educators will continue to leverage these devices to deliver instruction. While outlining some of the emerging practices in this effort, this review also documents the "idiosyncratic set of definitions, conceptual frameworks, and methods" inherent in a relatively recent and emergent field of study (Dede, 2011, p. 233). Due to the nascent and exploratory nature of AR, it is in many ways a solution looking for a problem. More accurately, AR is an instructional approach looking for the context where it will be the most effective tool amongst the collection of strategies available to educators.

Table 59.2 AR development platform function matrix (January 2012)

Function AR software	Browser-based editor	DO	LB	Overhead/ live-view	Archive	YouTube embed	Roles	Dynamic triggers	Assess	Data collect	D2D	QR	3D	SN
ARIS	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N
BuildAR	Y	Y	Y	Y	N	Y	N	N	N	N	N	Y	Y	N
FreshAiR	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	N
Hoppola	Y	Y	Y	Y	N	Y	N	N	N	N	N	Y	Y	Y
TaleBlazer	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	N	N	N
7Scenes	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	Y

Y yes, *N* no

The majority of the studies covered in this review use AR to replicate and guide the dynamic and complex nature of collaborative problem solving within a real physical environment. While the challenge of facilitating collaborative, experiential inquiry in and out of the classroom may be the best instructional problem solved by AR, researchers need to be continue exploring how this approach might ameliorate other persistent educational problems while also acknowledging its inevitable limitations within the expanding ecology of pedagogies.

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Web 2.0 Applications and Practices for Learning Through Collaboration

60

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Abstract

This chapter provides a review of the theoretical bases and international research on the uses of Web 2.0 applications for learning through collaboration. Web 2.0 applications empower users with a venue for personal expression, sharing, communicating, and collaborating with others, thus offering enriched opportunities for learning. In our review, we found evidence of engaging and effective uses of Web 2.0 applications such as blogs, wikis, collaborative documents and concept mapping, VoiceThread, video sharing applications (e.g., YouTube), microblogging (e.g., Twitter), social networking sites, and social bookmarking that applied contemporary and foundational educational theory. We also identified opportunities and challenges associated with learning through collaboration with Web 2.0 applications, which can inform research directions and areas to explore for ECT researchers.

Keywords

Web 2.0 • Learning through collaboration (LtC) • Affordances

Introduction

Web 2.0 applications include Web-based software and services that enable individuals to create, share, communicate, and collaborate on the web, regardless of geographical, temporal or technological skill constraints (O'Reilly, 2005). Ever since Dougherty coined the term in 2004 describing the new generation of Web-based applications (*applications* hereafter), technological advancements have continued to shape unprecedented ways and means for individuals to work and think together. Although Web 2.0 applications were not originally designed for education, by their very nature, these tools hold promise for creating collaborative learning opportunities for students. While Web 2.0 applications can support individual learning, the potential and value of these applications lie in the way they allow learners to collaborate with each other.

Stahl, Koschmann, and Suthers (2006) described collaboration as an activity that involves multiple people developing shared meaning while working together on common problems or issues. In education, the common problems to be worked on and solved make up the learning tasks themselves. *Learning through Collaboration* (LtC), therefore, comprises the spectrum of learning through interactions, including cooperative learning, collaborative learning, and collective learning that emphasize different levels and ways of learning by the group and community (Dillenbourg, 1999). In this way, our definition of LtC refers to collaborative knowledge construction (Barab, Hay, Barnett, & Squire, 2001) through interaction with others and through situated involvement in social, cultural, or professional activities and contexts (Brown, Collins, & Duguid, 1989). In this view, the group becomes the unit of analysis and learning assessment focuses

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on the achievement of group goals and how interactions among group members enable group advancement.

Web 2.0 applications provide the means to support collaborative learning activities that require shared meaning among participants while working together on common problems or issues. Web 2.0 practices, therefore, are those collaborative learning activities that use Web 2.0 applications for LtC.

Theoretical Underpinnings Linked to Web 2.0 Applications

The process, value and complexity of LtC can be captured and explained through the theory of distributed cognition, sociocultural theory, and situated cognition. *The theory of distributed cognition* posits that knowledge is spread across collaborators, external symbolic representations, tools, environments, and artifacts (Bell & Winn, 2000; Pea, 1993). Sharing of individual knowledge, however, is enabled only when it is represented externally for others to use and build upon. Therefore, learning platforms that would allow learners to create, or co-construct artifacts together and build on each other's work and progress would best suit this purpose.

Vygotsky's sociocultural theory emphasizes the critical role of interpersonal engagement of individuals through various tools, including cultural objects (e.g., machines), language, and social institutions (e.g., schools) that facilitate development and learning (Schunk, 2008; Tudge & Scrimsher, 2003). From the perspective of LtC, language is the most powerful tool because it serves as the instrument for interpersonal or social means to negotiate and create meaning during the learning process. Learning platforms that allow for exchanging ideas easily regardless of format (e.g., text or audio) during the process would be most ideal from this perspective.

The theory of situated cognition emphasizes learning and practices in authentic and meaningful contexts (Brown et al., 1989; Greeno & the Middle School Mathematics Through Applications Project Group, 1998; Lave, 1988). While communities of practice are neither the only authentic contexts for learning, nor the only contexts in which to situate cognition because cognition can be situated in smaller sociocultural unit (e.g., groups of a few individuals), they can serve as good contexts for discussing and perceiving this theoretical perspective. In learning communities where LtC occurs, individuals collaborate to co-construct knowledge. This situated-ness is evident in Communities of Practice (Lave, 1985) in which participants with common issues or problems reciprocally create authentic and meaningful learning experiences and serve as part of each other's "learning environment." Through sharing knowledge and experiences, Communities of Practice develop knowledge related to their field or their interest (Lave & Wenger, 1991), which is an aspect lacking for learners engaged in individual learning. Learning platforms that can help strengthen flexible communication and interaction at multiple levels (e.g., synchronous/asynchronous, text/audio/video) among community members would best support learning experiences in authentic and meaningful contexts.

Thus, to support distributing cognition across collaborators, external representations, tools, environments and artifacts, promoting interpersonal engagement, and situating learning and practice in authentic and meaningful contexts, necessary for LtC, a technology-based learning platform will need to (1) allow learners to create artifacts together and build on each other's work and progress, (2) allow for exchanging ideas easily regardless of format during the process, and (3) help strengthen flexible communication and interaction at multiple levels among community members. Web 2.0 applications provide the means to support knowledge building through multiple modalities for negotiating ideas and creating artifacts, multiple means for quick or thoughtful sharing, and multiple channels for exchanging shared and varied perspectives and feedback among the participants wherever they are. Therefore, LtC that leverages Web 2.0 applications in this way is theoretically supported to be richer, broader, and deeper as compared to individual learning.

Review of Recent Web 2.0 Research

The three theoretical underpinnings of LtC discussed above, including distributed cognition, sociocultural theory, and situated cognition, served as our lens for reviewing international research on educational practices applying Web 2.0 applications. The distributed cognition underpinning focuses on how learners create artifacts together and build on each other's work and progress, that is, strategies for co-constructing knowledge. The sociocultural theory view of interpersonal engagement focuses on allowing for exchanging ideas easily regardless of format during the process. The situated cognition aspect focuses on helping strengthen flexible communication and interaction at multiple levels among community members. Through this lens, we found six types of Web 2.0 practices from our literature review, including: (a) publishing and sharing learning progress and achievement; (b) supporting and achieving collaborative tasks; (c) making thinking, collaborative processes and products visible through tangible artifacts; (d) communicating ideas and disseminating artifacts with multimedia capacity; (e) social networking in authentic learning environments; and (f) building communities of practice for learning in authentic and meaningful contexts. We also found that these exemplary Web 2.0 practices integrated one or more of the following Web 2.0

Table 60.1 Recent research on Web 2.0 educational practices

Web 2.0 educational practices	Web 2.0 applications	Research reviewed in this chapter (listed in alphabetical order by practice)
Publishing and sharing learning progress and achievement	Blogs	• Chuang (2010) • Ellison and Wu (2008) • Ladyshewsky and Gardner (2008) • MacBride and Luehmann (2008) • Sharma and Xie (2008) • Shoffner (2009) • Tan et al. (2005) • Xie et al. (2008)
Supporting and achieving collaborative tasks	Blogs	• Fessakis et al. (2008) • Philip and Nicholls (2009)
	Wikis	• Vratulis and Dobson (2008) • Wheeler et al. (2008)
	Collaborative documents and concept mapping	• Ching and Hsu (2011)
Making thinking, collaborative processes and products visible through tangible artifacts	VoiceThread	• Augustsson (2010)
	Wikis	• Elgort et al. (2008) • Zorko (2009)
Communicating ideas and disseminating artifacts with multimedia capacity	Video sharing (YouTube)	• Haase (2009) • Burnett (2008) • Burke and Snyder (2008)
	Microblogging (Twitter)	• Hsu and Ching (2011)
Social networking in authentic learning environments	Social networking (Facebook)	• Kabilan et al. (2010)
Building communities of practice for learning in authentic and meaningful contexts	Blogs	• Luehmann and Tinelli (2008)
	Social bookmarking (Diigo)	• Tu et al. (2008)

applications, including blogs, wikis, collaborative documents and concept mapping, VoiceThread, video sharing applications (e.g., YouTube), microblogging (e.g., Twitter), social networking sites, and social bookmarking in their learning activities.

In the following six subsections, we discuss the Web 2.0 practices for LtC. In Table 60.1, we list the research studies reviewed in this paper, by the six types of Web 2.0 practices and corresponding Web 2.0 applications. After our review of these practices we draw a closer link to recommended characteristics of learning activities that explain and provide theoretical support for being representative of effective practice.

Publishing and Sharing Learning Progress and Achievement

Two most common educational uses of Web 2.0 applications found were publishing and sharing documents that promote reflective thinking through blogs, either through writing learning logs or creating portfolios to showcase the individual's learning progress and achievement. Publishing for the purpose of sharing learning progress is an important example of LtC.

Blogs as Learning Logs

In general, when blogs serve as learning logs, they provide a space for learners to express their observations and perspectives, and make connections between their experiences and what they learn (Gunawardena et al., 2009). The following studies used blogs as the means for LtC by allowing learners to exchange ideas about what they learned. In the Ladyshewsky and Gardner (2008) study, groups of undergraduate physiotherapy students collaborated online using blogs and focused their discussion on professional and evidence-based practice issues during their clinical fieldwork program. Through focus groups, the collected data showed that the blog helped students build trust, and supported the integration of theory to practice. The authors suggested that clinical fieldwork programs should consider blogging as a means to elevate the reflective practice component of professional development. Sharma and Xie (2008) also explored the use of blogs for individual reflective practice of eight participants in a graduate course. From the data analysis of this phenomenological study, the researchers indicated that participants found weblogs helpful for learning, reflecting, and developing a sense of community.

In a qualitative study, Shoffner (2009) investigated pre-service teacher attitudes toward blogs and the influence of those attitudes on the use of blogs for voluntary reflection that was undertaken by choice and not by course or program requirements. She found that while all eight pre-service teachers had positive attitudes toward blogs and used it for reflective practice, only two maintained their blogs throughout the study from Fall 2004 to Summer 2005. Xie, Ke, and

Sharma (2008) conducted an experimental study that examined the effects of blogging on 44 college students' reflective thinking skills and their learning approaches. In their study, students kept blogs each week throughout a whole semester. The researchers sampled two journals at the beginning and end of the semester for each student for data analysis. They found that students' level of reflective thinking increased significantly over time. Overall, this series of studies showed that college and master's students improved in affective (trust, community building), cognitive (application), and metacognitive areas (reflective thinking) by regularly keeping a blog to reflect on their learning, projects, or clinical field experiences.

Basically, blogs provided a space for storing one's work, thereby, blogging made it easier for students in these studies to reexamine, revise, and reflect on their previous work for the purpose of tracking their learning (Ferdig & Trammell, 2004). However, in a study by MacBride and Luehmann (2008) where they analyzed 1 year's worth of blog content from a high school math class, they found no evidence that students systematically reviewed their past work for synthesizing their learning, or took advantage of this affordance to review their materials for exams.

Blogs as Electronic Portfolios

In general, when blogs served as electronic portfolios, they enabled students to document and showcase portfolios of professional practice and reflect on their collected experiences. Because blogs allowed for multimedia presentation modes, learners were able to showcase their professional practice with enriched text, images, photos, audios, and videos. In order to select and organize evidence of their learning, learners had to reflect on their actions, which they could "make visible" especially when they were asked to showcase their portfolios to their communities. These Web 2.0 practices were more representative of learning alone, and then together, through simple exposure to other individuals, their work and thoughts.

Chuang (2010) explored how the use of blogs affected portfolio production and development for 31 student teachers in Taiwan. She also tracked how their blog-based portfolio experience shaped their reflective practice during the student teaching practicum. The qualitative data analysis revealed that about half of the participants used blogs to create their curriculum vitae that represented their work. Chuang found that the two features of the blog-based platform, including multimedia personal editorship and dialoguing with others, were the most influential on participants' reflective practice. The former empowered a portfolio creator to develop multiple literacies and play multiple roles such as a writer (through text), graphic designer (through images), and even film maker (through video). The latter allowed the portfolio creator to engage in LtC by reflecting and inviting others' support and feedback on their learning and reflection. In another portfolio-based study, Tan, Teo, Aw, and Lim (2005) examined the use of blogs as reading portfolios for learning Chinese by 72 secondary school students (7th–10th graders) in Singapore. Tan et al. (2005) found that all of the students agreed that they could improve their own (book) reviews by seeing how others wrote theirs. Ninety-three percent of the students also felt encouraged when seeing others' positive comments posted to their blogs. Although 30% of the students did not find using blogs as reading portfolios enhanced their sense of portfolio ownership as compared to developing it using physical notebooks, the effects of LtC were felt by the blog enabling them to build on each other's work and progress.

Overall, our review of the blogging studies found a positive impact on learning with additional affective benefits when learners used blogs to share learning progress and achievement with peers. In terms of learning, students assimilated relevant experiences through reading peers' portfolio entries or reflection on the blogs (e.g., Chuang, 2010; Ladyshewsky & Gardner, 2008), which is a form of learning through collaborative observation. Being able to read peers' blog entries also resulted in affective benefits, such as feeling connected to the community, and reducing a sense of isolation (e.g., Sharma & Xie, 2008). In some cases, reading peer blogs allowed students to understand that they were not alone when facing certain learning challenges and were likely to alleviate self-doubt and become more confident in their learning (Ladyshewsky & Gardner, 2008).

Supporting and Achieving Collaborative Tasks

From our review of the literature it appears that educational practitioners were also using Web 2.0 applications to support learners to achieve collaborative tasks or shared goals among group members. The technological capabilities of these Web 2.0 applications aided collaboration by providing the means for information sharing, tracking progress, managing projects, exchanging ideas, or creating knowledge. The following are the studies we reviewed that investigated the affective, process, and thinking effects of blogs, wikis, and collaborative document applications.

Blogs

In a study by Philip and Nicholls (2009), group blogs were adopted to support small groups of college students with the collaborative process of building a play. They found that students used class time more effectively for improvising and rehearsing because of the preparation between classes via group blogs. In another study by Fessakis, Tatsis, and Dimitracopoulou (2008), pre-service teachers used blogs as communication and information management systems for designing collaborative learning activities. Based on the analysis of the artifacts created, that is, the designed learning activities, the blog content and log files, and students' responses expressed upon completion of the activity, the findings of Fessakis et al. (2008) supported the educational uses of blogs when blogs were combined with a proper pedagogical approach. In these two examples, each small group had a group blog set up for collaboration among all the group members. Members in the group read and commented on the blog entries and shared information useful for the collaborative work.

Wiki

Another established and widely adopted Web 2.0 application that supported collaborative tasks was a wiki. In general, unlike group blogs where individuals contribute to their own section of writing, wikis enable users to edit each other's work on the same page, to track revision history made by users, and to "roll back" to previous versions through a "page history" feature. At the end of the process, wikis, themselves, become the artifacts of the co-constructed knowledge.

In a study by Wheeler, Yeomans, and Wheeler (2008), pre-service teachers used wikis as a space to store and edit the work from their research exercises, and as a forum for discussion. The pre-service teachers commented that they could develop critical thinking skills through working on a shared space, and tended to put more thought on their writing because it could be viewed by anyone. Interestingly, while the pre-service teachers liked to write on a wiki for others to read their work, they resisted having their contributions being edited or deleted by others in class. In the study by Vratulis and Dobson (2008), 36 pre-service teachers in small groups used wikis to achieve a shared goal to generate a communal response to a set of standards for teachers. Vratulis and Dobson found that the participants' collaborative writing and editing in the wiki environments over a 10-month period revealed established social hierarchies and negotiation strategies used in the group process and how the features of wikis aided in that establishment.

Collaborative Documents and Concept Mapping

Recently, there have been newly developed Web 2.0 applications equipped with features conducive to achieving collaborative tasks such as coediting, recording revision history, and communication/commenting. Some examples of these applications include those that offer a full suite of productivity tools (i.e., equivalent to Word, PowerPoint, Excel) such as Google Docs, Zoho, and Microsoft Web Apps. Other applications focus on concept mapping capability, such as Google Drawing (now part of Google Docs), Webspiration, bubbl.us, and Lucidchart. Ching and Hsu (2011) examined graduate students' use of a concept-mapping application as a platform for creating concept maps collaboratively of the instructional design processes that depict their understanding of the subject matter. Ching and Hsu analyzed the students' group concept maps and found that the concept-mapping application supported active and focused student interaction, communication, and their achievement of intended learning objectives despite the fact that some of the group processes might not have been entirely smooth or efficient.

Making Thinking, Collaborative Processes and Products Visible Through Tangible Artifacts

We found another educational practice using Web 2.0 applications that enabled group members to make their thinking and collaboration processes visible through multiple modes of tangible artifacts. Two examples of Web 2.0 applications that supported this practice were VoiceThread and wikis. In general, VoiceThread allows collaborators to comment on group video clips, images (e.g., flowcharts and concept maps), or presentations in live audio conversation, text, audio files, video, and drawings. These visible artifacts then are available to others for building and refining group understanding. Similarly, wikis allow tracking participation in creating artifacts by recording revisions made by members. This feature also makes participation more transparent to group members and instructors. Just as importantly, members' lack of participation is also evident through the artifacts. Therefore, the visibility of collaborators' tangible contributions have the potential to motivate, or perhaps urge, learners' participation in order to increase their presence in the task (Augustsson, 2010) and have their efforts recognized or evaluated.

Augustsson (2010) investigated collaborative social interaction when using VoiceThread in a university course. He found that the use of VoiceThread supported the collaboration processes as it revealed students' individual efforts, allowed the creation of "task ownership" for students, and strengthened students' identification with the group. Elgort, Smith, and Toland (2008) found that the instructors incorporating wikis in their Master's level courses appreciated the detailed audit trail that allowed them to closely scrutinize individual student contributions in the context of the whole project. To explore the factors that affected the processes learners used to collaborate, Zorko (2009) examined college students' perceptions of collaboration using a wiki in a blended and problem-based learning environment. She found while students preferred using Instant Messengers or e-mail instead of a wiki to communicate among themselves, they considered the instructor's comments left on the wiki helpful for them to communicate with the instructor. Also, Zorko found that the revision history on a wiki enabled the instructor to assess students' contributions more easily. With the collaboration process becoming visible through the revision history, instructors have a data-driven method to learn about students' collaborative process and hold students accountable for their own learning.

Communicating Ideas and Disseminating Artifacts with Multimedia Capacity

Web 2.0 applications also supported communicating and disseminating artifacts using a variety of multimedia modes. Web 2.0 applications' capabilities of disseminating video could provide great enhancement for learning. Video supports rich information and knowledge representation because it can contain all possible media in one deliverable format. YouTube, a video-sharing site, is a good example we found of a Web 2.0 application that enables users to share the content they generate using rich multimedia representations. Video-sharing sites usually allow users to comment on the content, which could also engage viewers in social interaction and knowledge construction. Thus, these applications can not only be used for communicating and disseminating ideas in multimedia format, but also provide learners unprecedented exposure to social and cultural information that are networked and visible for distributed meaning negotiation in a community of learners. We found, however, that current research on of this type of Web 2.0 practice mostly focused on studying how to use the sites for providing supplemental instruction (e.g., Burke & Snyder, 2008; Haase, 2009), or as content management and dissemination platform (e.g., Burnett, 2008), rather than on supporting collaboration.

Burke and Snyder (2008) suggested that YouTube be integrated into course materials to provide relevant information to supplement college course content and enrich the learning environment for all students. Haase (2009) stated that YouTube made it convenient for college faculty to upload videos of lectures and demonstrations for the purpose of helping students make up for classes or provide remediation. Burnett (2008) turned the focus to learner-generated uses and discussed the benefits of integrating YouTube in college marketing classes by having students create videos to introduce new ideas and products, thereby demonstrating their knowledge. He also suggested that students study and analyze relevant content and responses on the video-sharing site to help identify trends.

Another example is the use of microblogging (e.g., Twitter). Microblogging is similar to blogging in that it allows for easy self-publication on the Web but constrains character limit per entry of posting. Microblogging allows sharing multimedia information through directly posting images/photos or posting links to video on the Web. Hsu and Ching (2011) explored how microblogging application (e.g., Twitter) could be used to engage students in authentic learning and sustain a virtual learning community. In an online instructional message design course, the graduate students (22 of the 40 students participated in the study) around the world collected graphic design examples from their own daily environments by taking photos of those examples, shared the examples with their peers via Twitter, and critiqued the examples with graphic design knowledge they learned in the class. The microblogging activities helped students exchange their ideas about designing and disseminating design artifacts. Hsu and Ching found that some students indicated the examples inspired their own design work in class. The students overall had a positive sense of community as revealed from the survey responses. Some also explicitly commented that microblogging helped the class form a learning community because they followed each other on Twitter and got to know each other more through the design examples collected from others' daily lives and environments.

Social Networking in Authentic Learning Environments

With the growing popularity of social networking sites such as Facebook, Web 2.0 applications themselves can serve as authentic environments where the users become *residents* and spend several hours a day staying connected with friends and family. Social networking sites have become part of many people's daily life. As of December 2011, there were more than 845 million active Facebook users around the globe (about 80% of users outside of the U.S. and Canada) with approximately 50% of those users logging onto Facebook on any given day (Facebook, 2012). The large number of users and high volume of activity made Facebook an ideal virtual environment for authentic cultural and language learning in a social setting. We found that research on this type of Web 2.0 practice investigated the attitudinal effects of social networking sites.

In a survey conducted with 300 Malaysian undergraduate students, Kabilan, Ahmad, and Abidin (2010) found that students overall had positive attitudes regarding the potential of and value of Facebook as a learning environment to help enhance their writing and reading in English. The students indicated they could "tolerate language mistakes" on Facebook, which is an important factor for encouraging practice, use, and improvement of one's language. However, some students might not have considered activities on social networking sites as "real" or "serious learning" unless learning was done through published books or articles in school settings (Kabilan et al., 2010). Despite some students' perceived disconnection between "serious" learning and learning using social networking applications, Web 2.0 applications have demonstrated potential that could lead to learning in authentic and meaningful contexts, a possible enhancement in some formal learning environments lacking this richness.

Building Communities of Practice for Learning in Authentic and Meaningful Contexts

Web 2.0 applications, including blogging and social bookmarking, have the strength to situate cognition in contexts by providing an ideal platform for building authentic and meaningful communities of learning and practice. We found that research on of this type of Web 2.0 practice investigated the effects of blogging or social bookmarking to sustain authentic practice.

For example, in a study by Luehmann and Tinelli (2008), Western New York science teachers committed to inquiry-based science learning formed a professional learning community through blogging to support and sustain their practice. Luehmann and Tinelli found that 13 of the 15 participants (87%) considered the blogging activities valuable assets to their professional training. Tu, Blocher, and Ntoruru (2008) used a social bookmarking application, Diigo, to establish a community of practice to support a collaborative review process on journal manuscripts. Using Diigo, the community members discussed, annotated, highlighted, and commented on the manuscript webpage. In this community, junior researchers with less experience learned from the modeling and insight of senior researchers, while senior researchers supported the review process and cultivated scholars of the next generation. Although the contexts were different, the two studies revealed the potential and value of applying different Web 2.0 applications to support authentic and meaningful community building for learning during the collaboration process.

LtC with Web 2.0 Applications: What Was Missing?

By analyzing current practices against the theoretical underpinnings of Web 2.0 practices, we identified two missing areas of research. One missing area is how Web 2.0 practices can more effectively support knowledge construction and meaning negotiation through interpersonal engagement. The second area is an exploration of Web 2.0 practices that facilitate individuals in the community to build shared goals.

Supporting Knowledge Construction and Meaning Negotiation

In learning settings, ideas sharing and meaning negotiation take place through interactions among students, or between students and teachers. The promising communication and social features of Web 2.0 applications have capabilities to promote and support these types of interactions. They allow participant interaction, for example, using the commenting features in blogs or discussion features in wikis to construct knowledge and negotiate meaning. However, the findings of many research studies exploring the effectiveness of Web 2.0 applications to enable knowledge construction and meaning negotiation have been disappointing. The required effort, discomfort, and preference for other daily communication tools, were common reasons we found that seemed to dampen the sociocultural knowledge construction potential of these applications.

Kerawalla, Minocha, Kirkuk, and Conole (2009) found that students rarely made an effort to provide perspectives on peers' blogs if the students were not required to do so. Ellison and Wu (2008) found that college students were uncomfortable providing peer feedback using the commenting feature in blogs. Therefore, students received little feedback, if any, and whatever feedback they did receive was low in quality. Zorko (2009) attempted to identify factors that led to undergraduates' positive experience of collaboration when using a wiki in a problem-based learning activity, and examined how the wiki promoted peer and student–teacher interaction. Zorko found that students did not use the wiki for communication. Instead, students preferred using Instant Messenger, e-mail, or mobile phone to exchange ideas because those tools were an integral part of their everyday lives, and enabled immediate contact. Students only used the wiki for publishing their own work and reading other groups' work. On the other hand, students commented that the wiki helped them communicate more effectively with their instructors because they could easily access the comments the instructors left on the wikis. In another study, Karasavvidis (2010) investigated problems that students experienced while completing a wiki task. This task required students to create wiki pages and contribute to peer-created pages. Findings from the interview suggested that the wiki afforded limited communication opportunities; therefore, students had limited uses of wiki for their communication. The lack of peer interactions when using Web 2.0 applications was also reflected in findings of other research studies (e.g., Cole, 2009; Elgort et al., 2008; Kerawalla et al., 2009).

In addition, some studies found little evidence that knowledge was constructed collaboratively when Web 2.0 applications were simply assigned in the collaborative tasks without specific scaffolding. Grant (2009), for example, studied a group of secondary students using wikis for collaborative work. He found that students, although assigned to groups, mainly worked individually to finish their portion of the task without engaging in idea sharing, meaning negotiation, or discussing how to link their individually created wiki pages to form coherent group wiki sites. Lin and Kelsey (2009) examined graduate students' collaborative writing of chapters in a wikibook. This activity required students to compose three to four chapters collaboratively. Their study found that initially students hesitated to make their thinking visible to their peers through wikis, because students were unfamiliar with the wiki tool and were afraid they would mess up the writing. They were also uncomfortable sharing their thinking process with peers through the wiki. As a result, students wrote their individual portion using MS Word and contributed their individual portions on the wikibook. In a sense, they used the wiki as a presentation platform rather than using it for making their thinking process visible to achieve collaboration. In fact, no collaborative writing or editing happened in their first attempt of writing a chapter together. It was not until they used wikis several times that they felt comfortable sharing their thoughts and drafts, or editing each other's work to improve the quality of writing.

Based on the studies we reviewed, we assert that it takes time and sound instructional design to fulfill LtC with Web 2.0 (Lin & Kelsey, 2009). Rebertson (2008) also stressed that Web 2.0 applications (i.e., wikis) were tools, but not solutions to challenges associated with group-based knowledge construction. Future research in this area should focus on design strategies that make Web 2.0 use more seamless, practical and productive, yielding outcomes that are valued.

Shared Goals

The collaborative nature of the learning task (Bower, Woo, Roberts, & Watters, 2006) and the authenticity of the tasks (Bower et al., 2006; Grant, 2009) require the group to develop and attain shared goals. Only with shared goals will the task promote the kind of interactions that enable collaborative knowledge construction among the participating learners. For example, the study conducted by Vratulis and Dobson (2008) represents a good example of students engaging in a well-designed collaborative activity supported by a wiki. They set up a course wiki where small groups were asked to collaborate to create the content of communal response to a set of standards for teachers and present their ideas to the class through the course wiki. As a result, students negotiated meanings with their group members and successfully managed to cocreate knowledge. However, this result is not common. Elgort et al. (2008) found that while students perceived wikis as useful for arranging information and sharing knowledge, the use of wikis did not improve student attitudes toward group work. A significant number of the students in the study by Elgort et al. preferred to work alone and actually worked individually for a significant portion on their group project. In addition, Wheeler et al. (2008) found that students tended to engage only with wiki pages they created by themselves. In the studies by Elgort et al. and Wheeler et al., students engaged in individual rather than collaborative knowledge construction.

Emerging Issues of LtC with Web 2.0 Applications

From the distributed and situated cognition lens of our review, we also identified three significant issues that should be addressed when designing learning events that incorporate Web 2.0 applications. These issues deal with the nature of collaborative knowledge construction, contexts for learning, and balance between technology exploration and meaningful use of technology for LtC.

Co-construction of Knowledge and the Affective Nature of Writing

While LtC can be done through activities in various modalities, we found writing (i.e., textual format) was the major form of knowledge co-construction through Web 2.0 applications in our literature review. Multiuser knowledge construction that involves collaborative writing and editing can be very complicated. From the writer's perspective, students do not like to have peers change their writing because they feel attached to "their" work (Wheeler et al., 2008), hence making writing territorial (Grant, 2009). In addition, from the reviewer's perspective, students do not feel comfortable editing others' work because editing may be viewed as rude or interfering (Grant, 2009; Kear, Woodthorpe, Robertson, & Hutchinson, 2010), or may imply others' work is "incorrect" or "incomplete" (Karasavvidis, 2010). Lin and Kelsey (2009) further elaborated this complexity by three identified phases of using wikis, including *crisis of authority*, *crisis of relationships*, and *resolution of crisis*. In the first two phases, students are not comfortable with cowriting. *Crisis of authority* refers to students who feel they do not have the authority to edit peers' work because they may not be familiar with the material. *Crisis of relationships* refers to the lack of knowledge of team members' working styles, reaction to interdependence, and attitudes on territorial limits. Only after trust and rapport is established (i.e., *resolution of crisis*) do students become comfortable writing collaboratively with their peers.

Collaborative knowledge construction through writing and editing is also associated with the issue of ownership. Due to the technological capabilities that enable collaborative writing and editing of Web 2.0 applications, the lines between individual and group contributions are often blurred and sometimes frustrate or even threaten students regarding ownership. The ownership issue may also demotivate participants because content creators often want to receive credit for their own "creation" (Wheeler et al., 2008). On the other hand, members who review other authors' work may also feel uncomfortable editing others' work—by rudely interfering with others' ideas (Kear et al., 2010).

LtC presents new challenges to learner's habits and beliefs about writing. Learners who are accustomed to an individualistic practice of constructing knowledge may lack appropriate knowledge, attitudes, skills, and strategies needed to cope with LtC. For example, Pfaffman (2007) noted that making new collaborative or communicative tools available for students does not guarantee collaboration when engaging learners in LtC with Web 2.0 applications. The strength of evidence related to this issue elevates the importance of providing learner guidance on how to co-construct knowledge through modeling, scaffolding when integrating participation into the pedagogical approach to insure smoother and more productive group work and resolve problems in group dynamics.

Disparity in Perceptions Between Social Space and Learning (Work) Space

Kabilan et al. (2010) found students reluctant or completely resistant to associate social space with learning or work space, despite the instructors' efforts to leverage the social networking site (i.e., Facebook) that was familiar to learners for learning. Luckin et al. (2009) also found that, unless prompted by the researcher, learners generally considered an online networking site as a social space instead of a learning space. Both of the aforementioned studies revealed strong learner perceptions about how a social networking site should be used, which might provide challenges of integrating a naturally authentic social networking site into instruction and learning.

The Balance Between Exploiting Technology Affordance and Achieving Desired Learning

Web 2.0 applications, especially those with complex, nonlinear architectures, must be used skillfully to capitalize on their powerful learning affordances. Therefore, some students need more prescribed instruction to "navigate around" these tools, (e.g., Wheeler et al., 2008). The technological affordances of various Web 2.0 applications, such as allowing for collaborative editing, directly providing voice comments on others' multimedia work, or tracking revision history, can be exciting but can also overwhelm students and dilute the focus of desired learning goals because students may spend more time exploring the technology than focusing on the shared collaborative goals. On the other hand, students may not have genuine interest in the technology so they may not explore the technological affordances to the degree they should, leaving out possible learning or interaction opportunities. Hence, the question of balance between technology exploration and learning should be considered when designing learning activities.

Future Research Directions

LtC with Mobile Web 2.0

There is exponential growth of access to Web content and services via smartphones and other mobile devices. In Japan, for instance, 75% of Internet users make mobile devices their first choice for accessing the Internet (Johnson, Smith, Willis, Levine, & Haywood, 2011). Also, 425 million of the 845 million global active Facebook users access their account with mobile devices (Facebook, 2012). There is also an increasing trend and interests of developing mobile apps for different platforms, mostly noticeably for Apple's iOS and Google's Android.[1] Future research should leverage the combination of mobile computing and LtC with Web 2.0 applications by considering mobile devices' nature of anytime-anywhere Internet access and portability for Web 2.0 educational practice.

Microblogging for LtC

Microblogging has great potential for promoting conversation in collaborative work that supports collaborative knowledge construction and situates this knowledge in authentic and meaningful contexts. Microblogging is best exemplified by the popular application Twitter that has a large user base (Wikipedia, 2012). The limitation of message length by microblogging applications means relative little time is required for composing a message. This minimal effort required is likely to lead to faster response, which in turn, could result in more interaction. It is important to note also that the architecture of microblogging applications may work best for pairs or small-group work rather than open discussions for a large group (Honeycutt & Herring, 2009) because the reverse chronological display of brief messages, crossing threads and topics could easily make members feel lost. Recent practices of microblogging mostly focus on using Web 2.0 applications such as Twitter as a class feedback system, taking a poll in class or aggregating questions (see Johnson et al., 2011). Researchers found that microblogging applications, such as Twitter, are useful for estab-

[1]Over 500,000 mobile apps for iPhone in Apple's AppStore (http://www.apple.com/iphone/apps-for-iphone/, retrieved December 21, 2011) and over 380,000 for Android phones in Android Market (http://en.wikipedia.org/wiki/Android_Market, retrieved December 21, 2011).

lishing one's social presence as a member of a professional community and while engaging in learning (e.g., Dunlap & Lowenthal, 2009). Pauschenwein and Sfiri (2009) also found that using Twitter in online courses helped learners relate to their learning groups and support other members by acknowledging their input. However, research on the role of applying microblogging for communication during collaborative learning/work is still in its infancy (e.g., Hsu & Ching, 2011).

Learning Through Collaborative Video Editing and Production

Few studies investigate the potential of video-sharing applications for engaging students in conversation during collaborative learning. Future research should explore strategies that allow learners to discuss their collaboration process through text and video response while they actually create a video artifact. In addition, online collaborative video editing applications such as Pixorial, Stroome, and Kaltura, may help advance LtC even further. For example, in addition to allowing individuals to edit different components of a video clip (e.g., images, transitions, or soundtracks) directly online, Stroome has community features that allow users to join groups with established common goals to connect with each other, and foster communication of individuals working on the same video projects. By engaging students in collaborative editing, remixing, and producing video without constraints of time and space, learners can co-construct arguments and discourse on their topic of interests, allowing enriched LtC with varied forms of media and elaborated expression (e.g., video digital storytelling). Future research could examine motivation levels, types of learning, issues and challenges associated with LtC regarding community building during video production.

Understanding and Repurposing Learners' Social Space as Learning Space

Research should further explore how students' perceptions have changed, if at all, in terms of integrating Web 2.0 applications such as social networking sites for LtC. While there are strong technological affordances of sites such as Facebook for authentic and meaningful group communication and collaborative learning, recent evidence suggests that learners might still consider their social space for socialization only—or want to reserve the right to do so. Researchers of learning and instructional design should explore ways to capitalize on or change user attitude to repurpose and smoothly leverage the strength of social networking sites to engage learners in using the tools they are already familiar with.

Overall, we found that most quality empirical studies on Web 2.0 applications investigated the use of blogging and wikis, perhaps due to the early emergence of blogging and wikis among Web 2.0 applications. We encourage the international research community to explore how other emerging applications' technological capabilities can be applied to Web 2.0 practices so that they enhance and ensure opportunities for rich LtC activities as guided by contemporary learning theory.

Conclusions

While Web 2.0 applications have been flourishing since the term Web 2.0 was first coined in 2004, the nature and spirit of these applications have been enriched and transformed by the very innovations themselves coupled with advances in foundational learning theory. When reviewing Web 2.0 practices in education, it is insufficient to examine Web 2.0 applications alone. The affordances of Web 2.0 applications reciprocally interact with their educational practices to develop, evolve, and redefine Web 2.0 (Dohn, 2009). Due to their rich affordances, Web 2.0 applications inspired and led to a variety of innovative uses in learning and instruction. However, some uses did not maximize the real potential of Web 2.0 applications in terms of LtC. Our review of existing Web 2.0 studies identified and provided an explanation for the lack of success and made suggestions for enhancing the learning experiences. Activities designed for LtC with Web 2.0 applications should begin with overt, group-accepted shared goals that are authentic and meaningful to the community, followed by purposeful selection of applications that afford co-construction of knowledge in tangible and discussable artifacts. We also believe that the research reviewed in this paper provides a good snapshot of current international research on Web 2.0 applications for LtC—the potential, promise, void, and challenges, which should help future educators and researchers cultivate this exciting subfield of emerging technologies.

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Pedagogical Agents

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George Veletsianos and Gregory S. Russell

Abstract

In this chapter we synthesize the pedagogical agent literature published during 2005–2011. During these years, researchers have claimed that pedagogical agents serve a variety of educational purposes such as being adaptable and versatile; engendering realistic simulations; addressing learners' sociocultural needs; fostering engagement, motivation, and responsibility; and improving learning and performance. Empirical results supporting these claims are mixed, and results are often contradictory. Our investigation of prior literature also reveals that current research focuses on the examination of cognitive issues through the use of experimental and quasi-experimental methods. Nevertheless, sociocultural investigations are becoming increasingly popular, while mixed methods approaches, and to a lesser extent interpretive research, are garnering some attention in the literature. Suggestions for future research include the deployment of agents in naturalistic contexts and open-ended environments, and investigation of agent outcomes and implications in long-term interventions.

Keywords

Pedagogical agent • Conversational agent • Teachable agent • Intelligent tutoring system

Introduction

Pedagogical agents are anthropomorphous virtual characters employed in online learning environments to serve various instructional goals. For instance, they frequently act as instructors or motivators and can interact with learners via gestures, natural language, or facial expressions. Pedagogical agents are frequently integrated in online learning environments because they may be capable of providing cognitive support to the learner (Baylor, 1999) and social enrichment to the learning experience (Gulz, 2005). For instance, agents can provide human-like assistance (e.g., by answering questions), and reduce learner anxiety and frustration (e.g., by appearing welcoming and friendly). Two subcategories of agents often examined in the literature are conversational agents and teachable agents: Conversational agents are able to hold conversations with learners, and teachable agents are characters that the students teach to complete various activities (e.g., solve puzzles).

In this chapter, we describe and synthesize the pedagogical agent research that was published between 2005 and 2011. We begin by presenting a short description of pedagogical agents with regard to the topic's historical roots. Next, we discuss the theoretical foundations upon which the deployment of agents is grounded in the literature. Then, we identify claims made by pedagogical agent researchers and evaluate the empirical evidence that exists to support those claims. We conclude by synthesizing the current foci of the field and presenting fruitful lines of future inquiry.

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Historical Roots

The development of pedagogical agents can be traced back to the 1970s Intelligent Tutoring Systems (ITS). An ITS exhibits characteristics similar to a human tutor in that it may be able to answer student questions, detect misconceptions, and provide feedback. Such a rich system requires contributions from a number of fields including education, computer science, instructional design, and psychology, all of which have contributed to a deeper understanding of how virtual characters can be effectively utilized in educational settings. While the original ITS were abstract entities that focused on tutoring, the next three decades saw advances in agent representation (i.e., visual embodiment) and interactive capabilities. Over the years, ITS evolved into modern virtual characters that encompass complex visual forms, are able to interact with learners using multiple channels of communication (e.g., text, speech, and deictic gestures), and are able to exhibit social skills and intelligence by communicating with users on a broad range of issues that include not just the tutoring topic, but also topics of broader interest.

The vision and role of agents in the learning ecology has also shifted during these three decades. While ITS were initially seen as abstract intelligent systems able to assist learners cognitively (e.g., by posing or answering questions relevant to student tasks), more recently, agents are seen as inherently social (and relational) artifacts. In addition, the field has expanded its scope in terms of roles that pedagogical agents might play in learning environments. Such roles include tutors, coaches, and actors (Payr, 2003); experts, motivators and mentors (Baylor & Kim, 2005); learning companions (Kim, Baylor, & Shen, 2007); change agents (Kim & Baylor, 2008); and lifelong learning partners (Chou, Chan, & Lin, 2003).

Theoretical Foundations

The field's multidisciplinary roots contribute to the diversity of perspectives that its researchers employ to investigate the use of pedagogical agents in education. Chief among those perspectives are the Computers as Social Actors paradigm, socio-cognitive theories, and, more recently, cognitive load theory.

Computers as Social Actors

A large body of literature is grounded in the Computers as Social Actors (CASA) paradigm (Nass & Brave, 2005; Reeves & Nass, 1996). This paradigm suggests that humans interact with media in inherently social and human ways. To illustrate this idea, Reeves and Nass (1996) gathered social psychology experiments investigating the ways humans interact with, respond to, and treat each other based on various personality traits. For instance, studies have shown that individuals exhibit a preference for people who flatter them over people who criticize them. Whereas in the original experiments humans interacted with humans, in the experiments conducted by CASA researchers, humans interacted with media (e.g., a computer program). Results from the CASA set of studies paralleled the results of the original studies. In other words, humans responded to media in largely the same ways they would have responded to other humans. For example, humans rated flattering computers more favorably than computers that responded to them in less flattering ways (Reeves & Nass, 1996). Applying this paradigm to pedagogical agent research implies that learners will treat pedagogical agents in social ways. For instance, prior research has shown that learners may stereotype agents according to appearance (Veletsianos, 2010) and that visual appearance may enable agents to function as social role models for learners (Kim & Baylor, 2006; Rosenberg-Kima, Baylor, Plant, & Doerr, 2008).

Socio-Cognitive Theories

Kim and Baylor (2006) have argued that agents' pedagogical potential can be positioned in numerous socio-cognitive theories, which they summarize in their paper. The nuances and specific suggestions for pedagogical agent design derived from these theories are outside of the scope of this chapter, but if the reader is interested in these, she/he can examine Kim and Baylor (2006, 2008), and Veletsianos, Miller, and Doering (2009). For the purposes of this paper, we briefly mention common elements of socio-cognitive theories that apply to the design of pedagogical agents:

- Distributed cognition: Rather than residing in individual's minds, in this perspective human cognition is distributed among individuals, tools, and artifacts in the world. Viewed in this perspective, pedagogical agents (i.e., objects external to individuals) mediate, support, and extend cognitive processes. For example, agents can scaffold learners by asking questions, providing hints, or offering alternative perspectives.
- Social interaction: From this perspective, learning is viewed as a social process of interaction and negotiation with others. Pedagogical agents can create a social fabric within the learning environment, departing from traditional notions of computer-based instruction and technology-enhanced skill acquisition, and interact with learners as instructors, peers, collaborators, etc. For instance, agents can support learners' emotional states by exhibiting empathy and building and sustaining relationships with learners.

- Social-cognitive theory: Bandura (1986) noted that humans learn by observing others. For example, an individual might learn how to replace a kitchen faucet by watching a video of someone modeling this process. Similar to humans, pedagogical agents may serve as models in instructional scenarios. Designers can capitalize on appearance-related characteristics (e.g., gender) to influence attitudes and task engagement (Rosenberg-Kima et al., 2008). For example, women and underrepresented minorities comprise a small proportion of students enrolled in K-12 computer science courses (Wilson, Sudol, Stephenson, & Stehlik, 2010), and one way to encourage these populations to consider a computer science course may be through the development of a persuasive agent that serves as a social model (e.g., young, female).

Cognitive Load Theory

Cognitive Load Theory (CLT) (Sweller, 1994, 2004) is a psychological theory that attempts to explain how different tasks and technologies place varying demands on a working memory that has limited capacity. Human cognitive architecture theorists conjecture that humans process information using a three-component system comprising a sensory buffer, short-term storage, and long-term storage (Baddeley, 1992). CLT is concerned with the short-term (also called working memory) and the long-term components of the human cognitive architecture.

The main concern of CLT is the ease with which information is processed in working memory. Baddeley (1992) pioneered the idea that working memory is divided in multiple channels. Working memory load may be influenced by the nature of the learning task (intrinsic cognitive load) and the design of the instructional material. Specifically, instructional material design may influence cognitive processes unrelated to learning and schema formation (extraneous cognitive load) or cognitive structures related to schema formation such as processing, construction, and automation (germane cognitive load). The focal principle of CLT is to increase germane and decrease extraneous cognitive load (Kester, Lehnen, Van Gerven, & Kirschner, 2006; van Merriënboer & Ayres, 2005).

Concerning pedagogical agents, cognitive load theory posits that agent-specific information that is peripheral to the content/task (e.g., superfluous facial expressions that have little instructional purpose) would increase extraneous cognitive load by requiring learners to unnecessarily process information and invest cognitive effort where there is no reason to do so. Investing cognitive resources to information/media that are peripheral to the task will therefore hamper learning. Woo (2008) and Clark and Choi (2005) argued that agents may increase cognitive load because learners may have to split their attention between the agent's numerous visual elements (e.g., gestures and facial expressions), or between the agent and other information on the screen (e.g., text). For example, a split-attention effect may be created when an agent uses both visual and auditory information in their instruction.

Claims and Outcomes Associated with Pedagogical Agents

In this section we synthesize the literature in the field from 2005 to 2011 and provide continuity to the analysis that already exists in the literature. For this reason, we extend the analysis presented by Gulz (2004) in which she examined the claims and evidence presented in pedagogical agent research. In her analysis, Gulz found that researchers claimed that pedagogical agents could afford "increased motivation, increased sense of ease and comfort in a learning environment, stimulation of essential learning behaviours, increased smoothness of information and communication processes, fulfillment of need for personal relationships in learning, and gains in terms of memory, understanding, and problem solving" (p. 315), but that the evidence supporting these claims was often mixed and contradictory. The claims we identified in the current literature are described next.

Claim #1: Pedagogical Agents Are Adaptable and Versatile

One of the most prevalent claims (and rationales) for pedagogical agent integration is their perceived adaptability and versatility. Researchers claim that pedagogical agents are capable of aiding learning, delivering content, and supporting both cognitive processing and metacognitive skills (Clarebout & Elen, 2007) through flexibility, support, and scaffolded guidance (Biswas, Leelawong, Schwartz, Vye, & The Teachable Agents Group at Vanderbilt, 2005; Hawryskiewycz, 2006; Lin, Chen, Wu, & Yeh, 2008). In addition, researchers posit that pedagogical agents are able to monitor and adapt to students' learning styles, backgrounds, and behaviors in order to individualize instruction (Sklar & Richards, 2010; Woo, 2008). By using adaptive systems that are programmed to respond to users in an intelligent fashion, agents may provide learners with intelligent scaffolding via appropriate challenges or information. In essence, agents monitor learner behavior to ascertain when learners may need assistance, and then provide just-in-time support or guidance (Woo, 2008). The basis for this claim rests on the effectiveness of one-to-one *human* tutoring as an instructional strategy. Designing pedagogical agents as virtual tutors and positioning them in situations where they can offer one-to-one tutoring is expected to enhance learning (Graesser, Jeon, & Dufty, 2008). A widely cited example in the literature that effectively exemplifies these ideas is AutoTutor, whose pedagogical strategies include the use of dialogue, feedback, corrective statements, hints, fill-in-the-blank questions, and requests for more information from the user (Graesser et al., 2008).

The majority of research in the field focuses on pedagogical agents programmed with predetermined actions and activities. While this may be the case for a number of reasons, two likely explanations are (a) technological constraints and (b) the need for controlled environments to conduct experimental research. Technological constraints have limited the field in attaining the vision of widely deployed adaptive pedagogical agents, while the focus on experimental research in the field directs research towards the use of technologies with predetermined behaviors. Thus, our understanding of adaptive pedagogical agents and their use and impact is limited. The Tutoring Research Group at the University of Memphis, however, has been able to provide empirical evidence on this topic through their work with AutoTutor and the development of technologies capable of inferring learners' affective states (D'Mello, Craig, Witherspoon, McDaniel, & Graesser, 2008; D'Mello & Graesser, 2010). AutoTutor is capable of interacting with learners in a mixed-initiative format and has been shown to produce learning gains (Graesser, Chipman, Haynes, & Olney, 2005; Graesser, Jackson, & McDaniel, 2007). Other researchers have repurposed the Program Z artificial intelligence engine and the A.L.I.C.E Artificial Intelligence Markup Language to study pedagogical agents capable of holding content-related conversations with learners (e.g., Doering, Veletsianos, & Yerasimou, 2008; Veletsianos, Scharber, & Doering, 2008). Even though these studies have noted agents' versatility in conversing with learners on a number of topics, they also report instances in which agents were not capable of responding correctly or appropriately to learner inquiries. This finding highlights the limitations of mixed-initiative dialogue: whereas in agent-tutoring contexts the human and computer tutors tend to drive dialogue with limited input from students, in mixed-initiative settings agents encounter difficulties in managing learner-initiated input.

Claim #2: Pedagogical Agents Engender Realistic Simulations

Researchers have claimed that pedagogical agents provide realistic simulations by replicating human behavior (Sklar & Richards, 2010). For example, virtual agents may demonstrate procedural tasks, use gesture and gaze as instructional strategies, enact thinkalouds to simulate reasoning and metacognition, and model appropriate social behavior to demonstrate how humans act. In these ways, agents are actors, models, simulators, and manipulatives within digital learning environments. In addition, researchers hypothesize that pedagogical agents can add to the believability of simulations with a virtual body and by communicating in a natural manner with learners (Woo, 2008). Whether natural embodiment contributes to believability is unclear, however. For instance, Adcock, Duggan, Nelson, and Nickel (2006) conducted a study focused on teaching helping skills to 130 human service students by assigning them to one of two experimental conditions: an interactive learning environment with a pedagogical agent or static environment where they had to read a helper-client script. Although students perceived both systems positively, results showed that perceptions of believability did not differ significantly between the two environments, indicating that the two interventions were equally believable.

The literature also suggests strategies intended to enhance natural communication between agents and learners. These strategies include the use of relation-oriented dialogue such as small talk and remembering past interactions (Gulz, 2005) or having a visual representation that matches agents' roles (Veletsianos et al., 2009). If learners sense that they are accompanied by a real person, they develop a sense of companionship that increases self-identification (Baylor & Kim, 2005) and the overall emotional connection to the agent (Gulz, 2005; Woo, 2008). Agents can also embody personalities by sharing stories about themselves, demonstrating various attitudes, expressing opinions, displaying emotion and empathy, and providing encouragement (Gulz, 2005; Woo, 2008). Overall, natural communication is expected to add a sense of familiarity to the simulation, facilitate engagement, and increase enjoyment in both the learning process and domain content acquisition (Gulz, 2005; Kim & Baylor, 2006; Woo, 2008).

Claim #3: Pedagogical Agents Address Learners' Sociocultural Needs

Researchers have also claimed that agents can address a variety of learners' sociocultural needs in virtual environments by providing opportunities for social interaction (Kim & Wei, 2011). For example, when agents have appropriate skills and domain knowledge, they can act as peer learners and work alongside humans in collaborative activities (Gulz, 2005; Kim & Baylor, 2006; Sklar & Richards, 2010; Woo, 2008). As activity partners, virtual agents may lower learner anxiety and promote student empathy by providing peer-support, acting as role models, and allowing students to observe mistakes that the agent makes during the learning process (Chase, Chin, Oppezzo, & Schwartz, 2009; Gulz, 2005; Woo, 2008). It is also postulated that agents as peer learners may seem less intrusive or threatening than they do as overt instructors (Sklar & Richards, 2010). Furthermore, strategic use of pedagogical agents of various races and genders may provide learners from all backgrounds with social models that are similar to them, which may "positively [influence] their interest, self-efficacy, and stereotypes" (Rosenberg-Kima, Plant, Doerr, & Baylor, 2010, p. 35) about various professions, such as science and engineering. Similarly, an agent's appearance may activate stereotypes or trigger expectations of agent intelligence (Haake & Gulz, 2008; Veletsianos, 2007, 2010), and if agents do not live up to these expectations human counterparts may become irritated (Norman, 1997). For this reason, researchers have sought to manage and lower user expectations by proposing that designers take a more refined approach to agents' visual and aesthetic representations (Gulz & Haake, 2006).

When learners are given opportunities for unconstrained interaction with agents, the empirical literature shows that learners treat agents as conversational partners (Hubal et al., 2008; Louwerse, Graesser, Namara, & Lu, 2009) and interact socially with them. In qualitative studies of participants' experiences, learners have reported that such interactions have resulted in enjoyment (Doering et al., 2008). While the opportunity to interact with agents on topics that are not immediately relevant to the task may be perceived as distracting, Veletsianos (2012) showed that mindful integration of non-task contexts (e.g., greetings, interactions that establish common ground between agent and learner, etc.), may enable the "development of a social and relaxed atmosphere in which learning can happen" (p. 277). In an earlier study examining this same idea, Bickmore, Shulman, and Yin (2009) conducted a longitudinal randomized experiment in which participants ($n=26$) interacted with virtual exercise counselors that shared stories about *themselves* or with virtual exercise counselors that shared stories about *others*, and found that users conversed more and reported higher enjoyment with the agent that shared stories about themselves than with the agent that shared stories about someone else. In other words, the use of first-person narratives fostered greater interaction and enjoyment, lending credence to the hypothesis that non-task contexts might be beneficial to learning with agents.

Nevertheless, social interaction between agents and learners might also lead to frustration and disappointment, as well as reveal that learners often use abusive language, aggressive demeanor, and sexist commentary when conversing with pedagogical agents. For example, De Angeli and Brahnam (2008) conducted a descriptive lexical analysis of a random sample of 103 agent–user conversations (each consisting of 82 conversational turns on average) and found that approximately 10 % of user input could be categorized as offensive or insulting. Additionally, when 90 adolescents were asked to choose between a strictly task-oriented agent and a task- *and* relation-oriented agent, approximately 41 % of participants expressed preference for the strictly task-oriented agent, and rationalized this choice by explaining how a social agent might be distracting and tiresome (Gulz, 2005).

The different circumstances and designs of the studies described above may explain the differing results: Bickmore et al. (2009) reported on a long-term intervention focusing on exercise counseling while Gulz (2005) reported on a short-term study where students were asked to take on the role of a journalist conducting research in a foreign country. Similar results have been observed when examining the impact of agent gender, race, and ethnicity. For example, though research has shown that students tend to be influenced and persuaded by agents that match their gender, race, and ethnicity (e.g., Kim et al., 2007; Moreno & Flowerday, 2006), these results vary depending on other variables such as student age and race (Baylor, 2009). As a result, pedagogical agent studies have become more fine-grained in their treatment of agent variables. For instance, Gulz and Haake (2010) suggested that studying masculinity and femininity in agent appearance, as opposed to gender, may allow researchers to draw more refined inferences.

To summarize, the literature does not uniformly show that agents address learners' sociocultural needs. Pedagogical agents may initially be novel, but can become irritating after a while. Alternatively, agents may be helpful as navigational guides while being distracting as "talking heads." For this purpose, it is important for researchers and designers alike to examine and be mindful of the purpose that specific agents serve.

Claim #4: Pedagogical Agents Foster Engagement, Motivation, and Responsibility

Researchers often posit that increased motivation is a key function of pedagogical agent use (Kim & Baylor, 2006; Kim & Wei, 2011; Kramer & Bente, 2010; Lusk & Atkinson, 2007). For example, the social presence of an agent is expected to increase a learners' interest and attention, and, therefore, their motivation (Kramer & Bente, 2010) because (a) the agents' appearance can be representative of an ideal social model for the learner (Baylor, 2011), and (b) the agents can "enrich and broaden the communicative relationship between learners and computers as well as provide computers with motivational and affective instructional features that actively engage students" (Lusk & Atkinson, 2007, p. 748). Interaction with competent agents is also expected to facilitate motivation (Kim & Baylor, 2006; Kim, Baylor, & PALS Group, 2006).

The *persona effect* is a focal point in the literature. The persona effect suggests that the presence of agents causes learners to perceive their learning experience positively as a result of interpreting computers as social actors (Choi & Clark, 2006; Moreno, Mayer, Spires, & Lester, 2001). Furthermore, agents increase engagement by simulating believable human-to-human connections through the coordination of verbal communication with nonverbal cues, such as body language, gestures for attention, and navigational guidance (Dunsworth & Atkinson, 2007; Gulz, 2005; Lin et al., 2008; Lusk & Atkinson, 2007; Sklar & Richards, 2010; Woo, 2008). However, empirical support for the persona effect is mixed, possibly due to differences in the quality of agents employed. For instance, Baylor and Ryu (2003) found support for the persona effect; Frechette and Moreno (2010), Domagk (2010), and Choi and Clark (2006) found that agent presence did not contribute to student interest; and Hubal et al. (2008) found that the technology and setting in which an agent is being used is not sufficient to engage participants. Other researchers have encountered more complicated results. For instance, Dirkin, Mishra, and Altermatt (2005) evaluated 116 participants' perceptions of social presence and the learning experience in four experimental conditions: text only, voice only, voice and image, and fully social agent condition. Their results showed that students perceived higher degrees of social presence for the text only and fully social agent conditions than for the other two conditions. This evidence supports the persona effect hypothesis, but the fact that students in the text-only condition also rated their experience highly poses a conundrum that future research should investigate.

Researchers have also suggested that users can build valuable relationships with agents, and these relationships may increase learners' sense of responsibility, motivation, and reduce their sense of loneliness in a virtual environment (Gulz, 2005). Learner motivation is an integral part of the teachable agent paradigm (Schwartz, Blair, Biswas, Leelawong, & Davis, 2007). For example, Chase et al. (2009) discovered that when students were teaching their agents, they spent more time with the learning activities and were quick to acknowledge mistakes. The researchers hypothesized that teachable agents may engender a sense of responsibility as learners are motivated to teach their agents. The topic of agent–learner relationships introduces interesting philosophical, ethical, and social questions, and Bickmore (2003) has examined the possibility of agents establishing and maintaining long-term relationships with users. However, the topic of agent–learner relationships is one that has not, to date, been explored extensively in our field's literature. Is it ethical for pedagogical agent designers and researchers to design virtual characters that can connect with learners on a deep emotional level? If so, are such agents appropriate for all age levels? Regardless of how strong or weak a relationship is, what does it mean, in a phenomenological sense, for a learner to have a relationship with a virtual character? What does the future look like given that technology is continuously advancing and researchers are developing more believable, competent, and adaptive agents? These are difficult questions to answer, but scholarship investigating these questions will help us make sense of the possibilities, boundaries, pitfalls, and limitations of agent–learner relationships, and hence the degree to which agents can foster engagement, motivation, and responsibility.

Claim #5: Pedagogical Agents Improve Learning and Performance

The last claim that we found in the literature relates to agents contributing to learning and performance. Agent versatility, agent ability to engender realistic simulation, agent ability to address sociocultural needs, and increased motivation/engagement created through interactions with agents is expected to eventually lead to improved learning and performance outcomes (Gulz, 2005; Kim & Baylor, 2006; Kim & Wei, 2011; Kramer & Bente, 2010). Additionally, a number of researchers suggest that, compared to conventional information delivery, virtual agents tend to improve comprehension, retention, recall, problem-solving, self-efficacy, and transfer (Dunsworth & Atkinson, 2007; Gilbert, Wilson, & Gupta, 2005; Gulz, 2005; Murray & Tenenbaum, 2010). The affordances provided by pedagogical agents lead to deeper understandings in a variety of ways. For example, learning procedural tasks is improved through agents' use of nonverbal gestures, whereas attitudinal instruction is more effective with agents' use of facial expressions (Baylor & Kim, 2009). By combining verbal and nonverbal cues, agents may better support information procession than text or narration alone (Dunsworth & Atkinson, 2007). Use of natural language and communication is also expected to increase the effectiveness of dialogues and deepen learners' comprehension of domain content (Graesser & McNamara, 2010).

Furthermore, researchers claim that pedagogical agents help learners retain information longer (Kim & Wei, 2011; Woo, 2008), improve their problem-solving skills (Dunsworth & Atkinson, 2007), and foster knowledge transfer (Kim & Wei, 2011; Lusk & Atkinson, 2007). Learning from animated agents also results in "conceptually accurate solutions" (Dunsworth & Atkinson, 2007, p. 679) and an improved ability to transfer that knowledge (Lusk & Atkinson, 2007). Nevertheless, transfer of knowledge and skills in agent-based environments also requires pedagogical strategies such as the use of instruction that uses worked examples (Kim & Wei, 2011) and the use of subgoals in problem solving (Lusk & Atkinson, 2007).

Empirical research however, has shown that simply adding pedagogical agents in a digital environment does not lead to better learning outcomes, with any benefits observed usually being attributed to the pedagogy used by the agent, rather than to the agent itself (Clark & Choi, 2005; Moreno, 2004). For instance, Choi and Clark (2006) found no significant differences in learning between an a condition in which an agent was used ($n=32$) and a condition in which an arrow was used ($n=42$) in an experimental study conducted in the context of second language instruction. Louwerse, Graesser, Lu, and Mitchell (2005) found no significant differences in comprehension scores between learners assigned to a voice-and-agent condition and a voice-and-no-agent condition. The researchers suggested that "if enough social cues are provided by the voice only, the agent does not contribute much more to comprehension" (Louwerse et al., 2005, p. 701). Nevertheless, emerging evidence from the literature suggests that this finding may need further qualification (Domagk, 2010; Sträfling, Fleischer, Polzer, Leutner, & Krämer, 2010; Veletsianos, 2007, 2010). For example, Sträfling et al. (2010) and Veletsianos (2010) found differential effects between agents of different appearances. Evidence from Domagk (2010) indicated that even though the inclusion of a pedagogical agent does not have an impact on learning, (a) appealing agents promoted transfer (when compared to unappealing agents), and (b) unappealing agents (dislikable in image and voice) actually hindered learning. On the other hand, Jackson and Graesser (2007) found an inverse correlation between deep learning and liking the learning experience, noting that agent designers and researchers face the dilemma of creating effective learning environments that learners enjoy and want to revisit. These results suggest more refined pedagogical agent design, with renewed attention to enjoyment, appeal, and appearance of pedagogical agents.

Current and Future Directions

Our review of the empirical research suggests that the evidence for the claims presented in the literature is mixed. While recent technological advancements have enabled researchers to ask questions that arise out of our improved ability to design different types of virtual characters (e.g., teachable agents), our evaluation shows that no single claim is supported by unambiguous empirical results.

The current literature includes suggestions for future research. While the suggestions arise from individual studies, a number of future directions are recurrent. Such directions include the need for longitudinal and long-term research (Baylor, 2011; Choi & Clark, 2006; Dehn & van Mulken, 2000; Gulz, 2004), multidisciplinary investigations (Kim & Baylor, 2006; Veletsianos, Heller, Overmyer, & Procter, 2010; Yung & Dwyer, 2010), investigations of agent–learner interactions in situations where agent behavior adapts (e.g., agents are able to dialogue with learners) (Clarebout & Elen, 2006; Domagk, 2010; Dunsworth & Atkinson, 2007), exploration of agents' visual form, appearance, appeal, and aesthetics (Baylor, 2009; Domagk, 2010; Gulz & Haake, 2006; Veletsianos, 2007), and investigations of agents' nonverbal communication (Baylor & Kim, 2009; Frechette & Moreno, 2010). In addition to the research directions identified in existing literature, based on our synthesis, we suggest that the following three areas also need to be considered by pedagogical agent researchers: cognitive and sociocultural foci, methodological focus, and supporting student-centered inquiry within open-ended environments.

Cognitive and Sociocultural Foci

The majority of scholarly work on pedagogical agents has so far focused on cognitive concerns, such as the impact of agent image on retention (Moreno et al., 2001) and the extent to which the presence (vs. absence) of an agent facilitates learning/motivation (Domagk, 2010). More recently however, researchers have called for an increasing emphasis on sociocultural investigations (Gulz, 2005; Kramer & Bente, 2010). Examples of such investigations include research relating to the influence of agents' visual appearance (e.g., Baylor, 2009; Gulz & Haake, 2010) and pertaining to understanding how learners and agents interact (e.g., Veletsianos et al., 2008). Research into the sociocultural elements of agent–learner interactions will help us better understand agent–learner interactions and relationships, the learner experience, the design of future agent-based systems, and learning processes. Kim and Baylor (2006) argued that agent-based learning is a social process, and as such, taking a sociocultural lens to investigate agent deployments will inform future work.

Methodological Focus

The majority of the work on pedagogical agents has focused on experimental and quasi-experimental investigations (Adcock & Van Eck, 2005; Mahmood & Ferneley, 2006), in which researchers have evaluated the influence of agent-related variables on various outcomes. Qualitative and interpretive investigations in the field are noticeably fewer, even though researchers have argued that such investigations would allows us to gain a deeper understanding of pedagogical agent deployments (Veletsianos & Miller, 2008).

As pedagogical agents are increasingly integrated in complex digital learning environments (e.g., virtual worlds and video games), and especially in open-ended learning environments (see below), we need to understand not just the impact that pedagogical agents and their various features may have on learning outcomes, but also the meaning behind agent–learner interactions, the use of the agents within the context of the environments they inhabit, and the potential roles they serve in such environments (e.g., agent as tutors, agents as peers, etc.). Overall, to gain a deeper, richer, and more diverse understanding of agent technologies we need to employ diverse methodologies. Steps towards this goal are already evident in the literature. For instance, mixed methods investigations to understand learner experiences with pedagogical agents are already available. For example, Adcock et al. (2006) supplemented their experimental results with user comments on the usability of two learning environments used in their study, thus gaining a richer understanding of how to enhance the agent-based learning environment for future implementations. Similarly, Veletsianos (2009) combined a quasi-experimental design with a grounded theory lens to understand pedagogical agent expressiveness and the "existence of multiple, complementary, and contradictory truths that coexist within the use and deployment of pedagogical agents in education" (p. 350). That study revealed that while agents might enhance affective aspects of learning, they also introduce the notion of human–agent relationships in learning environments, with which designers now have to grapple.

Supporting Student-Centered Inquiry Within Open-Ended Environments

The pedagogical agent field's focus on cognitive concerns is in stark contrast to recent discussions in the educational technology discipline. Specifically, open-ended learning environments, such as social networking sites and video games, are gaining increasing popularity as locales of student-centered learning activity. In such environments, social interaction and user contributions are central aspects of the learning experience. Agents that are able to engage in social-oriented dialogue may therefore be of value in online learning contexts, but the current directions of the field generally view the agent as an expert figure quick to provide instruction as opposed to one that aims to support student-centered inquiry and activity. Future research focusing upon (a) agents within digital learning environments vis-a-vis stand-alone agents, and (b) agents in open-ended learning environments, will be beneficial to the field. Examples of both of these foci are already present in the literature (e.g., Clarebout & Elen, 2006, 2007; Zumbach, Schmitt, Reimann, & Starkloff, 2006).

Conclusion

This chapter synthesized the existing literature on pedagogical agents, summarized the claims that researchers have made with regards to the potential benefits of pedagogical agents, and evaluated the empirical evidence that exists to support those claims.

The pedagogical agent field is as complex as it has ever been. Numerous factors contribute to this complexity, including:

- The way that experiments have been designed may have contributed to mixed results (Clark & Choi, 2005).
- Varied agent modalities used in varied content areas make comparisons difficult (Baylor & Ryu, 2003).
- A multiplicity of variables, such as agent role, voice, and voice quality, interact in complex ways, making generalizations difficult (Louwerse et al., 2005).

Thus, pedagogical agent researchers advise that the use of agents in digital environments requires careful evaluation (e.g., Baylor, 2009; Dirkin et al., 2005; Moreno & Flowerday, 2006). To improve comparisons between research efforts, Clark and Choi (2005) proposed five design principles for pedagogical agent researchers conducting experimental studies on learning and motivation: separate pedagogical agents from pedagogical methods; evaluate a variety of learning and motivation outcomes; make sure that measures are reliable and have construct validity; calculate the cost and benefit of agent and non-agent comparisons; and avoid testing agents that are visually and aurally complex.

In 2004, Gulz noted

> …we are still at a very early stage in the development of character enhanced systems, and consequently it is too early to go into evaluations of potential benefits of these kinds of learning environments. We have to await systems that are built for long-term real use and leave short-time lab studies behind. Evaluations today are bound to give uncertain results (p. 326).

Between 2004 and 2011, a handful of long-term studies have been conducted (e.g., Lindström, Gulz, Haake, & Sjödén, 2011; Veletsianos & Miller, 2008; Wagster, Tan, Wu, Biswas, & Schwartz, 2007). These studies are informative, but introduce additional issues that pedagogical agent researchers need to consider. For instance, Veletsianos and Miller (2008) asked what our experiences interacting with pedagogical agents would be like if we interacted with them over several months or years. This question becomes more difficult to answer considering that pedagogical agent theory does not always match practice, and it can be difficult for the designer to foresee such mismatches (Lindström et al., 2011). How would an agent's knowledge base need to change to be able to interact with learners over time, and would we be able to form long-term emotional bonds with agents? We echo Gulz's concerns with regard to the need for longitudinal studies, and advise pedagogical agent researchers to focus more of their energy on long-term evaluations of pedagogical agent implementation in real-world settings. Such endeavors will help us understand the actual use of agent technologies in messy real-world contexts.

Equally important, Moreno and Flowerday (2006) asked whether they would have found "the same effects had we used different social cues, content materials, learning measures, agent representations, or student populations" (p. 204). The educational psychology literature recommends systematic investigation of outcomes to answer questions such as the one above. We believe that such studies should be examined in relation to the goals of agent use. Such goals vary. For instance, agents may be used to provide on-demand instructional support, social enrichment, or even social and cultural diversity. The goals we devise for agents impact their design and, in turn, their behaviors and functions. For this reason, we need to understand and describe the unique contexts of agent-based naturalistic interventions in order to highlight how the "real world" influences the use, effectiveness, and design of pedagogical agents. Descriptions of how agent designs changed over time as a result of implementations in naturalistic settings will provide much-needed design knowledge to inform future practice and scholarship.

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Adaptive Technologies

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Sabine Graf and Kinshuk

Abstract

Adaptive learning technologies provide an environment that intelligently adjusts to a learner's needs by presenting suitable information, instructional materials, feedback and recommendations based on one's unique individual characteristics and situation. This chapter first focuses on the concept of adaptivity based on four types of learner differences that can be used by adaptive technologies: learning styles, cognitive abilities, affective states and the current learning context/situation. In order to provide adaptivity, the characteristics of learners need to be known first. Therefore, this chapter discusses methods for identifying learners' individual differences as well as how the information about these individual differences can be used to provide learners with adaptive learning experiences. Furthermore, the chapter demonstrates how adaptivity can be provided in different settings, focusing on both desktop-based learning and mobile/pervasive/ubiquitous learning. Finally, open issues in adaptive technologies are discussed and future research directions are identified.

Keywords

Affective states • Cognitive abilities • Context • Context modeling • Learning styles • Student modeling

Introduction

Learning is increasingly mediated by educational technologies. The learners utilizing these technologies have different characteristics, including different prior knowledge, learning styles, cognitive abilities, motivation, and affective states. Students also learn in different situations/contexts, such as from different devices with different features and functionalities, at different locations, and so on. However, it appears that the learning systems that are most commonly used in technology-enhanced learning, namely, learning management systems (LMSs), typically present exactly the same course for every learner without consideration of the learner's individual characteristics, situation, and needs. Such a one-size-fits-all approach often leads to frustration, difficulties in learning, and a high dropout rate (Dagger, Wade, & Conlan, 2005; Karampiperis & Sampson, 2005).

Adaptive learning technologies address this issue by enabling learning systems to adapt courses, learning material and/or learning activities automatically to adjust to the learners' individual situation, characteristics and needs, and therefore provide learners with personalized learning experiences. By taking individual learning differences and contexts into account, adaptive learning systems can improve learning outcomes, require less effort, reduce time required, and result in higher learner satisfaction. A system can, for example, adapt learning material/activities to a learner's prior knowledge (Brusilovsky, Eklund, & Schwarz, 1998; Yang & Wu, 2009),

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preferred learning style (Graf, Kinshuk, & Ives, 2010; Popescu, 2010; Tseng, Chu, Hwang, & Tsai, 2008), affective states (D'Mello, Craig, Fike, & Graesser, 2009; Woolf et al., 2009), and so on. Furthermore, a system can take advantage of nearby objects or people who might be able to help in the learning process (El-Bishouty, Ogata, & Yano, 2007; Martín, Sancristobal, Gil, Castro, & Peire, 2008), consider the characteristics of the learner's environment, and take into account the features of the device a learner is using (Hwang, Yang, Tsai, & Yang, 2009).

Besides the term "adaptive technology" or "adaptive learning system," there exist other terms that are often used in similar contexts. The term "personalized learning system" emphasizes the aim of the system to consider a learner's individual differences and treat each learner as an individual person. The term "intelligent learning (or tutoring) system" refers to systems that focus on the use of techniques from the field of artificial intelligence to provide broader and better support for learners. On the other hand, the term "adaptive learning system" stresses the ability of a learning system to automatically provide different courses, learning material, or learning activities for different learners. However, many of the learning systems developed to tailor education to learners' unique characteristics and needs can be considered as adaptive, personalized, and intelligent. In order to accomplish the goal of providing adaptive learning, a system has to follow two steps: First, the respective information about a learner and/or his/her context and situation have to be identified and second, this information has to be used to provide adaptive support to learners.

The first step usually deals with student modeling and context modeling. Student modeling aims at building and updating a student model that includes information about the learners' characteristics and/or needs. On the other hand, context modeling focuses on identifying the learners' context and situation. Brusilovsky (1996) distinguished between two different methods of student modeling: collaborative and automatic. In the collaborative approach, the learners provide explicit feedback that can be used to build and update a student model, such as filling out a questionnaire or taking a test. In the automatic approach, the process of building and updating the student model is done automatically based on the behavior and actions of learners while they are using the system for learning. These two approaches also apply for context modeling, enabling a system either to identify the context information automatically or through feedback from learners. Furthermore, student modeling and context modeling can be done statically or dynamically. Static modeling refers to an approach where the student model or context model is initiated only once (mostly when the learners access the system the first time). In contrast, a dynamic modeling approach continuously monitors a learner and his/her context, and frequently updates the information in the student/context model.

In the second step, the identified information about learners' characteristics and/or their current situation/context is used to provide individualized learning experiences. Such individualized learning experiences can be provided in different ways, for example, with respect to the learning objects/activities that are presented in the course, the number of presented learning objects/activities, the sequence in which particular learning objects/activities are presented, the presentation and layout of the course itself, the amount of additional support provided to learners, the navigation within the course, and so on. Brusilovsky (2001) pointed out two distinct areas of adaptation techniques for adjusting online courses to students' characteristics and needs, namely, adaptive navigation support and adaptive presentation. Adaptive navigation support deals with providing students different ways to navigate through a course and includes features such as direct guidance, map adaptation, as well as adaptive sorting, hiding, annotating and generating of links. Adaptive presentation deals with how the content itself is presented to learners and includes, for example, adaptive multimedia presentation, adaptive text presentation, and adaptation of modality. In addition to changing the presentation and the way learners navigate through a course or course material, in a mobile and ubiquitous setting adaptive systems can also guide the learner to a particular real-life learning object, make a learner aware of other learners or experts in the vicinity, or adjust/select learning material based on the characteristics of the environment (Graf & Kinshuk, 2008).

Besides looking into *how* adaptivity can be provided, another important dimension of adaptive technologies deals with *which* information is used to provide adaptivity. The early adaptive and intelligent learning systems, such as InterBook (Brusilovsky et al., 1998), Intelligent Helpdesk (Greer et al., 1998), and AHA! (de Bra & Calvi, 1998), focused on characteristics such as learners' knowledge and learning goals. Later on, cognitive and pedagogical aspects have been considered more and more, leading to the development of systems that tailor courses and learning activities to learners' learning styles, cognitive abilities, affective states, learning interests, motivation, and the like. Furthermore, as recent technological advances make mobile, ubiquitous and pervasive learning increasingly popular, the context and situation in which learning takes place is becoming another important variable in providing adaptivity.

In this chapter, we focus on adaptive technologies that consider information about learners' learning styles, cognitive abilities, affective states, and context/situation. The first major section discusses the recent research on such technologies. In the second section, we discuss adaptive technologies in different settings, including desktop-based and mobile settings.

Table 62.1 Accuracy of learning style identification approaches

	Participants	Active/reflective	Sensing/intuitive	Visual/verbal	Sequential/global
García et al. (2007)	27	58.00	77.00	–	63.00
Graf, Kinshuk, et al. (2009)	75	79.33	77.33	76.67	73.33
Özpolat and Akar (2009)	30	70.00	73.30	53.30	73.30

Adaptivity Based on Individual Differences

Learning Styles

There are many definitions for the term *learning style*. A general definition is provided by Honey and Mumford (1992) stating that a learning style is a description of the attitudes and behaviors that determine an individual's preferred way of learning.

The field of learning styles is complex, and although a great deal of research has been conducted, some important questions remain unanswered. Coffield, Moseley, Hall, and Ecclestone (2004) pointed out several controversial issues, including the existence of many different views, definitions, and models of learning styles, the reliability and validity of instruments for identifying learning styles, the feasibility and effectiveness of incorporating learning styles in education, and the way learning styles should be used in education. While Coffield et al. concluded that learning styles are often misused and are limited in what they can achieve, many other researchers have argued that learning styles are an important factor in education (Felder & Silverman, 1988; Graf, 2007; Lu, Jia, Gong, & Clark, 2007). Especially in the last few years, several studies have been conducted that support this argument. Examples include the development of adaptive systems that consider learning styles such as TSAL (Tseng et al., 2008), WELSA (Popescu, 2010) and an adaptive mechanism for extending LMSs (Graf & Kinshuk, 2007). Evaluations of these systems have shown that accommodating various learning styles can decrease the time required for learning and increase overall learner satisfaction (Graf & Kinshuk, 2007; Popescu, 2010; Tseng et al., 2008).

Several different techniques are used in adaptive learning systems to accommodate students' learning styles and adjust instruction accordingly. Some of the most often used techniques include changing the sequence of types of learning objects presented in each section of a course (e.g., Graf & Kinshuk, 2007; Paredes & Rodríguez, 2004; Popescu, 2010), hiding learning objects, elements of learning objects and links to learning objects that do not fit students' learning styles well (e.g., Bajraktarevic, Hall, & Fullick, 2003; Graf & Kinshuk, 2007; Tseng et al., 2008), and annotating learning objects in order to indicate how well they fit students' learning styles and therefore recommending the ones that fit best (e.g., Graf, Kinshuk, et al., 2010; Popescu, 2010).

Most adaptive systems use a static and collaborative student modeling approach, where learners are asked to fill out a questionnaire to determine their learning styles. These questionnaires are based on the assumption that learners are aware of how they learn. Jonassen and Grabowski (1993) pointed out that "because learning styles are based on self-reported measures, rather than ability tests, validity is one of their most significant problems" (p. 234). Similarly, Coffield et al. (2004) identified that many learning style questionnaires have problems with validity and reliability. In recent years, research has been performed on investigating and developing automatic approaches for identifying learning style, where information about learners' behavior in an online course is used to infer their learning styles. For example, García, Amandi, Schiaffino, and Campo (2007) studied the use of Bayesian networks to detect students' learning styles based on their behavior in the educational system SAVER. In another study, Cha et al. (2006) investigated the usage of Hidden Markov Models and Decision Trees for identifying students' learning styles based on their behavior in a course. Another example is the work of Özpolat and Akar (2009) where they used an NBTree classification algorithm in conjunction with Binary Relevance classifier in order to classify learners based on their interests and then inferred learning styles from these results. Besides using machine learning/data mining approaches to generate data-driven models that can then be used to calculate learning styles, Graf, Kinshuk, and Liu (2009) proposed a literature-based approach, where the calculation of learning styles is, similar to a learning style questionnaire, based on rules derived from literature. All abovementioned studies were applied to identify learning styles based on the Felder–Silverman learning style model (Felder & Silverman, 1988). This learning style model describes the learning style of a student in very much detail, assuming that each student has a preference on each of the four dimensions: active/reflective, sensing/intuitive, visual/verbal, and sequential/global. The abovementioned studies were developed for different systems or for LMSs in general, and considered different behavior patterns of learners. Each of these approaches was evaluated by comparing the results of the approach with the results of the learning style questionnaire. Table 62.1 shows a comparison of the results for each of the four learning style dimensions of the Felder–Silverman learning style model. Each study used the same accuracy measure, which indicates the accuracy of the identified learning styles on a scale from 0 to 100. The study by Cha et al. (2006) has not been included in this comparison since their experiment used only data from the learning style questionnaire indicating a strong or moderate preference on a specific learning style dimension rather than including all data, as has been done by the other studies.

All of the above-mentioned studies focused on using behavior patterns such as the time a learner visited a particular type of learning object or the number of times such types of learning objects had been visited by learners. However, more complex behavioral patterns have been investigated as well. For example, Graf, Liu, and Kinshuk (2010) looked into navigational patterns, which indicate how learners navigate through the course and in which order they visit different types of learning objects and activities. Several differences in the learners' navigational patterns were identified, indicating that students with different learning styles visit learning objects in different sequences. These differences can be used to improve the identification process of learning styles. Furthermore, Spada, Sánchez-Montañés, Paredes, and Carro (2008) investigated mouse movement patterns with respect to students' sequential/global dimension of Felder–Silverman learning style model and found a strong correlation between the maximum vertical speed and learners' sequential/global learning style. Again, these findings can contribute to the improvement of the detection process of learning styles.

Since the learning style models that are commonly used in adaptive learning systems are based on the assumption that learning styles can change over time, recent research deals with considering such dynamic aspects. While the approaches described above use a certain amount of data to identify learning styles in a static manner, investigations are also being conducted on dynamic student modeling of learning styles, where the information about students' learning styles is updated frequently in the student model. Paredes and Rodríguez (2004) implemented a simple form of dynamic student modeling in their adaptive system TANGOW, which includes a mechanism that adjusts the system's record of a student's learning style whenever a behavior that is incongruent to the initially recorded learning style has been detected. Graf and Kinshuk (2013) investigated dynamic aspects of modeling learning styles in more complex settings and proposed a mathematical model to calculate how and when to revise information in the student model, assuming that new information about students' behavior is frequently added and therefore new information about students' learning styles is frequently gathered. Furthermore, they demonstrated how dynamic and automatic student modeling of learning styles can be integrated in LMSs.

Cognitive Abilities

Cognition can be defined as the mental process of knowing, including aspects such as awareness, perception, reasoning, and judgment. Cognitive abilities are abilities to perform any of the functions involved in cognition. Humans have a number of cognitive abilities. Several of these abilities are crucial for learning. These include abilities such as working memory capacity, inductive reasoning ability, information processing speed, associative learning skills, meta-cognitive skills, observation ability, analysis ability, abstraction ability, and so on.

Research on adaptivity based on cognitive abilities deals with identifying cognitive abilities of learners and then using this information to provide different support for learners with different cognitive abilities. Little research has been done in this area and what does exist is still in its early stages. Kinshuk and Lin (2003) provided suggestions for considering working memory capacity, inductive reasoning ability, information processing speed, and associative learning skills in online courses. These suggestions are based on the Exploration Space Control project (Kashihara, Kinshuk, Oppermann, Rashev, & Simm, 2000), which included elements that can be changed to create different versions of courses to suit different cognitive needs such as the number and relevance of paths/links, the amount, the concreteness and the structure of content, as well as the number of information resources. For example, for learners with low working memory capacity the authors suggested that an adaptive system might automatically decrease the number of paths and increase the relevance of paths in a course. Furthermore, less but more concrete content should be presented and the number of available media resources should increase. In contrast, for learners with high working memory capacity, fewer relevant paths can be presented while the amount of content as well as its level of abstractness can also be increased.

Jia, Zhong, Zheng, and Liu (2010) proposed the design of an adaptive learning system that is based on fuzzy set theory and can consider cognitive abilities such as induction, memory, observation, analysis, abstraction, deduction, mathematic, association, imagination, and logic reasoning. These cognitive abilities, together with the students' knowledge level, goals and preferences, are taken into consideration when learning resources are suggested to the learners. Furthermore, Jia et al. (2010) proposed a student model that detects students' cognitive abilities based on test questions about the learned topics.

Another way of identifying students' cognitive abilities is to infer them from students' behavior in a course. Kinshuk and Lin (2004) introduced the Cognitive Trait Model (CTM), which is a student model that profiles learners according to their cognitive abilities. Four cognitive abilities, namely, working memory capacity, inductive reasoning ability, processing speed, and associative learning skills are included in CTM. The CTM offers the role of a "learning companion," which can be consulted by different learning systems to provide information about a particular learner. The CTM can still be valid after a long period of time due to the more or less persistent nature of cognitive abilities of human beings

(Deary, Whiteman, Starr, Whalley, & Fox, 2004). When a student uses a new learning system, this system can directly access the CTM of the particular student, and does not need to "re-learn the student." The identification of the cognitive abilities is based on the behavior of learners in the system. Various patterns, called Manifests of Traits (MOT), are defined for each cognitive ability. Each MOT is a piece of an interaction pattern that manifests a learner's cognitive characteristic. A neural network was used to calculate the cognitive traits of the learners based on the information of the MOTs (Lin & Kinshuk, 2004).

A challenge of using learners' behavior and performance to infer their cognitive abilities is to get enough reliable information to build a robust student model. As a solution, the use of additional sources can help to get more information about the learners (Brusilovsky, 1996). In this context, investigations have explored the relationship between cognitive abilities and learning styles (Graf, Liu, Kinshuk, Chen, & Yang, 2009). In adaptive systems that consider either only learning styles or only cognitive abilities, this relationship can lead to more information. For example, a system that only considers learning styles can use this relationship to also have some information about the learners' cognitive abilities. In systems that incorporate learning styles as well as cognitive abilities, the relationship can be used to improve the detection process of the respective counterpart (e.g., improving the detection process of cognitive abilities by additionally considering data about learning styles and vice versa). This leads to a more reliable student model.

Graf, Liu, et al. (2009) investigated the relationship between the Felder–Silverman learning style model and working memory capacity. First, a comprehensive literature review was conducted. Second, a pilot study was performed where the learning styles and working memory capacities of 39 students were identified through questionnaires/tasks and then analyzed to explore any relationships between learning styles and working memory capacity. Since the results from the literature review and the pilot study were promising, a main study with 297 students was conducted (Graf, 2007; Graf, Liu, et al., 2009), using a similar research design as for the pilot study. The results of these experiments and detailed analysis showed that relationships exist between working memory capacity and three of the four dimensions of the learning style model. The identified relationships have high potential to improve the student modeling process of cognitive abilities and learning styles and encourage further research on relationships between learning styles and other cognitive abilities.

Affective States

Another aspect that can influence the learning process is one's affective state. The term *affective state* is typically used as a collective term for emotions, feelings, moods and attitudinal states. Affective states that are considered to be especially relevant in the learning process include, for example, boredom, confusion, frustration, confidence, satisfaction, and independence. Providing adaptivity with respect to affective states is a new area of research and only few adaptive learning systems have been designed and implemented addressing this issue. An example of such a system is AutoTutor (D'Mello et al., 2009), which detects learners' boredom, confusion and frustration and uses this information to select pedagogical and motivational dialogue strategies. Furthermore, an embodied pedagogical agent is implemented in the system, which considers learners' affective states and expresses emotions through verbal content, facial expressions and affective speech. Two versions of AutoTutor were implemented to provide empathy and encouraging responses if negative states had been detected. The first version provided more formal and supportive comments while the other provided more informal comments, attributing the source of the emotion to the learners themselves. Another example of an adaptive system that considers affective states is Wayang Outpost (Woolf et al., 2009), which is an intelligent tutor that lets students interact with a learning companion who reacts after a student has answered a question/problem by communicating with the student through text messages and/or mirroring his/her emotions. Affective states such as learners being confident/anxious, frustrated, excited, and interested/bored are considered within these communications. Furthermore, Khan, Graf, Weippl, and Tjoa (2010) proposed a framework consisting of several modules that attempt to incorporate learning styles and affective states including confidence, effort, independence, and confusion into LMSs. Once negative affective states are determined, the system provides additional guiding elements based on the learner's learning styles.

In order to identify affective states, either a collaborative or automatic student modeling approach can be used. In a collaborative student modeling approach, learners are asked to self-reporting their affective states from time to time. This approach runs the risk that learners are not honest about their affective states or get annoyed by reporting about them frequently. An automatic approach can use data from hardware sensors or behavior patterns. Woolf et al. (2009) summarized investigations of several hardware sensors, including facial expression cameras, pressure mouse sensors, skin conductance sensors, and posture analysis seat sensors to recognize different affective states. They concluded that sensors can help in predicting affective states relevant for learning and provide useful information about when students are in non-productive states and whether interventions worked or not. Khan et al. (2010) proposed an approach to identify affective states including confidence, effort, independence, and confusion by observing how students behave in an online course. These behavior patterns mainly dealt with the types of learning objects visited and the time students spent there.

Context and Environment

Instead of providing a definition, the term "context" is often described in the literature by giving examples or replacing the term with other terms. A general definition is provided by Dey (2001), describing context as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" (p. 5).

Due to the recent advances in mobile technologies, learning can take place anytime and anywhere, using not only desktop-computers but also mobile devices such as smart phones and tablets for learning. The learner's current context/situation as well as the characteristics of the surrounding environment in which one learns, therefore, become part of another important aspect to be considered by adaptive technologies. By incorporating information about the learner's context and environment into the adaptation process, new possibilities for providing adaptivity open up.

For example, an adaptive system can interact with learners and involve them in learning activities, considering their current context and surrounding environment. An example for such adaptive support is shown in the language learning system JAPELAS (Yin, Ogata, & Yano, 2004). JAPELAS teaches foreign students Japanese polite expressions. When a learner starts talking to another person, the system provides suggestions about the level of polite expression based on hyponymy, social distance and situation, by receiving information about the other person from his/her device and about the current context from sensors of the learner's device. For example, a different politeness level would be suggested if a learner meets a friend in a lecture hall or a professor in a park. Another example is the language learning system TANGO (Ogata et al., 2004), which detects objects around the learner, using RFID tags, and involves these objects in learning activities, for example, asking the learner to close a window or move a can from one place to another.

Furthermore, based on the location of the learners, adaptive systems can guide them to suitable places containing certain real-life learning objects where the system can present learning activities that are relevant and appropriate in the current environment. In order to help learners navigate to locations where learning can take place more realistically, adaptivity deals mostly with location-awareness and planning suitable learning activities. For example, a system can generate a personalized learning path based on learners' prior knowledge and guide them to places where they can learn concepts that are new or difficult to understand for them (Chang & Chang, 2006). Hwang, Tsai, and Yang (2008) described a similar scenario where the system asks a student to go to specific places to observe and identify particular plants.

In addition, information about the context and surrounding of a learner can enable adaptive systems to help learners in communicating synchronously with peers and experts in their vicinity, assisting them in forming learning groups or showing them who might be able to answer their questions. For example, Martín et al. (2008) presented a location-based application that gives information about people who are close to the learner. Furthermore, a system can provide suggestions for building learning groups based on the students' location as well as other characteristics of students, as proposed, for example, by Graf, Yang, Liu, and Kinshuk (2009).

Most systems that consider contextual information, focus on information such as learners' current location, surrounding objects, and peers/experts who are in the vicinity. A few other systems (El-Bishouty, Ogata, Ayala, & Yano, 2010; Hwang et al., 2009) have recently started to provide personalized recommendations for learning tasks and/or peer assistance not only from the information about the learners' environments but also from basic information contained in learners' profiles, namely, learners' knowledge and/or performance. Furthermore, Graf, Yang, et al. (2009) proposed a learning system that considers a learner's current location as well as different learner characteristics such as their progress, learning styles, interests and knowledge level, problem solving abilities, preferences for using the system, and social connectivity.

As for other learner characteristics, the identification of learners' current context/situation and the characteristics of their environment is a crucial part for an adaptive system that aims at using this information to provide adaptivity. While such context modeling can be achieved through a collaborative modeling approach (e.g., by asking the student about his/her location), in most cases context modeling is done automatically. A very common approach to identify context information is through the use of sensors, such as microphones, Web cameras, GPS, accelerators, and more. Hwang et al. (2008) provide a detailed explanation of different kinds of information that can be gathered to make a system context-aware and how it can be gathered, including not only sensors but also other sources of information. Five types of situation parameters have been identified: personal context, environmental context, feedback from the learner interactions with the mobile device, personal data and environmental data. The first situation parameter includes information concerning the students' personal context, which is sensed by the system, such as students' current location, the time of their arrival, and issues such as heartbeat and blood pressure. Another kind of information that can be sensed by the system is the environmental context, which includes information about the environment around a sensor, such as the sensor's location, the temperature around the sensor, and information about approaching objects/people. Furthermore, information can be gathered from the students' interaction with the system, including for example, stored documents, given answers to questions, and certain settings the learner made in his/her user interface. Moreover, the system can access a database, where students' personal data and environmental data are stored. Personal data can include the students' learning styles, course schedule, prior knowledge, progress in the course and so on. Environmental data provide more detailed information about the environment, such as a schedule of arranged learning activities or notes for using the site.

Adaptive Technologies in Different Settings

While the previous section discussed the current state of research about adaptivity based on learners' individual differences, this section looks into the use of adaptive technologies in different settings and modes of learning, including for example desktop-based and mobile/ubiquitous/pervasive learning; formal, nonformal, and informal learning; individual and collaborative learning; and instruction-based, assessment-based and game-based learning. In this section, we focus on desktop-based settings, where students learn via a desktop computer, and mobile/pervasive/ubiquitous settings, where students learn via a mobile device, and discusses how adaptive technologies can be used in these two settings is provided.

Many educational institutions, including universities, use LMSs for offering desktop-based learning in either blended or fully online courses. LMSs, such as Moodle (2011), Blackboard (2011) and Sakai (2011) aim at supporting teachers in creating, administering, and holding online courses by providing them with a variety of features. Such features assist them in administrative issues (such as enrollment), allow them to create courses with many different activities and resources, support communication between teachers and students as well as among students, and much more. However, LMSs typically do not consider individual differences of learners and treat all learners in the same way regardless of their needs and characteristics. In contrast, adaptive learning systems provide desktop-based learning that focuses particularly on supporting learners, tailoring courses to learners' characteristics and needs. However, such adaptive systems typically provide only basic functions for supporting teachers and administrators, which might be one of the reasons why they are only rarely used by educational institutions.

Although many adaptive learning systems have been developed to support desktop-based learning and evaluations of such systems have demonstrated positive effects and benefits for learners, very little research has been done on combining the advantages of today's LMSs to support teachers and administrators with the advantages of adaptive technologies to support learners. Examples of such attempts include work on incorporating adaptivity based on learning styles in LMSs. Graf and Kinshuk (2007) developed an adaptive mechanism that extends LMSs by enabling those systems to automatically compose courses that fit students' learning styles. An evaluation of this adaptive mechanism with 473 students showed that learners who learned from a course that matched their learning styles spent significantly less time in the course and achieved on average the same grades as learners who got a course that either did not match their learning styles or included all available learning objects (Graf & Kinshuk, 2007). Subsequently, the adaptive mechanism has been extended by making it more generic and applicable for different types of courses, such as courses with practical versus theoretical foci (Graf, Kinshuk et al., 2010). Another example for incorporating adaptive technologies into LMSs is the EU-funded project GRAPPLE (de Bra, Smits, van der Sluijs, Cristea, & Hendrix, 2010) that attempts to incorporate an adaptive learning environment into popular LMSs.

Desktop-based adaptivity mostly focuses on considering learners' characteristics such as prior knowledge, interests, learning styles, cognitive abilities, and affective states, and aims at fitting courses to those learner characteristics. In most cases, when using a desktop computer, the context and environment in which one learns is assumed to be constant and therefore, not much research has been done on adapting to different contexts and environments for desktop-based learning. However, in a mobile/pervasive/ubiquitous setting, the context and environment change frequently and become an important aspect to consider for providing learners with content and activities that are tailored to their current situation.

Mobile, pervasive and ubiquitous learning environments overcome the restrictions of classroom or workplace-restricted learning and extend e-learning by bringing the concepts of anytime and anywhere to reality, aiming at providing people with better educational experience in their daily living environments. The use of devices such as mobile phones and tablets allows new opportunities for learners by being intensely connected. Therefore, educational content can be accessed and interaction can take place whenever learners need it, in different areas of life, regardless of space and time.

Adaptivity based on the learners' context and environment can play a major role in such mobile, pervasive and ubiquitous settings since learning can take place differently in different situations and different support is required from the learning system depending on the respective situation and context. In contrast to desktop-based learning, many mobile devices have a variety of sensors embedded that can be used for rich context modeling, providing an adaptive system with accurate information about a learners' current situation. Furthermore, such sensors can contribute to the identification of learners' characteristics such as their affective states. Such rich information supports the adaptation process and can enable a system to provide learners with the right support at the right time.

Conclusions

Adaptive technologies have high potential in drastically improving instruction (Woolf et al., 2010) and much research has focused on designing adaptive learning systems, including the development of mechanisms for providing adaptive courses, learning materials and activities as well as approaches for identifying learners' characteristics, situations and needs. However, at present, adaptive learning systems are mainly used as research prototypes rather than in large-scale educational environments.

Therefore, one of the main open issues with respect to adaptive technologies is to bring these technologies into the classroom and to the learners. There are different ways of achieving this goal, including the development of add-ons and services that can be integrated into existing and commonly used learning systems such as LMSs. However, the focus here should be to combine the advantages of both adaptive technologies and LMSs and to create systems that have rich support for teachers and at the same time are able to tailor education to learners' characteristics and needs. This will require adaptive technology researchers and developers to focus not only on learners but also on making these systems easy to use by teachers and administrators. Furthermore, very little research has been done on using adaptive technologies for supporting teachers in their daily tasks of helping learners. This can include providing teachers with useful information about the learning processes of their students, alerting teachers if and when the system identifies that a student seems to have problems in learning, and so on. Furthermore, a system can make teachers more aware of how students use an adaptive system and what benefits it brings to their students.

Another open issue in the area of adaptive technologies deals with enriching adaptivity by combining different information about students' characteristics and context, and considering these different types of information when providing adaptivity. Open questions related to the combination of characteristics and context information include whether and how characteristics and context influence/compensate each other and how such effects influence the provision of adaptivity in the system. Another open question in this context deals with the selection of characteristics/contexts that should be considered when providing personalized courses and whether these characteristics/contexts should be the same for all learners or might vary for each learner or in different situations. Furthermore, another open question deals with the interdependencies between different characteristics and contexts for student modeling and context modeling, whether relationships exist between different characteristics/contexts, and whether they can help in improving the student modeling and/or context modeling process.

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Open Educational Resources: A Review of the Literature

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David Wiley, T.J. Bliss, and Mary McEwen

Abstract

This chapter begins by reviewing the many definitions of the term open educational resources and concludes by discussing challenges and opportunities for the approach. Open educational resources (OER) are educational materials either licensed under an open copyright license or in the public domain. Neither the term "open educational resources" nor the term "open" itself has an agreed upon definition in the literature. Research regarding open educational resources focuses on methods of producing OER, methods of sharing OER, and the benefits of OER. Significant issues relating to OER remain unresolved, including business model and discovery problems.

Keywords

Open educational resources • Reuse • Remix • Affordability

Defining Open Educational Resources

While a large number of competing definitions of the term "open educational resources" exist, with each focusing on different nuances of the copyright permissions structure or the different motivations for sharing open educational resources, a review of these definitions reveals a common baseline understanding. Educational materials which use a Creative Commons license or which exist in the public domain and are free of copyright restrictions are open educational resources. A rich collection of work and writing underlie this common understanding.

As an emerging construct, a significant amount of the existing literature is dedicated to defining the term open educational resources and clarifying the motivations underlying this body of work (Atkins, Brown, & Hammond, 2007; Baraniuk & Burrus, 2008; Brown & Adler, 2008; Geser, 2007; Gurell & Wiley, 2008; Hylén, 2006; OECD, 2007; Plotkin, 2010). Mike Smith, Director of the Hewlett Foundation Education Program which provided much of the early funding for work in the area of open educational resources, wrote, "At the heart of the open educational resources movement is the simple and powerful idea that the world's knowledge is a public good and that technology in general and the World Wide Web in particular provide an extraordinary opportunity for everyone to share, use, and reuse that knowledge" (Smith & Casserly, 2006, p. 10).

Writing in 1975, MacKenzie, Postgate, and Scupham said, "Open Learning is an imprecise phrase to which a range of meanings can be, and is, attached. It eludes definition. But as an inscription to be carried in procession on a banner, gathering adherents and enthusiasts, it has great potential" (p. 15). Rumble (1989) added, "Nearly 15 years later, one has to ask oneself whether there is a greater degree of clarity" (p. 29). In fact, the situation with regard to this word "open" is largely unchanged almost 40 years later.

The most frequently used definition of "open educational resources" comes from the report of the meeting where the term was first coined. In 2002, UNESCO convened the Forum on the Impact of Open Courseware for Higher Education in Developing Countries. It was in this Forum

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where Saul Fisher from the Andrew W. Mellon Foundation recommended the that the group adopt the phrase "open educational resources" to describe the new model of sharing educational materials that had brought the group together. The group agreed and offered the following definition:

> The open provision of educational resources, enabled by information and communication technologies, for consultation, use and adaptation by a community of users for non-commercial purposes (UNESCO, 2002, p. 24).

Forum participants set an idealistic goal for the idea of open educational resources later in this same document, inadvertently providing a second definition for the term: "a universal educational resource available for the whole of humanity" (UNESCO, 2002, p. 28). Since 2002, many other definitions have been offered. While none can be considered authoritative, a review of the definitions provides a more nuanced understanding of the term's meaning.

Defining the Term "Open"

Rather than try to define the entire term open educational resources, some researchers split the term up in order to define its components separately. Hylén (2006) problematized each of the three concepts in the name, questioning what is meant by "open," "educational," and "resources," as did Mulder (2007) and OECD (2007).

Wiley (2010) assumed common understanding of the term educational resources, and argued that open is a matter of (1) cost and (2) copyright licensing and related permissions. For Wiley, open means that a resource is available free of cost and that four permissions (called the "4Rs") are also made available free of cost. These permissions include:

- Reuse: the right to reuse the content in its unaltered/verbatim form (e.g., make a backup copy of the content).
- Revise: the right to adapt, adjust, modify, or alter the content itself (e.g., translate the content into another language).
- Remix: the right to combine the original or revised content with other content to create something new (e.g., incorporate the content into a mashup).
- Redistribute: the right to share copies of the original content, the revisions, or the remixes with others (e.g., give a copy of the content to a friend).

Wenk (2010) repeated the definition put forth by FreedomDefined.org in defining openness:

- The freedom to use the work and enjoy the benefits of using it.
- The freedom to study the work and to apply knowledge acquired from it.
- The freedom to make and redistribute copies, in whole or in part, of the information or expression.
- The freedom to make changes and improvements, and to distribute derivative works (p. 435).

Both the 4Rs framework established by Wiley and the "Freedom Defined" framework promoted by Wenk focus on granting permissions regulated by copyright. This is the reason many definitions of open educational resources include open licenses as a critical component. For example, Patricia, del Rocio, and Elizabeth (2010) defined OER as "resources that provide educational content with an open license that facilitates their use, adaptation and modification."

Tuomi (2006) took another approach to defining openness, though one still focused on permissions. Tuomi described OER as "sources of services" that:

(a) Provide nondiscriminatory access to information and knowledge about the resource (level I openness).
(b) The services of which can be enjoyed by anyone with sufficient nondiscriminatory capabilities (level II openness).
(c) Can be contributed to (level III openness) (p. 34).

Because definitions of OER place such an emphasis on copyright permissions and licensing, a basic understanding of the most commonly used open licenses, the Creative Commons licenses, is critical to understanding what OER are.

Creative Commons Licenses

In practice, an open educational resource is any educational material that uses a Creative Commons license or resides in the public domain (i.e., outside of copyright regulation). The Educause (2010) report, *7 things you should know about open educational resources*, stated that "such materials are generally released under a Creative Commons or similar license that supports open or nearly open use of the content."

The Creative Commons licenses comprise several components that can be mixed in a number of ways. The "Attribution" component (BY for short) requires individuals and organizations that use the openly licensed material to give credit to the original creator of the material. The "ShareAlike" component (SA for short) requires any revised or adapted versions of the material to be licensed under exactly the same Creative Commons license as the original material. The "Noncommercial" (NC for short) component prohibits individuals and organizations from using the material for commercial purposes. These components can be mixed in a number of ways to make different licenses. The most popular licenses for OER include the BY license, the BY-SA license, and the BY-NC-SA license. Creative Commons also provides a "No Derivatives" component (ND for short) which prohibits individuals or organizations from making any changes to materials, but because revise and remix are critical components of all definitions of OER, the ND clause and licenses containing it are not used by the OER community and excluded from the discussion below. A detailed legal overview of the Creative Commons licenses is provided by de Rosnay (2010).

The Creative Commons licenses (Lessig, 2003) used for OER guarantee that (1) users will enjoy no-cost (free) access to the materials and that (2) users have permission to engage in the 4R activities. The Creative Commons license guarantees both *in perpetuity* (see Section 3, “License Grant,” in any Creative Commons license). In theory, educational materials using other, similarly architected open licenses can be considered OER, but the overwhelming majority of openly licensed material in the world uses the Creative Commons licenses—over 400 million resources as of 2010 (*Creative Commons Corporation*, 2011). By comparison, a Google search for the two licenses most commonly used before Creative Commons reveals almost no modern usage—the Open Publication License and GNU Free Documentation License combine for fewer than 5,000 inbound links.

OER Definitions Operationalized in Policy

As the requirement to produce and use OER becomes common in grant policies and programs, a bright line definition of OER becomes necessary for compliance and reporting purposes. The Washington State Board of Community and Technical Colleges’ (2010) policy on Open Licensing on Competitive Grants states that all “digital software, educational resources and knowledge produced through competitive grants, offered through and/or managed by the SBCTC, will carry a Creative Commons Attribution License” (p. 4).

At the federal level, the 2010 Trade Adjustment Assistance Community College and Career Training Grant Program (TAACCCT) committed $2 billion in federal grant funding over four years to “expand and improve their ability to deliver education and career training programs” (p. 1). The intellectual property section of the grant program description requires that all educational materials created with grant funding be licensed under a Creative Commons BY license.

Summary of OER Definitions

Educational materials which use a Creative Commons license or which exist in the public domain and are free of copyright (thus providing permission for users to engage in the 4R activities) are open educational resources. Consequently, OER is an overarching term that encompasses open textbooks, opencourseware, and other designations. Open textbooks are simply OER organized as a textbook. Likewise, opencourseware are simply OER organized as online courses.

Major Categories of OER Research

OER research clusters into four categories: models of sharing OER, models of producing OER, the benefits associated with OER, and the challenges associated with OER. Research in each of these categories is reviewed below.

Different Models of Sharing OER

Open educational resources can be structured and shared in a number of different ways, including being shared as individual OER, being compiled and shared as open textbooks, and compiled and shared as open courseware.

First, like the learning objects that came before them, open educational resources can be tagged with metadata and stored individually in databases or repositories for later discovery and reuse as individual components. Sites such as OER Commons (http://oercommons.org) and MERLOT (http://merlot.org) take this approach to sharing OER.

Second, open educational resources can also be created or located and then aggregated into more familiar structures like textbooks before distribution. These collections are called “open textbooks.” Flat World Knowledge (http://flatworldknowledge.com/) and CK12 (http://ck12.org) publish Creative Commons licensed textbooks that can be broken down into individual OER for revising and remixing. Connexions (http://cnx.org/) is a Wikipedia-like site that allows users to create individual modules and compile these with modules created by other users to make textbooks (using a “one module equals one chapter” model). PediaPress (http://pediapress.com/) allows users to aggregate Wikipedia articles into printable books as well, where each Wikipedia article appears as an individual chapter in the printed book.

Third, open educational resources can be created or located and then aggregated into familiar structures like courses before distribution. These collections are called “open courseware” (OCW). This is the model pioneered by MIT OCW (http://ocw.mit.edu/) which created new OER and organized these as courses. This model has since been adopted by the over 200 member institutions of the OpenCourseWare Consortium (http://ocwconsortium.org/, Abelson, 2008).

Aggregating individual open educational resources into larger, familiar looking clusters can be key to enabling their reuse, especially among faculty with lower levels of comfort with technology. Open textbooks, for example, have seen adoption at several levels of formal education (Petrides, Jimes, Middleton-Detzner, Walling, & Weiss, 2010). There are successful open textbook initiatives at the high school level in the US (Wiley, 2011) and South Africa (Petrides &

Jimes, 2008), at the community college level (Petrides et al., 2010), and the university level (Hilton & Wiley, 2011).

Different Models of Producing OER

Two primary models for producing open educational resources emerged during 2001. These are the institutional production model (e.g., models used by MIT OCW) and the commons-based peer production model (e.g., the model used by Wikipedia).

The institutional production model of creating open educational resources involves converting or transforming materials used to teach formal classes (either face-to-face or online) into a format appropriate for open sharing. Experts with traditional academic credentials create these materials.

Lane (2006, p. 12) describes three variations on the institutional production model: the "integrity model," where the OER are very similar to the original material and as complete as possible; the "essence model" where the source material is cut back to the essential features before publication as OER; and the "remix model" where source material is used as a starting point for OER that are designed specifically for Web based delivery.

While proponents value the expert authorship of institutionally produced OER, critics claim that the model is unsustainably expensive. MIT OCW reports that the original cost to openly publish a course ranges from $10,000–$15,000 for courses without video to $20,000–$30,000 per course for which video was published (MIT OCW, 2011a). MIT OCW (2011b) now reports a current average cost of about $8,225 per course for ongoing maintenance-oriented activities.

Johansen and Wiley (2010) report the costs of running other institutionally based OER programs: approximately $5,000 per course for Utah State University's OCW, about $34,000 per course for the Open University of the Netherlands' OCW, about $6,000 for the Open University of the UK's OpenLearn program, and about $250 per course for Brigham Young University Independent Study's OCW program. Contextual factors including how much content is published and what format the content was originally produced in contribute to the wide variation in costs to publish institutionally created OER.

Commons-Based Peer Production

Benkler (2002) describes a new method of creating products, including educational resources, which he calls commons-based peer-production, in which "groups of individuals successfully collaborate on large-scale projects following a diverse cluster of motivational drives and social signals, rather than either market prices or managerial commands" (n.p). Benkler is describing large-scale projects like Wikipedia whose contributors are volunteers that are not motivated by financial interests or employment requirements.

Benkler (2007) later explained that this new means of production is "radically decentralized, collaborative, and nonproprietary," meaning that an undertaking like Wikipedia has no central coordinator who assigns tasks or tracks their completion and that the results of the group's work are made available to the public under an open license (p. 60). A variety of open educational resources are created and improved using this model. The creation and ongoing improvement of encyclopedia articles in Wikipedia operate on this principle. Benkler (2005) discusses the Wikipedia example at length. The creation and ongoing improvement of open educational resources in the Connexions repository, which is much like Wikipedia, operate on these principles as well (Baraniuk & Burrus, 2008).

Institutional production and commons-based peer production fall at opposite ends of a spectrum. On one end, open educational resources are created and vetted by a highly respected institution like MIT, Stanford, or Yale and published with the institution's imprimatur. On the other end, open educational resources are created and vetted by a decentralized group of individuals who may or may not be credentialed or formally qualified to participate in their creation and vetting and are published under the brand of a Web site like Wikipedia or Connexions. Several hybrid models exist between the polar institutional and commons-based models. For example, Burgos and Ramirez (2011) describe a model encouraging students to share their homework as OER, which might then be used by other students.

Benefits of OER

Education institutions have mixed incentives for engaging in open educational resources initiatives (Smith, 2009). Some of these incentives are mission-aligned. Hylén (2006) and D'Antoni (2009) provide good overviews of these mission-aligned motivations for producing and sharing OER, including the public outreach mission of publicly funded universities to educate the entire public whose funding supports their operation.

There are several self-interested reasons institutions, and faculty choose to create and share open educational resources that may or may not articulate clearly with the mission of the institution. The majority of the benefit claims in the literature fall into this category. For example, Caudill (2011) claims that access to OER makes the course development process quicker and easier—a claim that is echoed elsewhere (e.g., Hylén, 2006). Describing the Open University of the UK context, Hodgkinson-Williams (2010) notes the significant international attention, improved public relations, improved relationships with strategic partners, and improved internal publishing and production capabilities that come from well-publicized OER projects. Steve Carson (2006) describes these same benefits in the MIT OpenCourseWare context, while also demonstrating that MIT OCW positively influences freshmen decisions to attend MIT.

Explain from an economic perspective how "hybrid message and product (brand) placement concepts could be applied to open education resources by HEI [higher education institution] brands and be used to justify investment by HEIs in OER development on marketing grounds" (p. 8). They go on to demonstrate an applied instance of this concept, showing that distance learning programs can actually increase revenue using OER as a marketing channel. This particular form of cost recovery for OER programs has been the subject of a growing amount of research, as reported by Johansen and Wiley (2010). Almost 2 % of Open University of the UK enrollments over a 2-year period came from OCW users who became paying university students. The Open University of the Netherlands reported 18 % of users of its OCW site were "inspired to purchase an academic course." The University of California-Irvine (UCI) also reported that their OCW site consistently generates more sales leads for their online courses than any other form of advertising. After reviewing this literature, Johansen and Wiley (2010) demonstrate in financial detail an empirically validated model for increasing distance education enrollments using open educational resources—enough revenue to more than pay for the cost of the open sharing efforts.

The financial benefits that accrue to students who use open educational resources has been the subject of study as well. Hilton and Wiley (2011) received full access to the sales records of Flat World Knowledge, a commercial publisher of open textbooks. These textbooks are both available to be read online for free under a Creative Commons BY-NC-SA license and are available for purchase in print, audio, and other formats. After reviewing the sales database, Hilton and Wiley report that about 30 % of students whose faculty formally adopted a Flat World Knowledge textbook purchased a printed copy of a Flat World textbook, while about 20 % purchased a digital product through the company's Web store. With approximately 50 % of students opting to read the assigned texts online for free and not purchase anything, and the average purchase amount for the other 50 % being around $30, Hilton and Wiley report that students clearly save a significant amount of money under this model compared to the typical $150 college textbook.

Challenges for OER

In addition to ongoing research in sharing models, production models, and the benefits of OER, a number of unresolved issues remain open for future researchers to tackle. These include making OER easier for people to find (the discovery problem), making OER programs financially self-sustaining (the sustainability problem), dealing with the pervasive perception that, because they are free, OER are necessarily of inferior quality (the quality problem), improving our understanding of how to make OER more useful in a wide range of contexts (the localization problem), and understanding why people do not exercise their revise and remix permissions in OER (the remix problem). These five difficulties structure the discussion of research challenges that follows.

The Discovery Problem

Like the learning objects that came before them, OER can be difficult to find. Learning objects researchers undertook a significant amount of technical work on metadata and other standards and specifications in order to make learning objects easier to find (e.g., the IEEE Learning Objects Metadata standard). OER researchers build on top of this work with efforts like the Learning Resource Metadata Initiative (LRMI, 2011) which maps IEEE Learning Objects Metadata and Dublin Core fields focusing on licensing information and educational outcomes (like the Common Core standards for US K-12) into the Schema.org metadata framework to be used by major search engines like Bing, Google, and Yahoo. Being enabled to search the Internet by license and learning outcome would be a significant step forward for making OER easier to find.

Researchers try to make OER easier to find by implementing both conventional and advanced discovery solutions. Traditional approaches like referatories, sites that index and provide links to OER across the Web (e.g., http://oercommons.org or http://ocwfinder.org), are quite common. Minguillón and Rodríguez (2010) show how conventional social networking features, like tagging, rating, and commenting, can be integrated into open educational resources collections in order to make finding OER easier.

More advanced services, like recommender systems, have also been created to help user find the "right" open educational resources. Duffin and Muramatsu (2008) describe an OER recommender service that provides content-based recommendations along the lines of "if you like this OER, you might also like that OER." Kalz, Drachsler, van Bruggen, and Hummel (2008) describe another OER recommender service created in the context of the EU TENCompetence program.

Despite ongoing research in the area of discovery, finding the right OER remains a challenging task (Kalz et al., 2008) that needs significant additional effort from researchers.

The Sustainability Problem

Numerous articles have been dedicated to the topic of the sustainability of open educational resource programs, attempting to answer the question "how does one continue to fund, on an ongoing basis, a program whose goal is to give things away for free?" Dholakia, King, and Baraniuk (2006), Downes (2007), Koohang and Harman (2007), Wiley (2006a) have all written at length on the topic, each proposing overlapping taxonomies of sustainability or business models such as the public radio model (voluntary user contributions) and the "give away the razor, sell the blade" model.

The concern with sustainability is well grounded. For example, after the US economy entered a recession in the late 2000s, at least one major opencourseware initiative was forced to close (Parry, 2009). Pegler (2010) writes, "evidence of sustainability, or the potential to achieve this, is increasingly a pre-requisite for engaging in OER activity, whether imposed by funders, by institutions requiring a 'business case', or practitioners themselves" (p. 2).

Some of the business model-related writing about OER has been conceptual, lacking specific financial data (e.g., Pegler, 2010). Dholakia et al. (2006) argue that "unless the OEP site is able to *first* gain and maintain a critical mass of active, engaged users, and provide substantial and differentiated value to them in its start-up and growth phases, then none of the available and/or chosen revenue models will be likely to work for the OEP in the long run." In other words, if a site cannot engage and keep users, there is no need to worry about sustaining it in the long term.

Other research has focused more on the finances of OER, exploring specific impacts on institutional revenue. For example, Hilton and Wiley (2011) describe the income and costs associated with operating the for-profit publisher Flat World Knowledge in detail, examining the potential sustainability of the venture. Helsdingen, Janssen, and Schuwer (2010) also provide specific financial detail about the cost and impact of an opencourseware initiative on an online course provider, as do Johansen and Wiley (2010). These authors identify promising models that appear to work at relatively small scale and in a single context. Many more scaling up and verifying iterations of this work need to be conducted before the field can claim to have robust knowledge in the area of sustaining OER initiatives.

The Quality Problem

There are two aspects to the quality problem faced by OER researchers. The first is related to the common saying "you get what you pay for." Although the no significant difference phenomenon evident in media comparison studies is well documented (e.g., http://www.nosignificantdifference.org/), proponents of OER sometimes struggle to demonstrate that these freely available materials can be of equal or greater instructional effectiveness when compared to more expensive alternatives. The discovery problem relates to the quality problem. One can easily find 2,840,000 OER in Google relating to "biology," but which of these are high quality? When it is difficult to find high quality OER, it is difficult to argue persuasively that they exist.

Computational approaches to automatically assessing the quality of resources have shown promise (e.g., Bethard, Wetzer, Butcher, Martin, & Sumner, 2009; Custard & Sumner, 2005), though these techniques necessarily work only for a very specific operationalization of the construct "quality." Other sites allow users to assign a 1–5 star rating to OER in order to signal the quality of materials to future searchers (e.g., http://merlot.org/). Whether the quality of an open educational resource is assessed by a human or machine, one-size-fits-all quality ratings fail to recognize that quality is not a property of an open educational resource alone. The quality of an open educational resource is a joint property of a resource-and-user, the way that item difficulty and learner ability are linked in item response theory (Kelty, Burrus, & Baraniuk, 2008). An OER that is very high quality for an English-speaking community college student may be poor quality for a German-speaking university student.

The Localization Problem

Localization is one of the most important and least understood aspects of open educational resources. Once a user succeeds in finding appropriate resources, those resources likely need to be adapted before they are used. Lane (2006) defines localization as "re-contextualisation of content for the particular situation in which it is experienced by the learner" (p. 16). Smith (2009) describes how "the act of modifying an OER to meet language, cultural, or readiness requirements increases useful access and may be a creative learning endeavor" increases the usefulness of OER (p. 89). However, while one of the primary goals of openly licensing materials is to enable any future users to refactor the materials to meet their needs, this does not guarantee that eventual reusers will be sufficiently competent in the technical or pedagogical skills necessary to make needed changes. The possibility of changing open educational resources so that they function worse for the intended users is always present. Ivins (2011) examines the Nepalese context to determine the factors most salient to the process of localizing open educational resources in the developing world, concluding that "only a local can localize." Westerners simply do not possess the religious, cultural, and other local knowledge necessary to customize open educational resources for optimal use in Nepal. Building local capacity to engage in what are essentially user-design activities is necessary before OER can provide meaningful educational opportunities for the Nepalese.

The Remix Problem

While authors and creators go to great lengths to correctly license open educational resources, there is little empirical evidence that people actually exercise the additional 4R permissions granted by the Creative Commons licenses. Lane and McAndrew (2010) list several types of reuse—as-is reuse, technical adaptations, linguistic adaptations, cultural adaptations, pedagogical adaptations, and annotation as a form of reuse, but concludes, "the idealised cycle of adoption, reworking and recontribution has only had limited success" (p. 8).

Duncan (2009) found that, in the entire collection of over 5,000 modules in the Connexions OER repository, only 15 had been used, translated, or modified more than five times. Examining the same collection, Petrides, Nguyen, Jimes, and Karaglani (2008) also found that significant modification or revision of materials created by others happened very rarely. The Connexions repository may be a best-case research context because the site provides users with tools for revising and remixing OER inside the system, where data can be collected and analyzed.

Reuse can be extremely difficult because pedagogical and other design assumptions are rarely visible. Conole, McAndrew, and Dimitriadis (2010) describe tools that encourage people to separate their designs or pedagogical patterns from specific educational artifacts and upload these designs to a repository for examination and reuse. However, this approach has yet to yield significant uptake by users.

Future Directions for Open Educational Resources

Open educational resources research will likely continue in the areas identified above. However, open educational resources are also influencing neighboring areas of educational research and these crossover efforts are likely to play an important role in future research. Two areas that merit particular attention include open education policy and open assessment.

A number of nations and states have formally adopted or announced policies relating to the adoption of OER and open textbooks. The Open Policy Registry (http://oerpolicies.org/) lists several dozen national, state, province, and institutional policies relating to OER, including policies like a national open licensing framework and a policy explicitly permitting public school teachers to share materials they create in the course of their employment under a Creative Commons license. The overwhelming majority of these policies were implemented in 2009 or after. During June 2012, UNESCO convened a World Open Educational Resources Congress and released a 2012 Paris OER Declaration "calling on Governments to support the development and use of OERs" (UNESCO, 2012). The creation, adoption, and impact of OER policies will warrant ongoing research.

Surprisingly little work has been done in the area of open assessment. As of early 2012, there does not appear to be a single initiative dedicated to creating and sharing openly licensed assessment items in standard formats (like the IMS Question and Test Interoperability format) for use with existing open educational resources. However, if open educational resources are ever to reach their potential, they will need to be paired with open assessment resources that can serve formative and summative assessment roles for learners. This should be an area of intensifying activity and research over the next decade.

Conclusion

While the idea of open educational resources is relatively young, a vibrant literature is growing up around the concept. While no single definition is universally accepted, the literature reveals a broad consensus regarding the central features characterizing an open educational resource. A small but growing body of evidence is substantiating claims made by proponents of OER, but many obstacles remain to be overcome if this latest educational technology is to fulfill its potential.

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Enhancing Learning with Visualization Techniques

64

Joris Klerkx, Katrien Verbert, and Erik Duval

Abstract

The use of visualization techniques in learning is not new. They have been used in maps and drawings for thousands of years. This chapter analyzes how more novel visualization techniques can be used to enhance various activities during the learning process: finding and understanding educational resources, collaboration with learners and teachers, (self-) reflecting about learners' progress, and designing learning experiences. We illustrate our analysis with example tools and visualizations. Results of our analysis indicate that visualization techniques are beginning to be more widely used for learning but further research is needed to assess the added value of these visual approaches in terms of effectiveness, efficiency or other criteria that pertain to learning.

Keywords

Information visualization • Collaborative learning • Learning analytics • Learning design

Introduction

The use of visualization to present information is not new. Visualization has been used in maps and drawings for thousands of years. One famous example is Ptolemy's world map that was created at some point in the second century BC (see Fig. 64.1). Today, the field of visualization has become quite a bit more diverse, with applications in areas such as scientific visualization (Shneiderman & Bederson, 2003), knowledge visualization (Burkhard & Meier, 2005) and visual analytics (Keim et al., 2008).

Information visualization research is focused on enabling users to control the process of flexibly navigating through information spaces of abstract data, for which there may be no inherent mapping to space or a natural physical reality (Card, Mackinlay, & Shneiderman, 1999). Existing visualization techniques cover a wide spectrum of application domains. An increasing number of artists and designers have applied these techniques as a powerful and even artistic means of expression (Vande Moere & Purchase, 2011).

This chapter investigates how such visualization techniques are currently being used to support learning. We structure the chapter around five basic activities in the learning process:

- *Find*—How can visualization add value when learners or teachers are searching for relevant learning material about a certain topic?
- *Understand*—How can visualization facilitate better understanding of the subject matter of learning material?
- *Collaborate*—How can visualization support collaboration among learners? How can visualization support collaboration between learners and their teachers?
- *(Self-)Reflect*—How can visualization help learners reflect on how they are doing in a running course when compared with other learners? How can it help teachers gain insight into achieving desired learning outcomes?
- *Design*—How can visualization facilitate the design of learning experiences?

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Fig. 64.1 Reconstituted Ptolemy's world map—the British Library Harley MS 7182, _ 58v-59

This chapter begins with a background section, aimed at providing the reader with relevant pointers to the basic literature on information visualization techniques. The following sections then discuss the context and meaning, and the current use of visualization techniques for supporting each of the activities described above. Future directions for this area of inquiry and promising research opportunities are discussed in the concluding section.

Background: Information Visualization

Nowadays, there is an abundance of available data and information on the Web. However, it is only when this data is understood that it becomes valuable, not when it is just made available (Few, 2009). Information visualization is a powerful means of making sense of this data (Heer & Shneiderman, 2012) that has emerged from research in human–computer interaction, computer science, graphics, visual design, psychology, and quantitative data analysis. It is a growing field that is increasingly applied as a critical component in scientific research, digital libraries, data mining, financial data analysis, market studies, manufacturing production control, and drug discovery (Shneiderman & Bederson, 2003). The aim of this section is to assist the reader who is new to the field of information visualization to become aware its foundational literature.

The main intent of information visualization is to represent an abstract information space in a dynamic way, so as to facilitate human interaction for exploration and understanding. It relies on the design of effective and efficient—as well as sometimes playful and aesthetically pleasing—interactive visual representations that users can manipulate for open-ended exploration or to solve specific tasks. This approach is especially useful when a person does not know what questions to ask about the data or when she wants to ask better, more meaningful questions (Fekete et al. 2008). Information visualization makes use of the principles in Gestalt Theory regarding the human visual capacity as a powerful pattern-finding engine, to provide a powerful means of making sense of the abundance of available data. For example, the principle of *spatial proximity* posits that humans instinctively group data points that are perceptually close together. Visual *connectedness* between data points in the form of an edge between two nodes provides an even stronger relationship. Ware (2004) provides a thorough explanation of other Gestalt principles such as similarity, continuity, symmetry, closure, and relative size.

In order to visualize a data set, one needs to create a visual representation or encoding of one or more of its data attributes or types. This involves mapping these attributes to visual features like shape, size, orientation, and the like (Ware, 2004). Several data type taxonomies have therefore been described in the literature that can be used as guidelines during the visual encoding process (see Adnan, Daud, & Noor, 2008; Chi, 2000; Ellis & Dix, 2007; Keim, 2002). For each data type, appropriate visualization techniques and tasks have been designed (Shneiderman, 1996). The following list presents them, together with original publications that describe the techniques in detail:

- For one-dimensional data: fisheye views (Furnas, 1999), sparklines or line charts (Willett, Heer, & Agrawala, 2007).
- For two-dimensional data: spatial displays such as dense pixel displays (Keim, 2000), heatmaps (Pryke, Mostaghim, & Nazemi, 2007), and the like.

- For three-dimensional data: architectural renderings or metaphoric worlds (Santos et al., 2000).
- For temporal data: timeline visualizations such as theme rivers (Nowell, Havre, Hetzler, & Whitney, 2002), clustered time series (Van Wijk & Van Seelow, 1999) or time matrices (Yi, Elmqvist, & Lee, 2010).
- For hierarchical data: stacked displays such as tree-maps (Shneiderman & Johnson, 1991), hyperbolic trees (Lamping & Rao, 1996), dendograms, cone and radial trees (Nussbaumer, 2005).
- For network data: node–link diagrams (Elmqvist & Fekete, 2010) with graph layout algorithms such as Reingold and Tilford, H-trees and Balloon graphs (Herman, Melancon, & Marshall, 2000).
- For multidimensional data: scatterplots, elastic lists (Stefaner, Urban, & Marc, 2008), parallel coordinates (Inselberg, 1985), data meadows (Elmqvist, Stasko, & Tsigas, 2008), and the like.

These taxonomies have been widely accepted and assist designers to choose appropriate visual representations for their data sets. However, these representations often require dynamic interactions to figure out what the data means. Hence, they have been mapped against interaction technique taxonomies that consider interactive filtering, zooming, distortion, linking, brushing, and the like, as well as task taxonomies for visualization interfaces such as overview, zooming, filtering, panning, details-on-demand, relating, history, extract, sort, comparing, and more (Few, 2009; Heer & Shneiderman, 2012; Keim, 2002). The purpose of these filtering techniques is to remove information that is irrelevant and therefore distracting from the task at hand (Few, 2009). In the following sections, we show how combinations of these techniques are used to support various activities in the learning process.

Finding Learning Material

High quality learning materials such as texts, graphical illustrations, interactive demonstrations, tutorials, and audio and video presentations are essential for students to fully grasp and understand the meaning of a certain topic. To locate these materials for their classes, teachers often turn to conventional Web search engines such as Google, Yahoo!, and others, or to so-called learning object repositories (LORs) such as GLOBE (www.globe-info.org), an international network that interconnects networks of LORs. Such repositories contain learning materials that were produced by professional publishers or fellow teachers. The main advantage of searching these LORs is that the materials are often described with useful educational metadata such as intended target audience, learning time, and the like, that can help the user quickly find the sought after material. Teachers—as well as students who want to find relevant material independently from their teachers—typically express their information need as simple or advanced queries by filling out electronic forms. These forms enable users to compose Boolean combinations of search criteria. However, queries typed into search boxes are often not effective enough to meet all the demands (Marchionini, 2006). Both Web search engines and LORs present a ranked list of results to the users. Teachers can evaluate the results in this list and, if necessary, reformulate the query to filter out some results or include some more. This process of formulating queries and evaluating the results can be lengthy and is rather time-consuming and user-unfriendly (Duval & Hodgins, 2003). The intersection of information visualization and search interfaces, where rich presentation of search results can enable exploration, insight, and understanding (Ahn & Brusilovsky, 2009; Morville, 2005), is therefore especially relevant to this section. We provide pointers to examples of visualization techniques that can be used to flexibly and efficiently get access to a collection of educational resources.

We found that visual designers frequently use the hierarchical classification of the subject of the educational resources. For example, the classification of a resource that explains the algorithm of the “Towers of Hanoi” (Buneman & Levy, 1980) could be:

- Exact, Natural and Engineering sciences
- Informatics/Information Processing
- Recursion

This hierarchical classification is then visualized in a so-called stacked display, which is tailored to present data partitioned in a hierarchical fashion (Keim, 2002). As such, these stacked displays provide a visual overview about the subjects or topics of the materials that are covered in such a collection. For example, Bouzeghoub et al. (2009) presented the classification overview as a Venn diagram, although earlier studies (such as Rivadeneira & Bederson, 2003) showed that without extra hierarchical cues, users quickly become disoriented in such a display. Klerkx, Duval, and Meire (2004) and Clarkson, Desai, and Foley (2009) have both used tree-map visualizations to present this hierarchical information. Figure 64.2 shows a combination of this kind of stacked display with a filtering mechanism that enables end users to manipulate several controls over the metadata and zoom in on potentially more relevant material while still having access to an overview of how additional search criteria will restrict the remaining number of learning objects. An evaluation of this prototype has been conducted to measure its effectiveness (correct results) and efficiency (fast results). Task time, task accuracy and user satisfaction were measured in an experiment where the visual prototype and a traditional tool for finding educational resources were compared. Results indicated that the visualization design helped users easily keep track of the number of matching results.

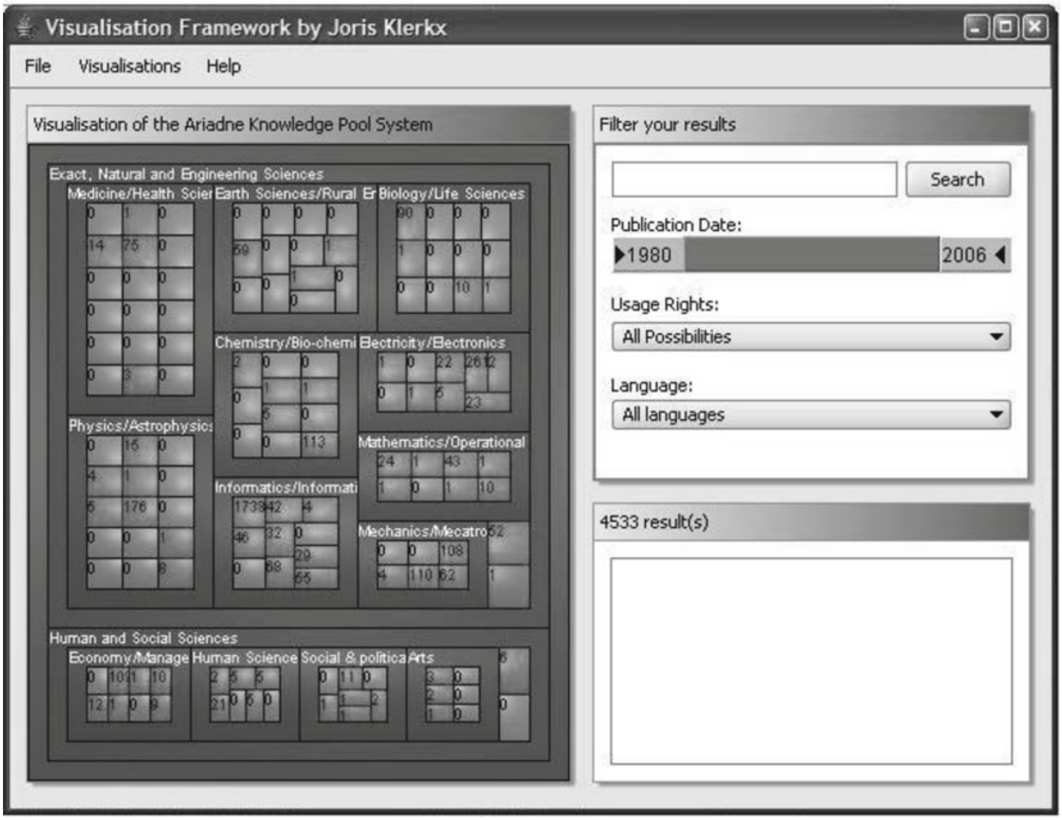

Fig. 64.2 Providing visual access to educational resources. On the *left side*, one can see an overview of the educational resources, classified by their topic description. Users can click on any of the groupings such as Medicine/Health Sciences to zoom in on its subcategories. The *numbers* in each *square* indicate the number of matching resources in a category, compared with controls of the filter mechanism on the *right* (adapted from Klerkx et al., 2004)

However, most users also needed time to get acquainted with navigating the tree-map visualization. Consequently, this prototype had a higher learning curve than a more traditional search tool. These results were confirmed in (Kobsa, 2004) and (Wang, Teoh, & Ma, 2006). From those evaluations, it can be concluded that the use of information visualization techniques is a useful alternative to more traditional ways of accessing learning object repositories. However, a number of recommendations were made in these studies to ensure that users know how to use the visualizations. For instance, adding navigational cues are important: if a user searches for "history," the resulting learning objects should be clearly highlighted in the visualization.

The applications presented in Sumner et al. (2005), Dicheva and Dichev (2006), Lee (2007) and Lalingkar and Ramani (2010) differ from the examples above, in that the applications do not provide visualizations of the metadata of the resources, but rather the resources' external ontologies—such as learning goals and subject domains. All of them created a graphical topic map browser for these ontologies. These are basically node–link graphs—discrete structures that consist of nodes or vertices at the one hand and links or edges at the other hand. Vertices correspond to the objects and the edges correspond to the relations between the objects. An example node–link graph can be seen in Fig. 64.6. In the applications above, teachers or students typically have to navigate these graphs and select those nodes that correspond with the subjects on which they are searching more information. Only when an interesting topic is selected, a query is issued to the repository of educational resources to see if there are potential matching resources. The drawback of this approach is that the user does not receive continuous feedback about how many resources still satisfy his criteria: the result is that users may lose time further refining criteria when the issued query does not return relevant resources in the result set, or, conversely, may consider the refinement process finished when still too many resources are included in the result.

Discussion

The examples that have been presented above show how visualization can help teachers and students to find relevant material when they are searching for instructional materials. Lab tests with small numbers of users indicate that the techniques make the process of finding resources more efficient. However, to our knowledge, no extensive user tests in real-life settings were executed to measure the success or impact of these tools. Also in other domains, attempts to use information visualization to improve search has not yet proven itself. However, as Hearst (2009) argued, "This is not to say that advanced visual representations cannot help improve search; rather that there are few proved successful ideas today" (Ch. 10, "http://searchuserinterfaces.com/book/").

Understanding Subject Matter

Once a relevant educational resource has been located, it is essential that it actually helps learners to grasp or understand its subject matter. The aim of this section is to present a number of successful case studies that use visualization techniques for provoking understanding of their meaning.

Mendeleev's periodic table of elements, which encodes several types of data in a small table format, is probably one of the most famous examples of visualization used in educational contexts (see Fig. 64.3).

This visualization is informative, efficient and can be considered one of the earlier beautiful visualizations of complex chemistry data (Steele & Iliinsky, 2010). Mendeleev's periodic table visualization is known by millions of students all over the world and is a perfect example how visualization can be effectively used to support understanding of subject matter.

There are many successful examples of this kind in education. Studies have also demonstrated the effectiveness of these visualizations. For example, in computer science education, there is a long history of data and algorithm

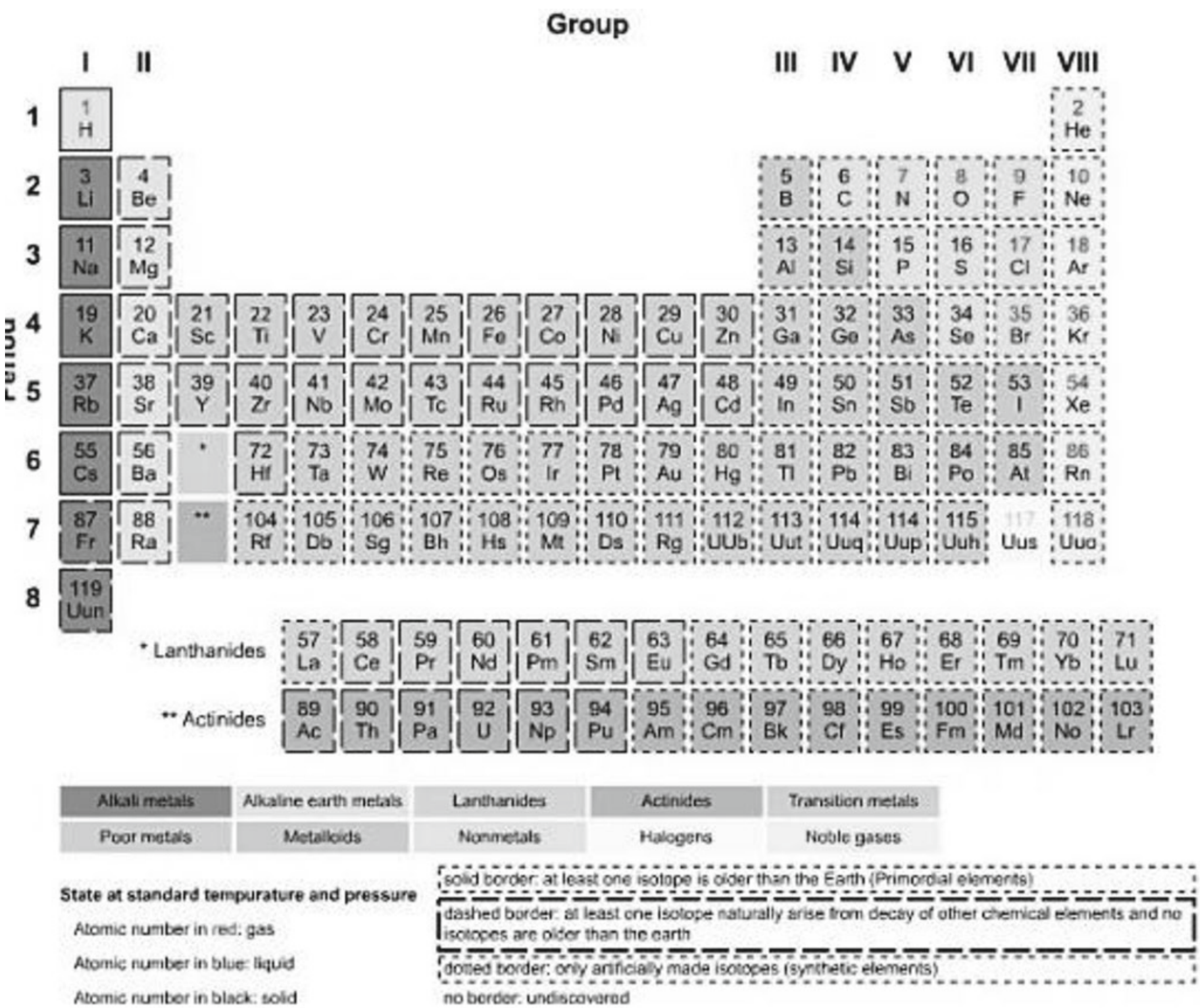

Fig. 64.3 Mendeleev's periodic table of elements (from Steele & Iliinsky, 2010)

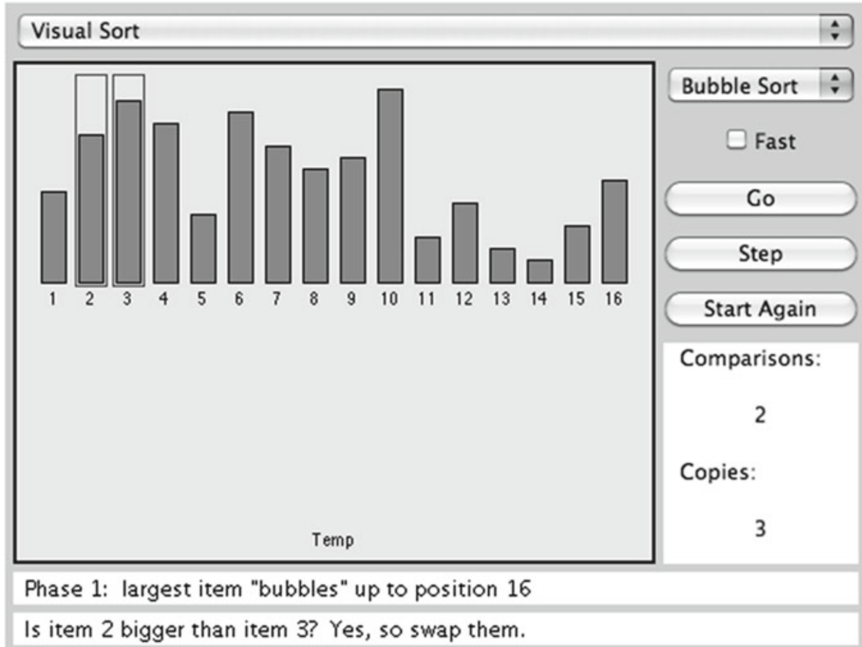

Fig. 64.4 Providing understanding of the inner-workings of the bubble sort algorithm (Eck, 1995)

visualizations and animations (Shaffer, Cooper, & Edwards, 2007). The AlgoViz wiki lists 513 different interactive visualizations that help to explain several kinds of programming algorithms, such as sort, graph, compress, and many more (http://wiki.algoviz.org/AlgovizWiki/Catalog). These kind of interactive visualizations are often used to explain different aspects of software algorithms to students. For example, Fig. 64.4 shows an interactive java applet that visually explains the bubble sort algorithm (Eck, 1995), which is often used to introduce the concept of a sorting algorithm to introductory computer science students. The algorithm works by iterating a list of numbers. Starting from the beginning of the list, it compares every pair of items, swaps them if needed, and moves on until the end of the list. Then the iteration starts over until the complete list is sorted. The interactive visualization in Fig. 64.4 allows students to learn this algorithm by stepping through this whole process while it compares, and potentially swaps adjacent bars.

Hundhausen, Douglas, and Stasko (2002) did a meta-analysis of 24 studies on algorithm visualization effectiveness. About half of these studies reported no significant effect of the visualization on the performance of students. About half however did report a positive, significant effect. One study reported a significant negative effect. The authors related the algorithm visualizations to four "theories of learning" (epistemic fidelity, dual-coding, individual differences and cognitive constructivism). Cognitive Constructivism proposes that learning is an active process where learners construct their knowledge through experience (Kanuka & Anderson, 1999). It has been the most tested of these theories, and algorithm visualization studies utilizing tools that are grounded in constructivist pedagogical approaches have obtained the greatest number and highest percentage of significant differences. As such, cognitive constructivism has gathered the most consistent empirical support in the studies they reviewed. The meta-analysis was inconclusive, however, on the question of whether algorithm visualizations mainly contribute to conceptual or procedural understanding of algorithms.

Visualizations also play an import role in other learning domains such as mathematics where they enable students to see the unseen in data. Arcavi (2003) argued:

> Visualization has a powerful complementary role for mathematics students in three aspects: as (a) support and illustration of essentially symbolic results, (b) a possible way of resolving conflict between (correct) symbolic solutions and (incorrect) intuitions, and (c) as a way to help us re-engage with and recover conceptual underpinnings which may be easily bypassed by formal solutions (p. 223).

It is hard to find any mathematics textbook that does not use visualization techniques for explaining mathematical concepts such as the Pythagorean theorem. Presmeg (2006) provided a thorough review of research on visualization in learning and teaching mathematics since 1980. She stipulated a list of 13 research questions that are of major significance for future research on visualization in mathematics education. She discovered that a neglected area of research is how visualization actually interacts with the didactics of mathematics. The author concluded:

> Effective pedagogy that can enhance the use and power of visualization in mathematics education (Woolner, 2004) is the most pressing research concern at this period: very few studies have addressed this topic (p. 234).

Discussion

The examples above indicate that teachers and learners should consider using visualization techniques in order to facilitate understanding. Naps et al. (2003) have thoroughly surveyed current practice by teachers in computer science. Out of 93 instructors, *all* agreed that visualizations have the potential to help students as they learn computing concepts. 90 % believed that visualizations make the teaching experience more enjoyable. 86 % had anecdotal evidence of an improved level of student participation. 76 % believed that visualization provides a powerful basis for discussing conceptual foundations. 72 % claimed anecdotal evidence and 52 % claimed objective evidence of improved student learning. However, the same instructors also claim that actually using visualization techniques is hindered because of the time required to search for good examples (93 %), the time it takes to learn new tools themselves (90 %), the time it takes to develop visualizations (90 %) or to adapt them to course content (79 %), and the lack of evidence of the effectiveness of visualizations (59 %). Even if those results cannot be directly generalized to other domains in education (Naps et al., 2003) strongly believes that the educational impact in classroom instruction can be augmented if instructors are induced to integrate visualization techniques in their classes. It seems reasonable to project similar expectations to augmentation of non-classroom situations, including informal learning. However, this hypothesis has to be validated in further research.

Collaborative Learning

Interactions with peer learners are a core aspect of how learning is organized. This is particularly relevant for Computer Supported Collaborative Learning (CSCL) where learning is not only a matter of accepting fixed facts, but it is the dynamic, on-going, and evolving result of complex interactions primarily taking place within communities of people (Stahl, Koschmann, & Suthers, 2006). Visualization of a social network can therefore be extremely useful to make people aware of their social context and to enable them to explore this context (Heer & boyd, 2005). In a CSCL setting, visualization can support learners in coordinating their actions—one potential advantage is that this can help to overcome the so-called over-scripting problem that often occurs in CSCL (Dillenbourg, Järvelä, & Fischer, 2009). A collaboration script is a set of instructions that describe how students should work together, form groups, and how they should collaborate to reach a common goal such as solving a prescribed problem. Over-scripting may interfere with the learning process by forcing students to interact in a unnatural ways (Dillenbourg, 2002). CSCL approaches to visualization vary from mirroring systems, which display basic actions to collaborators, metacognitive tools, which represent the state of interaction via a set of key indicators, and coaching systems, which offer advice based on an interpretation of those indicators (Soller & Jermann, 2005). Especially the first two aspects lend themselves well to visualization approaches, as we show in the examples below.

Kirschner, Simon, Buckingham, and Chad (2003) presented an overview of how *collaborative decision-making* through argument visualization can be supported through node–link diagrams where nodes are either arguments or statements and links between the nodes represent inferences between those. Figure 64.5 shows how DebateGraph is used to facilitate the debate on climate changes by visualizing different points of view to comprehend the topic at hand, in this case the environmental debates. Such visualization not only helps the decision-making process in climate change congresses, but it also provokes understanding of various opinions and provides insights how other learners construct their arguments. Users construct these diagrams themselves with such visualization tools. Braak, van den Oostendorp, van Prakken, and Vreeswijk (2006) did a critical review of Belvedere (Suthers, Weiner, Connelly, & Paolucci, 1995), Convince me (Schank & Ranney, 1995) Questmap (Carr, 2003) and Reason!Able (van Gelder, 2002). They investigated how those tools were evaluated in practice. All evaluations tried to measure the tools' ability to help learners become better reasoners and to improve the quality of their constructed arguments. The authors stated that, while the findings were not significant statistically, they did find a positive trend in this direction.

Closely related to collaborative decision-making is *collaborative concept mapping*; a well-know visualization technique providing an external representation of relationships between concepts relative to a particular topic. Molinari et al. (2008) did an experiment with 58 students to find out how they "refer to," "do something with" or "build upon" other students' contributions in the common concept map. Students were divided in groups of 2. The two students worked with a tool divided into three parts where they could see their own concept map, their partner's concept map, and a combined one. Results showed that it took much time and effort for the pairs to visually compare and coordinate their concept maps. Working with two maps instead of one combined concept map therefore seemed to provoke lower learning performance. We can learn from these results that not all visualization techniques provide an added value in each context. Where node–link diagrams work rather well in collaborative decision-making, they do not necessarily enhance collaborative concept mapping. Each specific context therefore needs thorough evaluation in real-life settings to assess added value of these visual approaches.

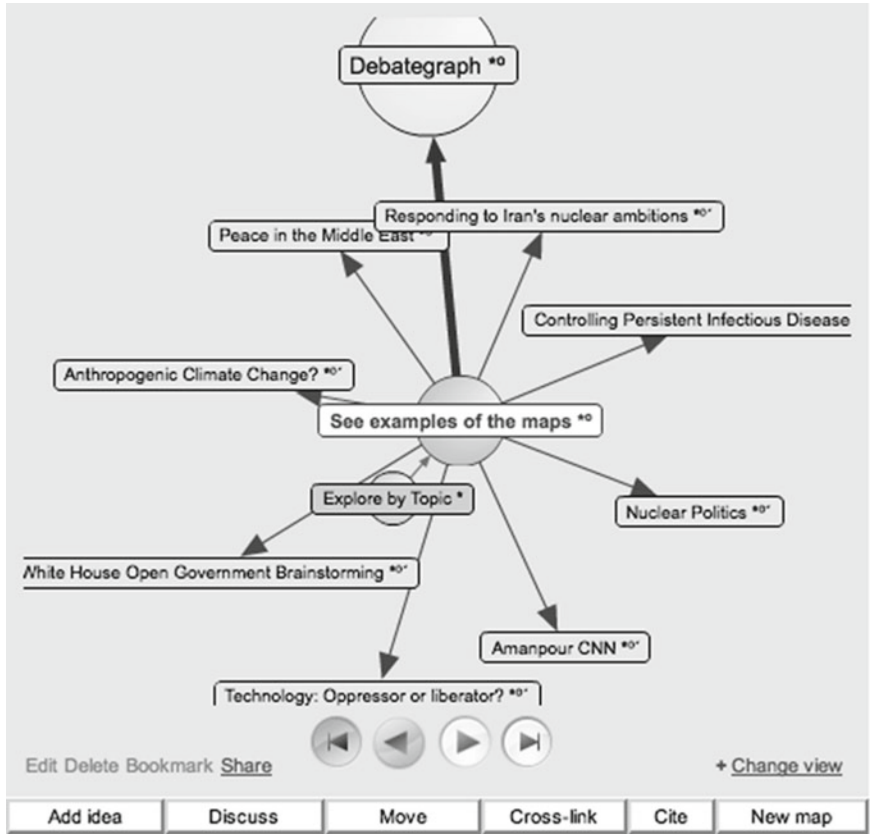

Fig. 64.5 Facilitating argumentation and discussion in CSCL through visualization (created with DebateGraph)

As a second example, there is a rich body of research on the use of social network analysis (SNA) visualizations to provide awareness of co-workers in Computer-Supported Collaborative Work or research networks (Klamma, Spaniol, Cao, & Jarke, 2006). With the explosive rise of social networks like FaceBook, google+ or Twitter, and tools based on visual representations of these networks (Heer & boyd, 2005), we expect that these tools will be widely leveraged where social software is being deployed in collaborative learning environments as well. One example is the Social Networks Adapting Pedagogical Practice (SNAPP) tool that allows users to visualize the network of interactions resulting from forum posts and replies (Dawson, 2009). Figure 64.6 shows how these kinds of visualizations allow seeing the group dynamics within a learning community in a course and potentially provide insights in which students are, for example, becoming disconnected from the community.

Similarly, new hardware provides affordances for subtle visual ambient feedback: a nice example is Reflect (Bachour, Kaplan, & Dillembourg, 2008), where an array of LEDs is used to give feedback on the participation of learners around a table that monitors interaction through embedded microphones. Making the group dynamics accessible and open to interpretation can motivate participants to reflect on their contributions, in a learning setting as well as in other contexts (Gilbert & Karahalios, 2009; Viterbo, Barsotti, & Vande Moere, 2011).

The third example (see Fig. 64.7) illustrates how contributions to an open source software project are visualized: a similar approach could help to understand contributions to Massive Open Online Courses (MOOC's) (Fini, 2009). This kind of social visualization for learning has only been studied on limited scale so far: the Comtella project researched this approach in the context of shared papers, not only for research but also for learning (Vassileva, 2008). Findings showed that users who made more original contributions, consulted this visualization more often than users who made fewer contributions. However, the quality of the contributions themselves deteriorated when the number of contributions increased. Ways to "game the system" and exaggerate contributions to gain higher status and visibility were quickly found by several users. In such a context, a visualization that shows subtle cues on the quality of participation can help (Erickson, 2007). Visual social cues including dynamic rewards, indications of reputation and virtual currencies for rating contributions by others, were therefore included as well.

Other existing applications focus on visualization of activities within a team in order to increase collaboration among team members. For example, the Activity Radar (Kay, Maisonneuve, Yacef, & Reimann, 2006) consists of a circle, representing the range of participation, and colored dots that represent team members (see Fig. 64.8). A dot is placed on a radius and moves to the center as the level of

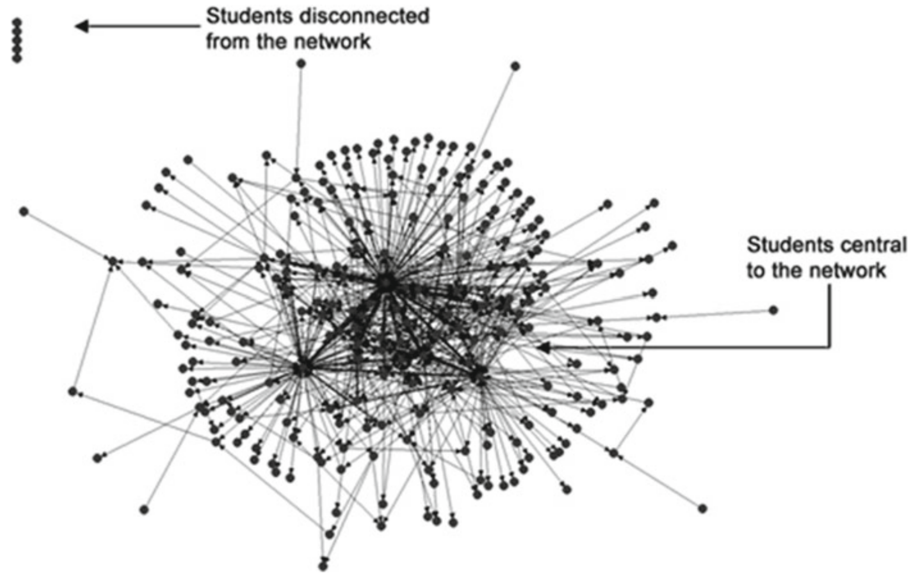

Fig. 64.6 Social Network Analysis diagram based on interactions on discussion forums allows seeing disconnected and key network students (from Dawson, 2009). Nodes in this node–link diagram represent students, where the edges represent relationships between students

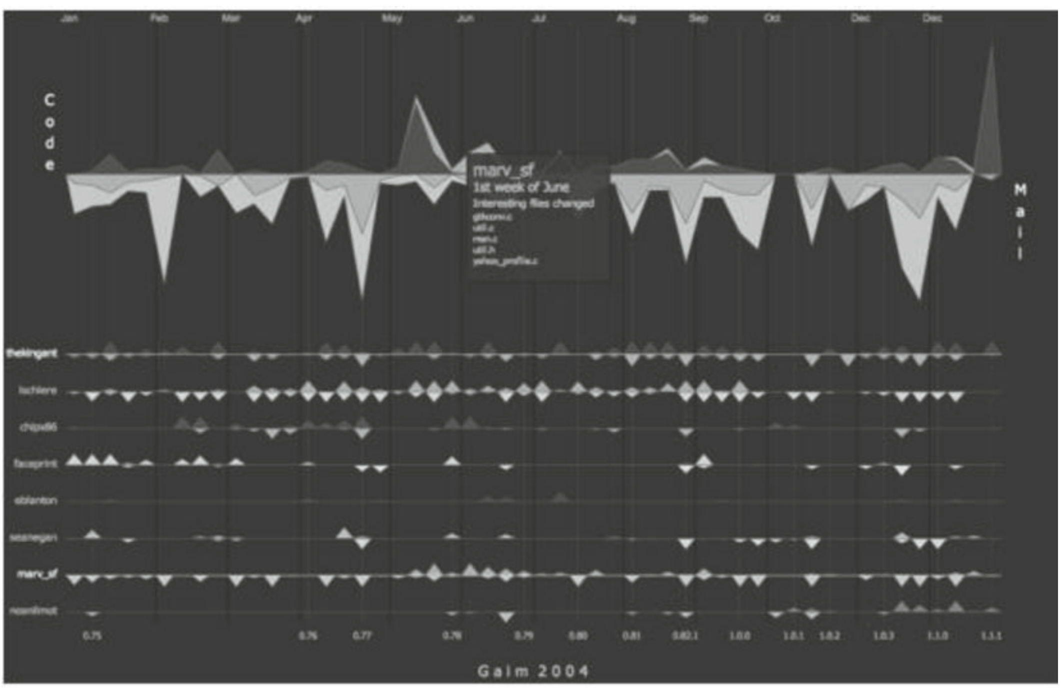

Fig. 64.7 Visualizing code share contributions over time (*x*-axis). The visualization contains a combined view of all users (*top*) and a detailed view per user (*bottom*). Adapted from Gilbert and Karahalios (2009)

participation increases. The inner, darker perimeter represents the average level of participation. In addition to supporting awareness and self-reflection for both teachers and learners, the visualization is targeted to increase collaboration among learners in group work.

Discussion

The use of visualization techniques for enhancing collaborative learning is not limited to the examples above. For more examples readers should refer to the work of Soller and

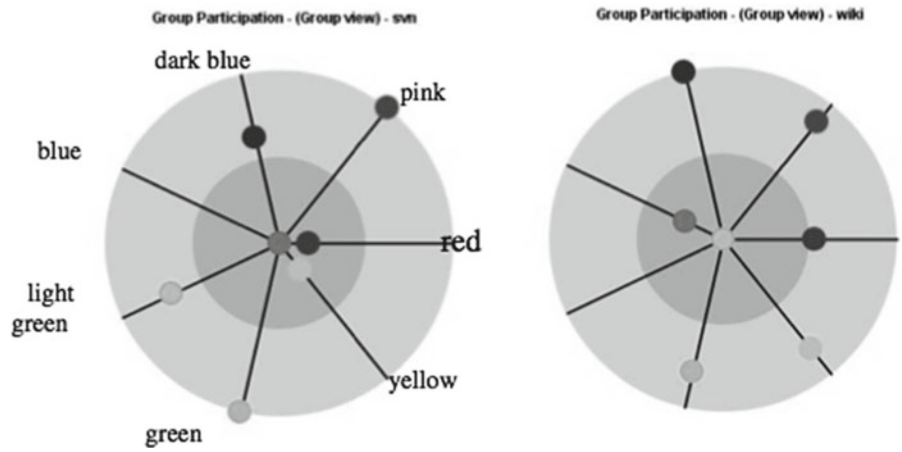

Fig. 64.8 *Dots* in the Activity Radar represents the average level of participation in group work (from Kay et al., 2006)

Jermann (2005). The effect on learning effectiveness of many of these techniques is still unclear. As an example, Janssen et al. (2007) reported the effect of visualizing participation in CSCL for learners in a secondary school in the Netherlands. Basically, both the number and size of intra-group messages were visualized for groups of students working together on an inquiry task. Those with access to the visualization used it intensively and engaged in more coordination activities. However, this did not lead to increased quality of the group products. Further research is needed to assess the added value of visual approaches in terms of effectiveness, efficiency or other criteria that pertain to learning. Outside of a CSCL context, the social context and more specifically, social awareness, may also help a learner to situate his efforts and performance with respect to his peers—this is the topic of the next section.

(Self-)Reflection About the Learning Process

Researchers are focusing increasingly on the need for better measurement, tracking, analysis and visualization of data about learners while they are learning. The field of "learning analytics" therefore focuses on the tracking and analysis of activities to help understand and optimize learning and the environments and contexts in which it occurs (Blakelock & Smith, 2006). Data on user activities is often captured and analyzed as a basis for researching learning processes (Alavi, Dillenbourg, & Kaplan, 2009). Visualization of such data is a key for gaining insight into learning effects achieved and potential impact of technologies on learning. In addition, the application of visualization techniques has been researched to support self-reflection and awareness and collaboration among learners or teachers (Soller & Jermann, 2005). It offers both learners and teachers a feedback or evaluation loop for what is working and not working in the learning process, which materials are used and how many times, how active the students are, and the like.

Several tools have been developed to visualize monitoring data as a basis for self-reflection and awareness. Hardy, Bates, Hill, and Antonioletti (2008) developed a tool that can visualize in the form of a directed graph the path taken through a course session, including all pages, online accesses and pop-up windows (see Fig. 64.9a). In addition, the length of time on each page is visualized. These visualizations are—in essence—directed node–link graphs, with nodes representing pages and edges representing access between pages (see Fig. 64.9b). The size of a circle represents the total time spent on a page. The time of page accesses is also visualized, with a vertical line representing a page access. Lines that are close together show rapid access, while lines further apart show less frequent access times (see Fig. 64.9c). The main added value of this tool is that it enables researchers to gain insight into the complex spatial and temporal routes taken by students through the material. Neither students nor teachers used the visualizations themselves. Hence, no conclusions about the added value of this tool in the learning process can be drawn.

Mazza and Milani (2005) presented the GISMO system that also visualizes accesses to a course and its resources. Among others, the application relies on a simple matrix visualization of student names (on the *Y*-axis) and resource names (on the *X*-axis) to represent resource accesses. The color of cells in this matrix range from light blue to dark blue according to the number of times a learner accessed a resource. Besides this, time can be chosen on the *X*-axis, which enables users to gain insights into the sequence of resources that were used. However, instead of estimated time, the number of resource accesses is used. Like the first approach, the Student Activity Meter (SAM) (Govaerts, Verbert, Klerkx, &

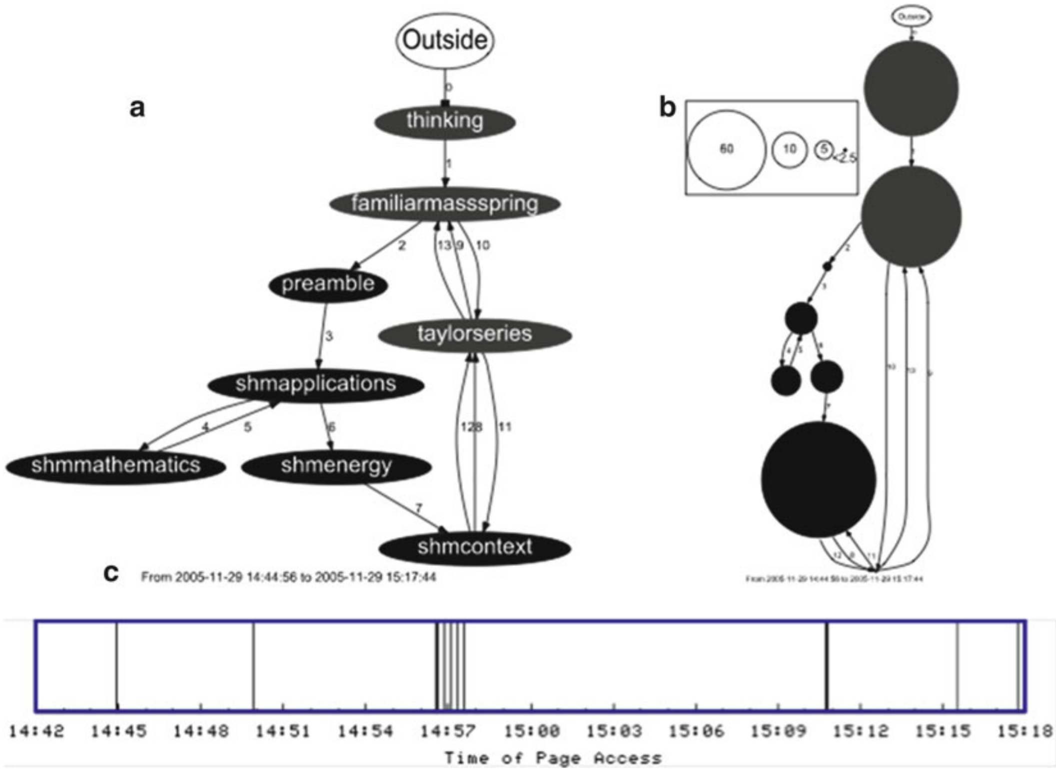

Fig. 64.9 Path taken (**a**), time spending (**b**), and access time (**c**) visualizations (from Hardy et al., 2008)

Duval, 2010) is focused on time estimates as a basis to support awareness and self-reflection. Figure 64.10 shows some of the visualizations that SAM provides:

- The line chart (vis. A in Fig. 64.10) shows a line for every student, connecting all the timestamps when she was working with the cumulative amount of time spent. The inclination of the line shows the effort of the student. A steep line means an intensive working period. A flat line shows inactivity.
- Statistics of global time spent and document use are shown in box 2 in Fig. 64.10. Next to the actual numbers, a graphical view is presented with color-coding of the minimum, maximum and average time spent and documents used, to give the user a visual comparison.
- The recommendation pane in box 3 allows navigating through the most used and the most time spent on resources.

Through a usability test with interviews and the think aloud protocol, the authors found out that SAM is easy to work with the tool the first time (Govaerts et al., 2010). The numbers of errors were low and no unrecoverable errors were encountered. A System Usability Scale (SUS) test for measuring user satisfaction achieved an average score of 73 %, which puts the tool on par with mainstream software tools. Based on these findings, the authors concluded that such visualizations appear to be useful for both teachers and learners during the learning process.

Visualizing knowledge levels of students has been explored in ViSMod (Zapata-Rivera & Greer, 2002), the UM toolkit (Kay, 1995) and KERMIT (Hartley & Mitrovic, 2002). VisMod uses concept maps to render a Bayesian learner model. The UM toolkit uses different types of geometric forms to represent known and unknown concepts. KERMIT uses histograms to represent knowledge levels of learners. The visualizations of these systems provide a representation of a learner model, which is built automatically using artificial intelligence techniques (Mazza & Milani, 2005). As these inferences are often challenging, many other visualization tools rely on self-assessment tools to capture the current knowledge level of a learner (Nussbaumer, 2008).

Discussion

The tools presented in this section visualize different indicators aimed at fostering awareness and reflection about learning processes or changes in them. These indicators include—among others—resource access, time spent on learning activities, and knowledge level indicators. Many of the tools enable learners to compare and contrast their data with peers. The visualization tools are also often intended to increase teacher awareness of how learners spend their time and what resources they use, and to provide teachers with

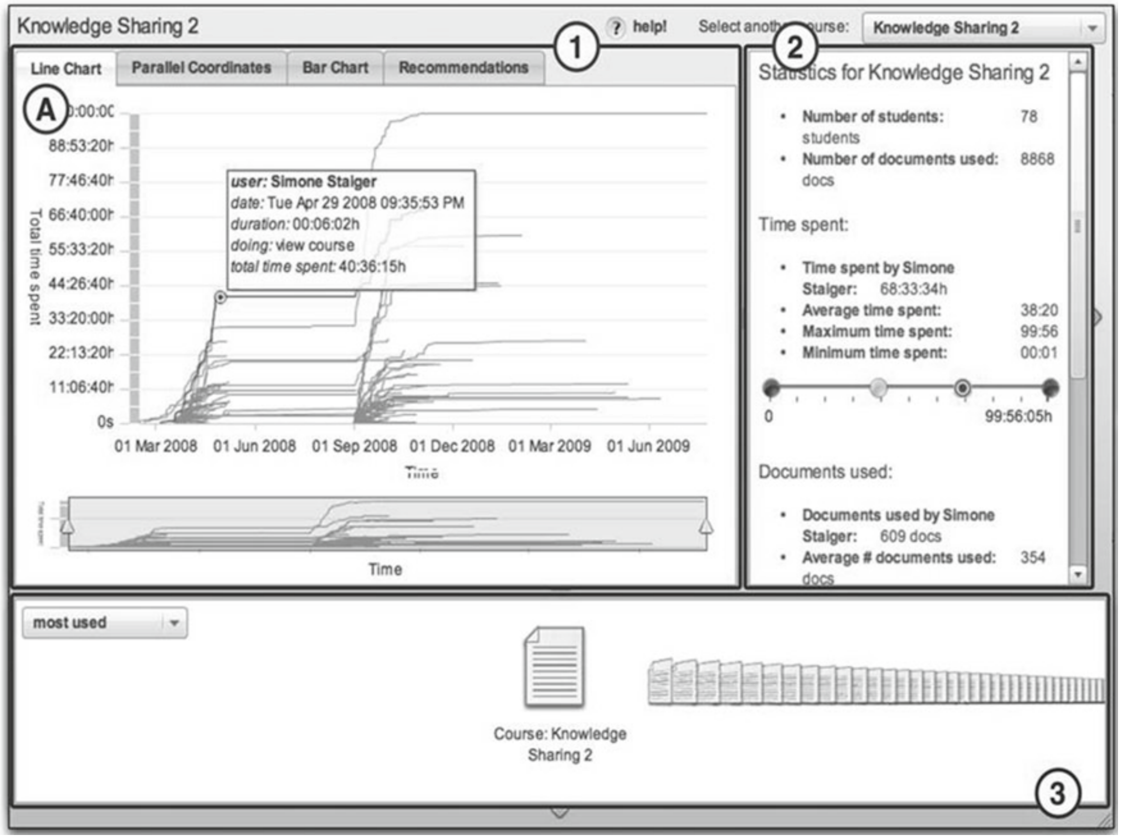

Fig. 64.10 Student activity meter (SAM) (from Govaerts et al., 2010)

feedback on well they designed their own courses. Whereas the tools presented in this section illustrate the potential of visualization techniques to support these objectives, the effect on learning outcomes from many of these techniques is unclear. Evaluation studies have so far only assessed the usability and usefulness in controlled experiments. The perceived usefulness by both teachers and learners is in all cases high. However, real-life case studies that evaluate the impact of visualization techniques for learning analytics on learning effectiveness and efficiency have not yet been carried out.

Designing Environments to Facilitate Learning Processes

The goal of instructional design is to create instructional learning experiences that make the acquisition of knowledge and skill more efficient, effective, and appealing (Merrill, Drake, Lacy, & Pratt, 1996). The ADDIE process model distinguishes the main stages of the instructional design process: Analysis, Design, Development, Implementation, and Evaluation (Molenda, 2003). The outcome of each stage feeds into the next stage. One accepted improvement to this model is the use of rapid prototyping that includes continuous feedback in the instructional design process. In this section, we aim to show how visualization techniques can facilitate the analysis and design stages of the instructional design process.

During the analysis phase of instructional design, one tries to understand the audience needs, constraints, existing knowledge, skills, the desired outcome of the course, the learner environment, the timeline for the learning experience, etc. This information is then fed into a design stage where learning objectives, methods for presenting relevant information, assessment criteria, and the like are specified. A so-called learning design captures this kind of information in an explicit way and is therefore typically defined as the application of learning design knowledge when developing a concrete unit of learning, e.g., a course, a lesson, a curriculum, or a learning event (Koper & Tattersall, 2005). A popular formal language to describe such learning designs is the IMS Learning Design (LD) specification, which provides elements such as roles (for instance students or educators), activities (for instance a discussion about a topic), and environments (for instance a learning management system), to describe designs of the teaching and learning process in a formal way. IMS LD is sometimes considered hard to understand and it would therefore take considerable effort from

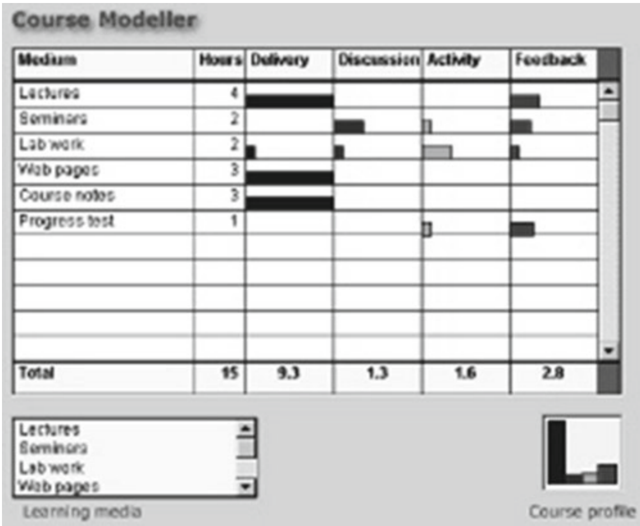

Fig. 64.11 The London Pedagogy Planner: distributing learner time over learning activities such as discussion, lab work, lectures, etc. (from San Diego et al., 2008)

teachers to apply it in concrete situations (Griffths & Blat, 2005; Neumann & Oberhuemer, 2009).

Visualization can facilitate the analysis and design stages by providing visual support. OpenGLM (Neumann & Oberhuemer, 2009), the London Pedagogy Planner (San Diego et al., 2008), CompendiumLD (http://compendiumld.open.ac.uk/), and LAMS (Dalziel, 2003) are only some of the many examples of tools that support lecturers in analyzing, designing and sharing learning designs in a visual way. Several visualization techniques are used in these tools. The London Pedagogy Planner, for example, includes a spreadsheet-like overview where lecturers distribute the available learner time over different cognitive activities, as well as a schedule of topics and a visualization of how they related to learning outcomes (see Fig. 64.11). The idea is to visually support teachers through interactive, adaptive, reflective, discursive, and collaborative learning designs.

CompendiumLD includes mind maps, concept maps, Web maps, and argumentation maps such as the ones that were discussed earlier (see Fig. 64.5). Those maps are in fact node–link diagrams where nodes can represent typical LD elements such as activities, roles, and environments and links can represent flows between activities. Similar maps are used in the OpenGLM tool (see Fig. 64.12).

The middle part of the user interface of the Open GLM enables the user to visually create a sequence of activities. Connections between activities can be drawn in that area by making use of the design palette (upper right corner). The graphic design is interpreted by the GLM after which the corresponding manifest file of the IMS LD package is automatically generated (Neumann & Oberhuemer, 2009). The main added value of this tool is that it enables its users to offload information from their cognitive working memories. The authors performed a user evaluation with a test population of 21 users to validate if the graphical editor actually reaches its goal of removing technical barriers that instructional design in general and IMS LD in particular presents. The test participants successfully created complete learning designs that were exported as units of learning and reported good usability in their feedback. For an overview of a similar tool, we refer readers to the work of Dodero, del Val, and Torres (2010).

Discussion

The power of the visualization techniques for the analysis and design phase comes from the fact that it is possible to have a far more complex concept structure, such as an instructional design, represented externally in a visual display than can be held in visual and verbal working memories of users while designing their courses (Ware, 2004). Apart from this generic design support that visualization techniques offer, these tools also hide some of the technical complexities in standards such as IMS LD—a specification that has not yet been widely adopted since its inception (Derntl, Neumann, Griffiths, & Oberhuemer, 2010). In that sense, we can say that the visualization techniques can facilitate the design stage of the learning process.

Conclusions

As the field of Visualization is becoming more mature, visualization techniques are moving out of research laboratories (Plaisant, 2004) into application domains such as e-learning. There are a multitude of educators and learners who are interested in data on educational resources, learning processes, student activities, social learning networks, and the like, whose analyses can benefit from the field of visualization. These techniques make it possible for learners, educators, researchers, and the general public to obtain insight in these data in an efficient and effective way, thanks to the unique capabilities of the human visual system (Van Wijk, 2005) that allows us to detect interesting features and patterns in a short time. In addition, it enables users to offload information from their cognitive working memories.

The role of visualization in an educational context is potentially much more versatile than simply increasing information awareness: as has been shown in this chapter, visualization applied to resource searching, collaboration, reflection, and instructional design has the unique potential to help shape the learning process and encourage reflection on its progress and impact. Examples in this chapter have shown how these techniques can enhance several activities

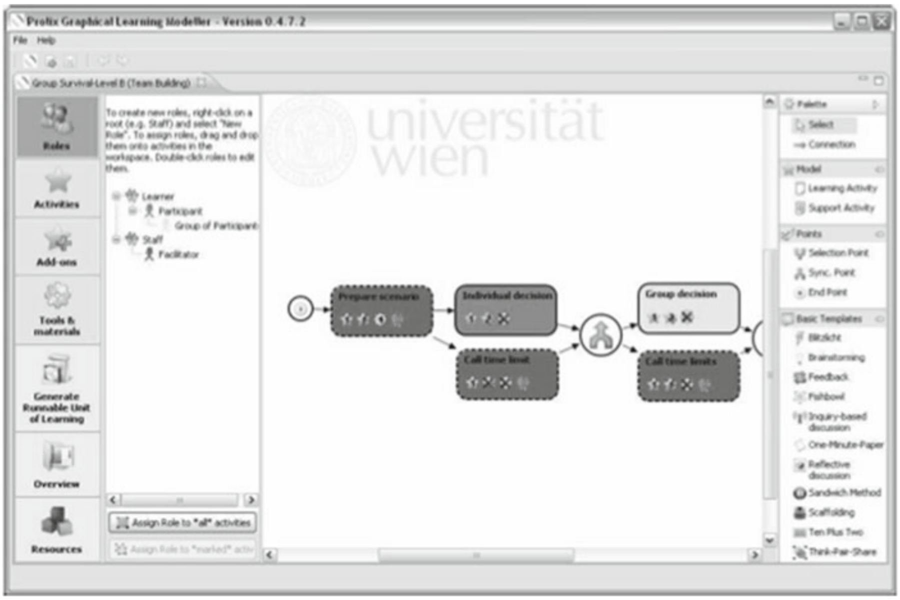

Fig. 64.12 The Open Graphical Learning Modeler: visualization helps to offload information from working memories of teachers (from Neumann & Oberhuemer, 2009)

of the learning process. However, we do want to point to a lack of thorough experiments in real-life settings to assess usefulness of these techniques during the learning process. One reason for this might be the difficulty of evaluating visualization applications and more specifically the difficulty to understand and measure the impact of visualization in learning (Fekete et al., 2008). We can thus conclude that visualization techniques are becoming more common tools in the learning process but further research is needed to assess the added value of these visual approaches in terms of effectiveness, efficiency or other criteria that pertain to learning, including—for instance—aesthetical appeal and fun.

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Emerging Representation Technologies for Problem Solving

65

Ton de Jong

Abstract

When learners solve problems they often create an external representation to organize the information given in the problem statement, to translate this problem description into underlying domain terms, and to complete this with knowledge they already have. This representation is subsequently used to solve the problem. For creating such a representation learners have many formats available: text, diagrams, formulas, and the like. The choice for a specific representation format partly determines the solution strategy that is triggered. Today, technology supported representations have become available that extend the possibilities for learners. Technology can be used to present different but connected representations, to adapt the representation to the problem solving phase and to add aspects such as dynamics, reified objects, three dimensional (3D) representations, and haptic experiences. These new representational formats open new affordances but also create new challenges for learning. In this chapter the different affordances that representational formats offer are explored with an emphasis on modern technology supported representations.

Keywords

Problem solving • Representation • Technology

Problem Solving and Representations: Introduction

Problem solving is often seen as one of the most fundamental human skills and is defined as bridging the gap between a current situation and a desired situation without knowing beforehand the steps to take (e.g., Jonassen, 2010; Robertson, 2001). Problems exist in many variations and in many domains. There are physics problems, algebra word problems, design problems, syllogisms, and the like. In the literature, we find two general dimensions of problems (see, de Jong, 2005). One dimension involves the amount of domain knowledge that is necessary to solve the problem (semantically rich versus semantically poor problems), and the second dimension has to do with the way the start state, end state, and necessary operators in the problem are defined (well defined versus ill-defined problems). The type of problem together with the skills and knowledge the problem solver brings to the task determines the chance of success (and thus difficulty) of the problem.

A central element in problem solving is the *internal problem representation*, which is the evolving depiction of the problem in the mind of the problem solver. Problem solvers alter the problem representation continuously while solving, either by adding domain information or by applying operators that change the state of the problem. The starting state is the problem statement or description as given to the problem solver; the ultimate representation is the problem's solution. An adequate mental representation of the problem comes as a first requirement for successful problem solving. A problem solving process begins with reading the problem statement. Information is selected from the initial statement,

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knowledge from memory is added, and the various elements are connected to form a structured mental representation of the situation (Braune & Foshay, 1983; Thevenot, 2010). This representation influences the reasoning process of students (Gamo, Sander, & Richard, 2010). It can, for example, give rise to an interpretation in terms of intuitive explanations (diSessa, 1993) or underlying physics principles (Larkin, 1983). Finally, the representation provides a basis for attempting a solution approach (Chi, Feltovich, & Glaser, 1981). Expertise plays a role in the creation of problem representations. Experts' problem representations are more helpful than beginners' representations are, and proficient beginners' representations are better than those of weak beginners (Chi et al., 1981; de Jong & Ferguson-Hessler, 1991, 1996; Larkin, 1983). Research shows that novices have a preference for working backward from the desired state of the problem, whereas experts work forward from the givens (Larkin, McDermott, Simon, & Simon, 1980; Sweller, Mawer, & Ward, 1983) which assumedly is caused by a different initial problem representation. But also within the group of novices we see different approaches. Proficient novices develop a coherent mental model of the situation and less proficient novices elaborate much less on the initial problem representation (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Savelsbergh, de Jong, & Ferguson-Hessler, 2002), but even proficient students still profit from support on situation elaboration (Savelsbergh, de Jong, & Ferguson-Hessler, 2011).

In addition to the internal representation, problem solvers often rely on *external representation* for solving a problem. An external representation is a depiction of the state of a problem in a medium (computer screen, paper, oral account) external to the problem solver. Internal and external representations do not need to have a one-on-one relation. The format of the external representation (partly) determines how the internal representation can be externally expressed; an existing external representation will undergo transformations when it is internalized. The *solution* of a problem normally is externalized so that it can be communicated to the teacher. The *intermediate states of the problem* are also almost always externalized (e.g., by making drawings while problem solving) so that the student's problem solving process is supported by the external representation (see, e.g., de Jong & Ferguson-Hessler, 1996). External representations help students to structure the problem (hiding irrelevant aspects, highlighting important characteristics), to find necessary relations and translate superficial characteristics into domain relevant terms, and to help memorize previous states of the problem, so that in case of an impasse students may return to an earlier phase. External representations thus play a central role in the problem solving process. By highlighting and hiding aspects of the problem statement the selection of appropriate domain knowledge and the necessary inference processes are facilitated. Studies show that using multiple external representations is correlated with success in problem solving (Kohl, Rosengrant, & Finkelstein, 2007; Rosengrant, Van Heuvelen, & Etkina, 2009). In collaborative learning settings external representations may also serve the communication between learners and help the development of a common view on the problem. In this context, Schwartz (1995) found that representations that students created in a collaborative setting, differed from individual representations (in collaborative contexts they were more abstract).

In this chapter we focus on the use of external representations in the problem solving process and touch upon the role that technology can play. The external representation can be created by problem solvers themselves and here technology can expand the possibilities but also deliberately constrain the expression facilities of problem solvers to push them into the right direction. Technology can also be used to offer students external problem representations and use new formats for these representations.

The Format of the External Representation and Problem Solving

Representations come in many formats: tables, diagrams, concept maps, formulae, drawings, models, and the like. Each type of representational format has specific affordances for the problem solving process. This idea, that different representations that have the same content can still offer different processing opportunities is called *computational effectiveness* (Larkin & Simon, 1987) or *specificity* (Stenning & Oberlander, 1995). The fact that representational format influences the problem solving process was clearly established in two classical studies by Zhang. In a first study, Zhang and Norman (1994) found that the external representation given to students influenced their choices in solving the Tower of Hanoi problem. In a second study Zhang (1997) found that subjects' playing strategies in a tic-tac-toe game were largely determined by the representational format they had available. While these studies concerned semantically poor problems, differences in problem solving process related to representation use have also been reported for semantically rich problems as well—although the results are not unequivocal. For example, Larkin and Simon (1987) found in their seminal study that *search* processes in physics problems (in this case a pulley problem) are much more easily performed with textual representations than with diagrammatic representations. Contrary to this finding, Meltzer (2005) found that vector diagrams led to a higher number of wrong responses than verbal problem descriptions when students were presented questions on physics situations in the domain of forces. Lee (2010) found that students' conceptions of seasons were influenced by characteristics of orbit diagrams that they were presented with and a recent study by Frederiksen, Kehoe, and Wood (2011) found that students who had used a causal map diagram next to a business simulation performed better than students who had a text accompanying the simulation. Liu and Shen (2011) observed students of different (lower) grades solve concentration problems and inferred from eye movements that representation (symbolic or iconic) influenced the problems solving strategies of students; with the iconic representation students used intuitive rules, whereas with the symbolic representations students relied on a more formal, calculation-based, strategy.

There is also debate in the literature whether more abstract (mathematical representations) or more concrete (contextually grounded) representations should be used. Koedinger and Nathan's (2004) exemplary study on the relation between representation format and problem solving compared students solving traditional story problems in which the mathematical problem was embedded in a real world context with students solving problems with context free, algebraic, representations. They found that concrete representations lead to the highest percentage of successfully solved problems. This finding was confirmed in a follow-up study by Koedinger, Alibali, and Nathan (2008) which also found that the advantage for concrete representations only holds for the solving of simple problems. Koedinger et al. (2008) concluded that simple problems had an advantage because students can use informal strategies to solve them; these strategies fail for more complex problems when more abstract formal reasoning is required. In a recent study involving physics problem solving activities within the topic of electricity and magnetism Moreno, Ozogul, and Reisslein (2011) found that a combination of abstract (electrical circuit drawings) and concrete representations (batteries and bulbs) worked best for students' problem solving achievements. Moreno et al. (2011) pointed to the fact that concrete representations are close to the students' daily experiences and students need less knowledge of science conventions to work with these representations. Abstract representations help students to focus on structural instead of superficial characteristics of the problem. In their study Moreno et al. found that the combination of both representations worked best and from this they concluded that a careful design that allows the concrete representation to be transferred into abstract ones is necessary. This conclusion is in line with the work by Goldstone and Son (2005) who found that students who worked with a computer simulations were best supported in their learning when a concrete representation gradually became more abstract (idealized).

So far, we have described the influence of representational format types on success in problem solving but there are indications that the representational format also influences what students can learn from problem solving in the sense that different representational formats seem to have different affordances for cognitive processes that accompany problem solving. Ainsworth and Loizou (2003) studied students' self-explanations when trying to understand text or a diagram on the human circulatory system and found that diagrams gave rise to more self-explanations than texts. Cheng (2002) presented an extensive study in which the processing affordances for different representations for electrical circuits were analyzed and tested in a study focusing on what students learn from solving these problems over different representations. In his work Cheng came to a few overall principles for the design of representations that are effective for learning. One of those is that the representation should show the basic structural characteristics of the underlying domain. If true, this principle implies that, when a domain is rather complex, a combination of different representations will be necessary. According to Cheng the notational system used should not be arbitrary but naturally linked to the underlying domain. Along these lines, Cheng recommended, as also indicated above, a combination of different levels of abstraction. This enables students to move backward and forward between concrete and abstract cases. Somewhat similar is Cheng's recommendation that the representation should be able to show deep, invariant characteristics of the domain (e.g., conservation laws) together with local differences. Further, representations should allow taking different perspectives on the domain.

It is clear from all these studies that representational formats influence problem solving behavior and the learning of how to solve problems, but there seems to be no general rules on how this works (Scaife & Rogers, 1996). Like others cited above, Kohl and Finkelstein (2005) found clear differences in success rate for solving isomorphic problems on different representations but also found this to vary over domains and problem types, which makes it very hard to draw general conclusions. Also, it appears that effective interfaces do not take one single representational perspective but rather use combinations of different representational formats in order to merge different affordances. However, to make these combinations successful students will need a proper level of prior knowledge. Cook, Wiebe, and Carter (2008) found high prior knowledge students were better able to coordinate a combination of macroscopic and molecular representations in a chemistry domain than low prior knowledge students. Also, expertise with a particular type of representation, such as equations, makes this type of representation more effective (Sherin, 2001). As a final determinant of the effectiveness of particular representations, cognitive style (more specifically spatial ability and the visualizers-verbalizers distinction) comes into play (see, e.g., Cox, 1999). In conclusion, we can say that research recommends combinations of representations for problem solving and also indicates that the effectiveness of specific (combinations of) representations also depends on a complex interplay between domain characteristics and types of problems with students' prior knowledge, expertise with representations, and cognitive styles.

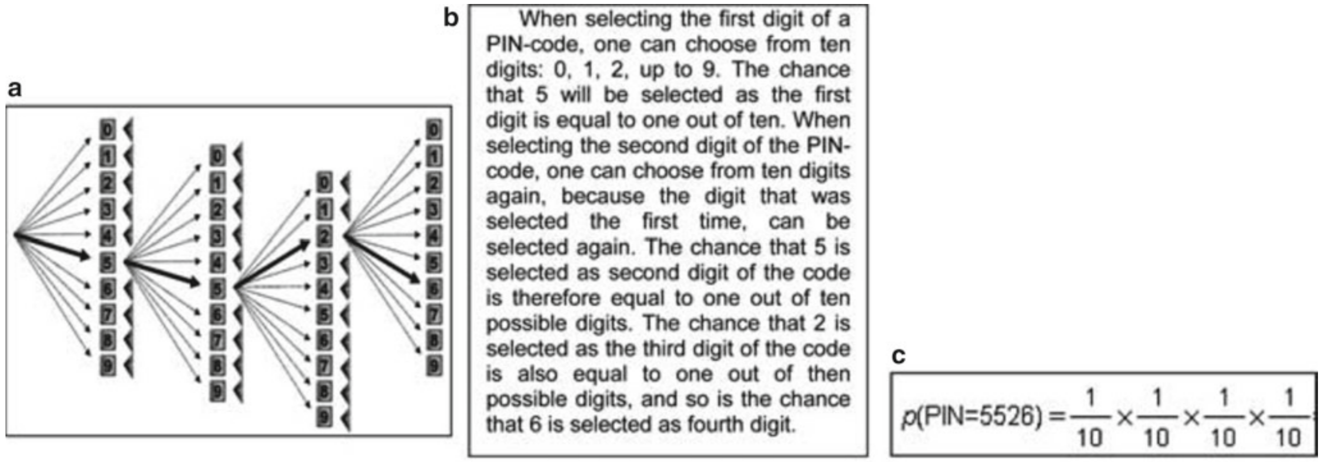

Fig. 65.1 Examples of three different representational formats (from Kolloffel et al., 2009)

Technology and External Representational Formats for Problem Solving

Traditionally, external representations for problem solving were created on paper or blackboards or other two-dimensional formats with a rather open range of expression. Computer technology for problem solving has now been studied for some time (see, for example, Duffield, 1991) and has extended this traditional approach in a number of ways: in computer technology different expressional formats can be more elegantly connected, representational formats can be adaptively used over problem solving phases, and specific characteristics can be added such as dynamics, reified objects, 3D, and haptic sensory experiences.

Multiple Connected Representations

What has become clear from the overview of research above is that different representational formats have different affordances. This also implies that, for optimal problem solving, representational formats could differ between problem solving phases, domain content, and learners. Technology can play an important role here since it may facilitate an easy *change between different formats* and it may also be used to show *connections between formats* in this way combining the different affordances of different formats. For example, Kolloffel, Eysink, de Jong, and Wilhelm (2009) had students solve problems in combinatorics on the basis of several (combinations of) representations (see Fig. 65.1). The diagram and formula representations were interactive in the sense that the representation changed when the students changed the characteristics of the problem (such as the number of digits). Their results showed that a combination of a textual and arithmetic representation worked best for the participants in this study. In a recent study, Kollöffel (2012) confirmed the superiority of the textual and arithmetic representations but also that students themselves tended to have a preference for the diagrammatic representation, which was a less effective representation.

The earlier work by van der Meij and de Jong (2006) showed how different representational formats can be combined. In their work, students learned about principles in the physics domain of momentum by the use of an interactive physics simulation that had different external representations of the same problem situation: a concrete situation (such as a hand and a spanner), diagrams, formulae, and graphs. These four representations were used by students to solve on-line problems. All students received all representations but in the condition in which the representations were both integrated (displayed on the same physical location) and dynamically linked (a change in one representation also occurs in the other representations) students' achieved more in the more complex part of the environment as compared to single representations and not integrated multiple representations (see also, de Jong & van der Meij, 2012). A similar approach is used in the SimCalc (MathWorlds) software where math problems are presented through dynamically interrelated graphs and animations (Roschelle, Kaput, & Stroup, 2000; Tatar et al., 2008).

Adaptive Representations

An example of technology-based *adaptive representations* can be found in Gräsel, Fischer, and Mandl (2000), who studied problem solving by medical students. In one problem-based learning environment they used a video to show the sequential aspect of solving medical problems (in this case diagnosing anemia). In the video a medical expert showed her reasoning while diagnosing. Using technology (a video) in this case can have two advantages. One is the personalization aspect, the medical expert is someone a student can identify with which may help to raise engagement. Second, the sequential aspect of the reasoning process is inherently shown in a video. Gräsel et al. (2000) found a number of positive effects of the modeling (compared to an environment in which the model was absent). The students supported by the model, for example, more often used additional knowledge to correct comprehension failures. However, the problem representation that students had to create did not show differences in quality between the two groups. Thus, it can be concluded that showing the problem-solving procedure in a different representation (a model) did not work positively in the end. In this experiment students also had access to background information in the form of hypertext. In a follow-up study Gräsel et al. (2000) changed this hypertext to adapt to the phase of learning and automatically show interrelations of all specific aspects of the problem. Students could also create their own graphical overview and compare this with the automatically generated one. One group of students was prompted to use the graphical information and explained how to do this; the other group did not receive prompts and explanations. The prompted group made better use of the graphical information and better used (e.g., better integrated) and improved their representation.

Scheiter, Gerjets, and Schuh (2010) focused on the *dynamic features* of multimedia-based information. In this study students were presented with worked out algebra word problems. In one experimental condition the worked out examples were presented to the student in text format. In the other condition the examples were accompanied by a visualization that changed dynamically as students stepped through the solution. Students who received the animations clearly outperformed the students who worked with the text-only representation. This result is in line with other work that showed that a gradual move from concrete to more abstract representations is fruitful for learning (Goldstone & Son, 2005; Nathan, Kintsch, & Young, 1992). It also important to note that in earlier work Scheiter, Gerjets, and Catrambone (2006) found that presenting students with only realistic animations was detrimental for problem solving performance. From this it can be concluded that there seems to be virtue in having the representation develop over the problem solving process.

Dynamic Representations

An excellent example of a technology that helps students understand the *dynamics* of a problem solving process is Algebra Touch (see http://www.youtube.com/watch?v=A4SdNUwgkcg). Algebra Touch is an app for the iPad that was developed by Landy and Goldstone and that supports students in solving equations (for background information on the development see Goldstone & Landy, 2010; Landy, 2010). In the app, students can drag terms in the equation to the other side of the equal mark and see the sign change while dragging it. They can add or multiply terms by dragging them together and clicking them. Terms can be divided by simply dragging a line through them. Composite terms can be decomposed by tapping them (e.g., by tapping 12 in the counter of a fraction students can choose between 6×2 and 3×4, depending on the number in the denominator). This simple but seemingly very effective application clearly shows students the dynamics involved in solving equations. Compared to the traditional way of representing in which transformations of equations are shown in a successive, table-like, manner, Algebra Touch emphasizes the transformations directly and through the intuitive direct manipulation interface students are "drawn into" the equation. Similarly van der Meij, van der Meij, and Mulder (2012) investigated representations using another very popular technology: electronic blackboards. These researchers compared teaching with static and dynamic representations on an electronic blackboard on a mathematics topic (views on 3D objects) and geography (water cycle). They found that, for mathematical views, dynamic representations were superior (students could see objects from all different angles) but, for the water cycle, no difference between the static and dynamic representation could be found. Yet another example in which the dynamics of technology is used for problem solving can be found in eXpresser, a tool students can use to dynamically create patterns so that they understand the use of abstractions (Noss et al., 2009). This is a good example of how technology allows students to build their own patterns and see the dynamics in repeating patterns.

3D Representations

Technology is particularly well suited to presenting *3D dynamic representations* which, for a number of domains (such as geometry, chemistry), is of crucial importance. The number of software programs that help students visualize 3D chemical representations is increasing rapidly (see, Battle, Allen, & Ferrence, 2010). Wu, Krajcik, and Soloway (2001) described eChem, a software program that helps students to construct organic molecular models, to visualize these structures in different types of graphical representations, and to connect the models at different levels. Wu et al. (2001) found that the software helped students to move between 2D and 3D representations but also that most probably both types of representations are necessary for fruitful learning. Concerning the use of multimedia for chemistry learning Kozma and

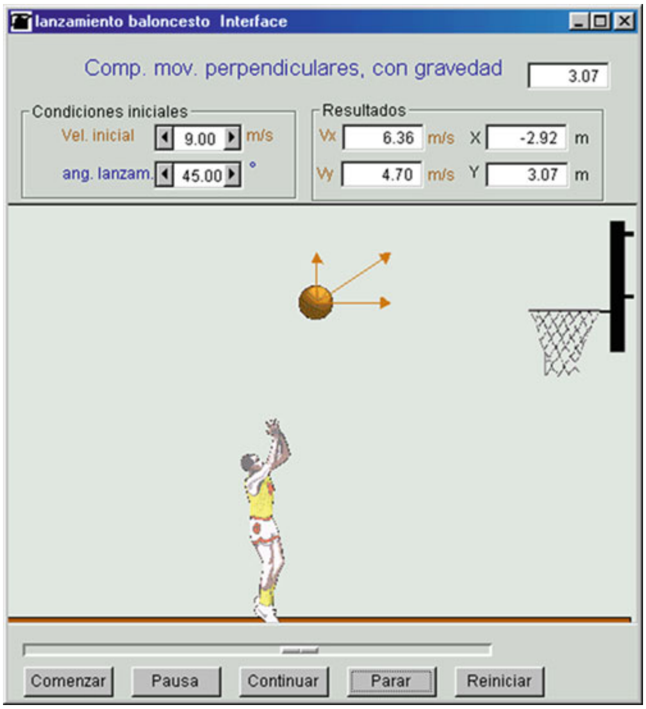

Fig. 65.2 Example of reified objects

Russell (2005) concluded that, although there are many studies that show an advantage of including (3D) animations in learning material, it is not clear if it works for all students and all topics.

Reified Objects

Technology can be used to present abstract concepts that are not visible in the natural world, such as velocity vectors, light beams, and the like. In a problem solving process students often create these abstract representations themselves but technology can be used to provide students with these reifications on-line. Figure 65.2 shows an example of reified objects, the velocity vectors of the ball are displayed and change dynamically with the change of the ball.

In a recent study Olympiou, Zacharia, and de Jong (2013) explored the function of reified objects for students studying the domain of optics. They found that showing students reified objects, such as light rays, helped the students with low prior knowledge in the less complex parts of the learning environment but did not help the students with high prior knowledge, possibly because they could create the reified objects themselves. For the more complex parts of the learning environment all students profited from having reified objects presented. Once again, these results show the complicated nature of working with specific representational affordances.

Haptic Experiences

A final technological innovation is the addition of *sensory augmentations* to learning environments. Minogue and Jones (2009) studied the effects of adding such a haptic device to a simulation in the domain of cell biology that simulated transport through a cell membrane. This haptic device enabled students to feel the forces that accompanied transport of substances through the cell membrane. Results showed that learners using the haptic version of the simulation reached higher levels of understanding compared to students who had no access to the haptic device. Tolentino et al. (2009) and Birchfield and Megowan-Romanowicz (2009), described a similar approach in SMALLlab; a simulation environment in which students engage in haptic and auditory experiences through sensory peripherals.

Conclusion

Technological environments for problem solving are emerging, especially in STEM domains. Examples are the well-known cognitive tutors (e.g., Aleven, Roll, McLaren, & Koedinger, 2010), SimCalc (Tatar et al., 2008), Physhint (Pol, Harskamp, Suhre, & Goedhart, 2008), and quite a few others. These environments focus on supporting problem solving activities of students. While these environments often use multiple, dynamic representations, the research that has been conducted to date has not focused on isolating the effects of these representations on learning. However, we may also infer from other literature that including multiple representations facilitates learning (see, e.g., Verschaffel, de Corte, de Jong, & Elen, 2010). Basic research is also clear that representations matter for success in problem solving but this has not, as yet, translated into research that focuses on specific affordances of representations in technology. There is, therefore, much research to be done before we will have concrete recommendations of the use of specific types of representations for combinations of domain and learner characteristics.

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Section VIII

Technology Integration

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This section of the Handbook focuses on how various technologies are integrated into different practical contexts. One indicator of successful technology integration is that the focus—in the classroom or with the learner—is no longer on the technology itself, but rather on the task at hand. For example, in today's classroom, no one talks about a piece of chalk and how to use it to mark on a blackboard and teachers do not submit to special in-service workshops on the use of a book, how to turn pages, where to find the index, and the like. When educators and learners have stopped talking about how to point and click, how to search and find, how to drag and drop, how to cut and paste, and so on, then we know that they have integrated those techniques into their routine suite of technology-oriented behaviors.

That being said, it is clear from the chapters in this section that the challenges for effective technology integration in learning, instruction, and performance are quite significant and the research somewhat limited. As Rogers (2003) observed, "getting a new idea adopted, even when it has obvious advantages, is difficult" (p. 1) and often involves a sort of *social change* that alters the very structure and function of a social system. Cuban (2001) agreed and argued further that, consequently, instructional technology integration initiatives often go hand in hand with discussions of educational reform and systemic change—as will be seen in the chapters that follow.

This section is divided roughly into micro- and macro-level views of the question of technology integration. The first two chapters take a micro-level view by focusing on learners' varying characteristics and levels of readiness that can affect their adoption of technologies for learning. The chapter by Eunjung (Grace) Oh and Thomas C. Reeves, for example, explores recent research on generational differences among learners' attitudes, aptitudes, and interests in technology use. While many have speculated that today's technologies are critical to meeting younger learners' learning needs, the authors conclude that there is little tangible research evidence to support this supposition. The authors note further that there is evidence to suggest that *Millennial Generation* students do not generalize their technology use to learning settings. This chapter reviews the recent research in this area and discusses the ramifications of these findings for educational technologists and the future of education.

Rhonda Christensen's and Gerald Knezek's chapter synthesizes the existing, albeit scant, literature on assessing learners' technology readiness and skills. The authors claim that verifying stand-alone technology skills is not sufficient as a means of assessing whether students evaluate and use these tools in an appropriate manner across content areas for use in higher level learning activities. They suggest, instead, that there are likely minimum levels of technology skills that we would expect our students to have before they are able to make informed decisions on which tools they will use. This chapter explores the existing research into emerging assessment techniques as well as prospects for new forms of assessment unique to new digital media.

The remainder of this section comprises chapters that take a larger, more macro-level perspective on the issue of technology integration in a variety of contexts: K-12 schools, medical education, and multicultural settings. In their chapter on technology integration in school settings, Randy Davies and Rick West organize their review of the recent research on three broad areas of focus: increasing access to technology, increasing technology use, and improving the effectiveness of technology use. The authors conclude that the primary benefit to date of technology integration in school settings has been increased access to information and communication. They suggest that further study is needed to provide guidance on how technologies can be used better to facilitate learners' cognitive processing toward improved learning outcomes.

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In the next chapter on medical education settings, Tiffany A. Koszalka, John Epling, and Jennifer Reese-Barnes discuss the extent of technology integration from the perspective of recent calls for medical school reform in the USA. The authors' review of the existing literature reveals that few studies report widely studied technology initiatives or provide sufficient evidence to support technology use as a way to inform curricular reform among medical schools. The authors conclude the chapter by calling for collaborative and interdisciplinary research aligned with medical curriculum enhancement themes.

Lastly in this section, Konrad Morgan reviews international best practice for how technology can be successfully integrated into multicultural settings. Examples provided here include a wide range of technologies and practical implementations at the intersection of multicultural education and instructional design. The author reviews the challenges of supporting multicultural differences in digital learning systems as well as potential solutions for overcoming those obstacles.

Clearly there are other contexts for instructional technology integration that might have been included here as well, such as work settings or informal learning settings, higher education generally, and other professional school education contexts (such as law). Unfortunately, circumstances and a general lack of research did not make it possible for us to include discussions of those topics in this edition. We will leave it to the editors of the next *Handbook* to consider including research reviews in these areas there.

References

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[*] An asterisk next to a reference entry throughout this Handbook indicates a reference that the author(s) considers to be central to the topic.

Generational Differences and the Integration of Technology in Learning, Instruction, and Performance

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Eunjung Oh and Thomas C. Reeves

Abstract

Generational differences have been widely discussed; attention to and speculation on the characteristics of the Millennial Generation are especially abundant as they pertain to the use of educational technology for education and training. A careful review of the current popular and academic literature reveals several trends. First, whether based on speculation or research findings, discussion has focused on traits of the newer generations of students and workers and how their needs, interests and learning preferences can be met using new media, innovative instructional design and digital technologies. Second, generally speaking, although in the past few years there have been more critical and diverse perspectives on the characteristics of the Millennial Generation reported in the literature than before, more substantive studies in this area are still necessary. This chapter discusses trends and findings based upon the past 10 years' literature on generational differences, the Millennial Generation, and studies and speculations regarding school and workplace technology integration that is intended to accommodate generational differences. There is still a lack of consensus on the characteristics of the newer generation sufficient to be used as a solid conceptual framework or as a variable in research studies; thus, research in this area demands an ongoing, rigorous examination. Instead of using speculative assumptions to justify the adoption of popular Web 2.0 tools, serious games and the latest high tech gear to teach the Millennial Generation, approaches to integrating technology in instruction, learning, and performance should be determined by considering the potential pedagogical effectiveness of a technology in relation to specific teaching, learning and work contexts. Clearly, today's higher education institutions and workplaces have highly diverse student bodies and work forces, and it is as important to consider the needs of older participants in learning with technology as it is to consider those of the younger participants. Recommendations for future research and practices in this area conclude the chapter.

Keywords

Generational differences • The millennial generation • Technology integration

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Introduction

In virtually any organization today, a broader range and variety of generations (mostly representatives of the Baby Boomer Generation, Generation X, and the Millennial Generation) work together than ever before. People are living and working longer. Although the first wave of Baby Boomers turned 65 in 2011, the traditional retirement age for

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workers in North America, many of them will work for many more years because of a weak economy, inadequate retirement savings, personal preferences and other factors. What makes this era especially interesting for those working in the field of educational technology is that these same generations are also often learning together in our colleges and universities and various types of training and professional development centers.

Generational differences have been discussed literally for generations, but over the past decade particular attention has been paid to how characteristics of the Millennial Generation differ from those of previous generations, and what these differences mean for people who educate, train, and/or supervise this generation. Various authors with unique interest in a particular aspect of different generations have used diverse perspectives to describe their area of concentration. Despite a growing interest in this topic and a body of literature in the popular press, business-oriented books, and some scholarly work, there has been no clear consensus in this area. For example, active debates about generational differences in education persist, especially concerning the characteristics of the Millennial Generation as learners and their use of technology (Bennett, Maton, & Kervin, 2008; Elmore, 2010; Prensky, 2010). Enthusiasts proclaim that these students are *Digital Natives* (Prensky, 2001, 2010; Rosen, 2010) whose lives have been immersed in a variety of emerging technologies since birth. It is argued that these digital natives thus have learning preferences different from previous generations; accordingly, current education and traditional pedagogical approaches need to be reformed in a way that will accommodate and optimize their learning experience. On the other hand, skeptics (Bennett et al., 2008; Bullen, Morgan, & Qayyum, 2011; Kennedy et al., 2009) claim that for various reasons, there is insufficient evidence in the body of literature to support the argument that these students have exceptionally sophisticated knowledge of and skills with emerging technologies or that they have markedly different learning preferences compared to previous generations.

The purpose of this chapter is threefold. First, we discuss a review of recent literature on generational differences. Second, we address various perspectives on Millennial Generation students' characteristics, needs, and interests in terms of academic competency, technology skills, and learning preferences. Finally, we make recommendations for further research and development in this area.

Generational Differences

Reeves and Oh (2007), in the AECT third edition *Handbook of Research on Educational Communications and Technology*, reviewed the literature on generational differences including the characteristics of various generations, the nomenclature used, and chronological dates as asserted by different authors. First, as summarized in Table 66.1, many authors have identified detailed differences among generations; however, there is a lack of consistency among these authors in how they delineate these characteristics (e.g., core values, attitudes, work habits), nomenclature, and chronological dates for each generation. Second, although there may be differences among generations that are defined by chronological dates, these characteristics vary greatly among individuals

Table 66.1 Generational labels and dates reported in different sources (from Reeves & Oh, 2007)

Source	Generational labels and dates				
Howe and Strauss (1991)	Silent generation	Boom generation	13th generation	Millennial generation	
	1925–1943	1943–1960	1961–1981	1982–2000	
Lancaster and Stillman (2010)	Traditionalists	Baby boomers	Generation Xers	Millennial generation Echo boomer Generation Y Baby busters Generation next	
	1900–1945	1946–1964	1965–1980	1981–1999	
Martin and Tulgan (2002)	Silent generation	Baby boomers	Generation X	Millennials	
	1925–1942	1946–1960	1965–1977	1978–2000	
Oblinger and Oblinger (2005)	Matures	Baby boomers	Gen-Xers	Gen-Y NetGen Millennials	Post-millennials
	<1946	1947–1964	1965–1980	1981–1995	1995–present
Tapscott (2009)		Baby boom generation	Generation X	Digital generation	
		1946–1964	1965–1975	1976–2000	
Zemke, Raines, and Filipczak (2000)	Veterans	Baby boomers	Gen-Xers	Nexters	
	1922–1943	1943–1960	1960–1980	1980–1999	

within a generation. Therefore, assumptions about an individual's characteristics cannot be made based solely on his or her chronological membership in a certain generation. Third, in addition to birth years, Howe and Strauss (2000) discussed three attributes that are important factors in determining the characteristics and nature of different generations: *perceived membership*, *common beliefs and behaviors*, and *common location in history*.

- *Perceived membership*—The self-perception of membership within a generation that begins during adolescence and coalesces during young adulthood.
- *Common beliefs and behaviors*—The attitudes (toward family, career, personal life, politics, religion, etc.) and behaviors (choices made about jobs, marriage, children, health, crime, sex, drugs, etc.) that characterize a generation.
- *Common location in history*—The turning points in historical trends from liberal to conservative politics and significant events, such as the Vietnam War, that occur during a generation's formative years, especially adolescence and young adulthood.

Although theories and assertions about the different attributes of generations are discussed in popular books, many of these ideas are not based on evidence from valid empirical research (Bennett & Maton, 2010). While discussions in academic literature regarding generation theories and comparisons of characteristics among generations are supported by very limited evidence, some people, including a few educational technology researchers, persist in using popular theories and unsubstantiated claims as conceptual frameworks to position their arguments in describing the needs of newer generations of students and employees and the kinds of support they need.

Despite these limitations, generational difference is now a topic in which many academic and corporate organizations show greater interest than ever before, as reflected by the numerous popular books, conferences and workshops devoted to generational differences that have appeared over the past 5 years. Perhaps this is a "growth industry" because almost everyone can relate to it in one way or another. After all, everyone belongs to a generation, no matter how that generation is perceived and characterized. The time of a person's birth influences his or her life experiences and choices, including pop culture, world events, social trends, economic realities, behavioral norms, and worldview throughout his or her life (Twenge, 2006).

Millennial Generation

For the past decade, one of the most popular and controversial topics in generational differences is the nature and importance of the so-called Millennial Generation. Members of this generation were born between the years of 1981 and 2000 (approximately) (Reeves & Oh, 2007), and they have been entering colleges and workplaces for the past decade. In the past few years, the body of literature and discussion on this topic has grown rapidly, perhaps because this generation is the largest since the Baby Boomers.

The Next Great Generation

Until recently, the dominant view of the Millennial Generation was very optimistic, as many popular books emphasized this new generation's exceptional and distinctive characteristics, and depicted how promising and rosy the future would be because of its members. For example, consider the works of Neil Howe and William Strauss, authors of a series of popular books such as *Generations*: *The History of America's Future*, *1584 to 2069*; *13th Gen*: *Abort*, *Retry*, *Ignore*, *Fail*?; *The Fourth Turning*; *Millennials Rising*: *The Next Great Generation*; *Millennials Go to College*: *Strategies for a New Generation on Campus*; and most recently, *Millennials and the Pop Culture*. In their best-selling book, *Millennials Rising*: *The Next Great Generation*, Howe and Strauss (2000) made the following claim, as based on their survey study of a limited and unrepresentative sample of 202 teachers and 655 high school students in an affluent suburban area outside Washington, DC:

> As a group, Millennials are unlike any other youth generation in living memory. They are more numerous, more affluent, better educated, and more ethnically diverse. More important, they are beginning to manifest a wide array of positive social habits that older Americans no longer associate with youth, including a new focus on teamwork, achievement, modesty, and good conduct (p. 4).

Their optimistic perspectives of these Millennials, although not based on a sound empirical foundation, have been accepted and used widely to justify numerous special programs and changes in higher education as well as in the workplace. However, over the past 5 years, several authors and scholars have also strongly criticized Howe and Strauss's claims. For instance, Twenge (2006) described this generation as *Generation Me* and claimed that:

> My perspective on today's young generation differs from that of Neil Howe and William Strauss, who argued in their 2000 book, *Millennials Rising*, that those born since 1982 will usher in a return to duty, civic responsibility, and team work… But I see no evidence that today's young people feel much attachment to duty or to group cohesion. Instead, as you'll see in the following pages, young people have been consistently taught to put their own needs first and to focus on feeling good about themselves… Strauss and Howe also argue that today's young people are optimistic. This is true for children and adolescents, who have absorbed the cheerful aphorisms so common today… Yet this optimism often fades—or even smashes to pieces—once Generation Me hits the reality of adulthood (pp. 6–7).

Based on the results of twelve empirical research studies conducted over 13 years on generational differences and using data from 1.3 million young Americans, Twenge (2006) surmised that although this Generation Me demonstrates unique characteristics, it would not be, as Howe and Strauss described, the greatest generation. According to Twenge and Campbell (2009), the characteristics of Generation Me result from the "self-esteem movement" that encouraged admiration of the self, based on the belief that self-admiration will improve one's life. However, Twenge and Campbell (2009) argued that the encouragement of a culture of self-esteem and self-admiration engendered overconfidence and an epidemic of narcissism in this new generation, especially in the USA and other affluent nations. The problem, according to Twenge and Campbell (2009), is that when these Generation Me individuals encounter the tough realities of twenty-first century life, there is a gap between what they believe they deserve and what they actually can attain as they become adults no longer protected by their parents and teachers. In her *Generation Me* book, Twenge (2006) discussed many strategies and provided useful advice for a variety of people including parents, employers and marketers/entrepreneurs. For instance, she says that young employees and students

> will work hard, but even harder if they are praised and appreciated. This is true of any generation, of course, but it is especially true of GenMe'ers, who were raised on extensive praise and almost expect it. This generation is not motivated by feelings of duty—working hard is not virtuous in itself, but it is worth it if they are singled out and recognized (Twenge, 2006, p. 217)

This need for praise and recognition among the Millennials appears to be accompanied by a desire for "hands-on guidance and direction" in the workplace according to the results of a 2011 survey of nearly 5,000 workers in the insurance industry in the USA (Howe & Nadler, 2012). The survey results indicate that 70 % of Millennial insurance company workers agreed with the statement "I like my supervisor to provide me with hands-on guidance and direction" whereas only 40 % of Boomer and Gen-X workers agreed with this statement.

Digital Natives

Another recent debate concerns the technology use of this new generation with the implication that their use of technology differentiates them from previous generations. For the past decade, Mark Prensky (2001) has argued in numerous publications that today's students are Digital Natives who have been surrounded by technology since they were born. Therefore, they have a natural tendency and ability to speak the language of computer technology in what has been labeled the Digital or Information Age (Eisenberg, 2008). According to Prensky, members of this digital native generation are very technologically savvy and have a high reliance on emerging technologies. On the other hand, their parents and teachers are *Digital Immigrants* who were born and grew up in a pre-digital age but who have had to integrate technology into their lives as it has rapidly evolved to become essential. Accordingly, it is assumed that the Digital Immigrants' levels of understanding of and skills with technology are not as sophisticated and fluent as those of Digital Natives. Proponents of the "wired generation" perspective (Prensky, 2001; Rosen, 2010; Tapscott, 2009) who support the notion of the uniqueness of Digital Natives have two primary assumptions:

- Young people of the Digital Native generation possess a sophisticated knowledge of and skills with information technologies.
- As a result of their upbringing and experiences with technology, Digital Natives have particular learning preferences or styles that differ from earlier generations of students (Bennett et al., 2008, p. 777).

Based on assumptions that the respective differences in Digital Natives' and Digital Immigrants' technology use and literacy are especially significant, some authors have argued that current educational methods are not effective with digital native students. Prensky (2010), in his recent book, *Teaching Digital Natives*: *Partnering for Real Learning*, discussed the changes in our world because of technology and globalization and called for a shift in the thinking of teachers and parents and a change in schools' pedagogical approaches.

> But there is a huge paradox for educators: the place where the biggest educational changes have come is *not* our schools: it is everywhere else *but* our schools. The same young people who we see bored and resistant in our schools are often hard at work learning afterschool (a term I use to encompass informal learning through peers, the Internet, YouTube, television, games, cell phones, and lots of other emerging opportunities, as well as through organized programs such as FIRST Robotics). It is in the afterschool world, rather than in schools, that many of our kids are teaching themselves and each other all kinds of important and truly useful things about their real present and future (pp. 1–2).

Some proponents of the digital native perspective have gone so far as to conclude that having a technology-rich lifestyle and culture has fundamentally changed the way these younger students learn and think (Rosen, 2010). Prensky (2010) also contended that the educational system and methods used for years with previous generations, such as the Boomer Generation and Generation X, will not help these younger students to become prepared for their future in this radically changing Digital Age.

Although the research support for fundamental changes in how students think and learn is weak, it is true that many Millennial Generation students are immersed in media in most aspects of their lives and their use of time has drastically changed from that of previous generations. For example, in the 1920s, fourth through sixth grade students devoted 3 hr per day to amusements such as playing, watching motion-picture shows, riding, and reading (Goldberg & Pressey, 1928). In contrast, according to the recent Kaiser Family Foundation report on today's American youth, students from ages 8–18 years are exposed to digital media for 7 hr and 40 min per day but spend only 30–40 min with print media, including books and newspapers (Rideout, Foehr, & Roberts, 2010). Some argue that this ubiquitous engagement with digital media prepares students for a bright future (Prensky, 2001; Rosen, 2010; Tapscott, 2009) whereas others predict much less desirable outcomes (Bauerlein, 2008; Carr, 2011; Jackson, 2009). Neither side of the argument is armed with adequate research.

It is not surprising that a number of scholars have begun to raise issues concerning optimistic assertions about Digital Natives in terms of (1) their technology use and skills and (2) their learning styles and preferences, and, accordingly, about (3) calls for fundamental changes in education (Bennett et al., 2008; Bullen et al., 2011). Although the members of the Millennial Generation, Digital Natives, are exposed to media for a considerable amount of time every day, and many of them perhaps think that their use of technology is savvier than that of their Digital Immigrant teachers and parents, the variety of technologies with which this younger generation is engaged, and their abilities with them, are limited (Bennett et al., 2008; Bullen et al., 2011; Charsky et al., 2009; Kennedy et al., 2009; Oblinger & Oblinger, 2005). For example, Oblinger and Oblinger (2005) referred to this generation as Net Gen and claimed that they are not as digitally literate as they are generally perceived.

> Having grown up with widespread access to technology, the Net Gen is able to intuitively use a variety of IT devices and navigate the Internet. Although they are comfortable using technology without an instruction manual, their understanding of the technology or source quality may be shallow (p. 2.5).

In a *2005 Annual Study of Students and Information Technology* conducted with 18,039 freshmen and senior students on their experience with IT in higher education, Caruso and Kvavik (2005) reported that a majority of students responded that they owned one computer and one cell phone, and they used technology, mostly computers, for studying, social interaction and entertainment. These students reported preferring a moderate use of technology in classrooms, which is helpful but supplemental to their course experience and not something to transform or substitute for teaching and learning. Many students perceived that they are quite skilled in using technologies. However, based on Caruso and Kvavik's survey results, their top three technology uses were (1) creating, reading and sending email (99.7 %), (2) writing documents for coursework (98.9 %), and (3) surfing the Internet for information to support coursework (98.4 %). These are common technologies that do not require much in the way of specialized knowledge or skills. In contrast, their reported least used technology skills were (1) creating graphics using Photoshop and Flash (48.7 %), (2) creating Web pages using Dreamweaver and Frontpage (24.9 %), and (3) creating and editing video/audio using Director and iMovie (24.1 %). In summary, respondents reported using common technologies widely on a personal level, but their use of specialized technologies was limited and mostly in relation to their course curricula.

A few years ago, several Australian scholars from three higher education institutions conducted an interesting study using a questionnaire given to 2,500 college students and faculty, and focus group interviews with 46 freshmen students and 31 faculty members. Their research project, *Educating the Net Generation* (http://www.netgen.unimelb.edu.au/overview/index.html) explored (1) students' and teachers' current technological experiences and preferences and (2) a range of issues associated with the implementation of emerging technologies in local learning and teaching contexts (Kennedy et al., 2009, p. 25). Based on their extensive data, these researchers reported six major findings:

1. The rhetoric that university students are Digital Natives and university staff are Digital Immigrants is not supported.
2. There is a great diversity in students' and staff experiences with technology and their preferences for the use of technology in higher education.
3. Emerging technologies afford a range of learning activities that can improve student learning processes, outcomes, and assessment practices.
4. Managing and aligning pedagogical, technical and administrative issues is a necessary condition of success when using emerging technologies for learning.
5. Innovation with learning technologies typically requires the development of new learning and teaching, and technology-based skills, which is effortful for both students and staff.
6. The use of emerging technologies for learning and teaching can challenge current university policies in learning and teaching and IT (pp. 25–26).

In agreement with Caruso and Kvavik (2005), the researchers in this Australian study found that young people stated that they rely on common core technologies such as email, cell phones and the Internet, and their purposes for using those technologies were limited to information gathering using Google and communication through various social media. In contrast, their use of emerging tools such as Web 2.0 tools including blogs, wikis and social bookmarking, which require higher-level thinking and can benefit their learning, was very limited. Overall, these researchers concluded that differences in technology use patterns between the younger generation (students) and the older generation (staff) were small. Rather, demographic variables such as gender, socio-economic status and cultural background accounted for more differences in students' technology use.

Bullen et al. (2011) conducted focus group interviews with 69 students and collected survey responses from a random sample of 438 second-year students at a large (43,000 students) public technical training institute in Canada. They found no meaningful differences among the digital skills of different generations of students in their sample. For members of the Millennial Generation, they reported that these students "use a limited set of ICTs and their use is driven by three key issues: familiarity, cost and immediacy" (p. 1). These findings corroborate the survey results obtained from 8,353 students enrolled at 25 colleges and universities in the USA conducted in the first quarter of 2010 by Head and Eisenberg (2010):

> Despite their reputation of being avid computer users who are fluent with new technologies, few students in our sample had used a growing number of Web 2.0 applications within the past six months for collaborating on course research assignments and/or managing research tasks. For over three-fourths (84 %) of the students surveyed, the most difficult step of the course-related research process was getting started. Defining a topic (66 %), narrowing it down (62 %), and filtering through irrelevant results (61 %) frequently hampered students in the sample, too. Follow-up interviews suggest students lacked the research acumen for framing an inquiry in the digital age where information abounds and intellectual discovery was paradoxically overwhelming for them (p. 3).

Other than e-mail and cell phones, some of the most popular technologies with which so-called Digital Natives spend most of their time are social networking tools such as Facebook, MySpace and YouTube. Among all kinds of Web 2.0 tools that enable more user-centered information creation and sharing, it is important to think about why these particular social media tools have become so popular among members of this generation. Twenge and Campbell (2009) speculated on the reasons for this popularity:

> Web 2.0 and cultural narcissism work as a feedback loop, with narcissistic people seeking out ways to promote themselves on the Web and those same websites encouraging narcissism even among the more humble. The name "MySpace" is no coincidence. The slogan of YouTube is "Broadcast Yourself." The name "Facebook" is just right, with its nuance of seeing and being seen, preferably looking as attractive as possible (p. 107).

A recent study by Correa, Hinsley, and Zúñiga (2010) appears to support the views of researchers who have concluded that individual differences in personality factors such as narcissism and extraversion are stronger predictors of social media engagement than generational membership. Correa et al. (2010) investigated the relationships between individual personality traits and social media use, based on a national sample of adults in the USA. They found that extraverted men and women tend to use social media more frequently than introverted people. Interestingly, they found that young adults who are extraverted and older people who are predisposed to being open to new experiences are equally likely to engage in social media activities. Another interesting finding is that men with emotional instability and with greater levels of neuroticism tend to engage more in activities with social media, perhaps as a way to express themselves and their feelings and to be supported by others.

Social media tools can undoubtedly have great value in the lives of people of all ages today, allowing them to remain connected with their friends with ease by sharing their current interests and status among family, friends, and even, if sought, a global audience. For example, some people post useful information by maintaining blogs in their specialized areas and interests while others use blogs as their personal diaries to post pictures and events of their lives. These Web 2.0 tools certainly offer the benefits of enhanced communication, information-gathering facilitation, and even the provision of informal learning opportunities. Whether the active use of social networking tools has contributed to an increase in the cultural narcissism in our society, as argued by Twenge and Campbell (2009), or an increase in narcissism has contributed to the popularity of social networking remains unsettled.

In addition to assertions about the limited types of technology used by the Millennial Generation students and their low levels of technological literacy in general, it has been noted that they do not naturally adopt and adapt technologies in academic settings. Charsky and her colleagues (2009) taught college freshmen about organizational communication by having the students immerse themselves in a 4-week participatory simulation using virtual teamwork. Initially, students' own choices and use of technologies such as Facebook, Yahoo Groups, Google Docs and instant messaging for team work and collaboration were not successful because some tools were not inclusively useful among group members due to individual differences in technology proficiency and preferences. Some tools were simply not effective or appropriate for supporting teamwork because the tools publically disseminated confidential information. Subsequently, the instructor and researchers used a mock intranet that included synchronous and asynchronous tools to facilitate communication within and among virtual teams working for a fictitious company. However, researchers found that so-called Digital Native students, whose innate abilities in adopting and adapting technology have been praised by Prensky (2010) and others, actually required training in using communication technology to facilitate teamwork.

> Millennials are not able to integrate their supposedly inherent technology adeptness into academic work even when they perceive the digital communication technology as authentic and potentially beneficial. Despite being provided with technology

> that had the same functionality as their more popular commercial equivalents, the students did not integrate these tools into their academic work, which, in this particular course, mirrored activities taking place in many organizations…. Future analysis and research is needed regarding why students did not transfer their supposed technology adeptness into an academic context that simulated organizational work (Charsky et al., 2009, p. 48).

In summary, it is obvious that more and more of today's younger students have been exposed to and/or have immersed themselves in digital technology, especially when compared with previous generations. Technology is, to an appreciable extent, an important part of their lives. In light of these facts, some popular commentators surmise that Digital Native students are dissatisfied, disappointed and disengaged in learning at formal educational institutions, and accordingly, they argue that there is an urgent need to transform the outdated and irrelevant instructional methods used in schools (Prensky, 2001, 2010; Tapscott, 2009). However, studies reveal that there is little evidence that Millennials have a superior ability to integrate technology into their personal or academic lives (Caruso & Kvavik, 2005; Charsky et al., 2009; Kennedy et al., 2009). In addition, there is no strong evidence in the literature that the Millennials express serious dissatisfaction with or disengagement from learning (Bennett et al., 2008; Caruso & Kvavik, 2005). Bennett et al. (2008) argued that this current Digital Native debate can be seen as an "academic moral panic" in which "public concern can achieve prominence that exceeds the evidence in support of the phenomenon" (p. 782).

It is important to note that both optimists and skeptics in this debate see a gap between the kinds of roles that digital technologies play in these students' school and afterschool existence. The literature reviewed for this chapter supported the same conclusion drawn in a recent literature review by Bennett and Maton (2010):

> The lack of evidence for the existence of an entire generation of Digital Natives seriously undermines arguments made for radical change to education because of a proclaimed disjuncture between the needs of young people and their educational institutions. This is not to say that education should not change at all, but merely, that the basis of the argument, as it is currently made, is fundamentally flawed (p. 325).

Indeed, few K-12 teachers and college faculty would deny that digital technology is now an important part of their students' lives, and many, perhaps most, instructors seek meaningful ways to integrate technology in their teaching to support the learning process. In addition to considering how technology can improve teaching and learning, educators should consider how best to enable their students to develop advanced information literacy skills. Educational institutions have not been effective in undertaking to teach these students how to use emerging technologies appropriately and effectively for learning, as well as in their lives as citizens of the Digital Age.

Discussion

Diversity

For the past few years, voices have urged exploration of the characteristics of the Millennial Generation and their differences from other generations by considering more diverse groups of people, such as the poor. It is problematic that the major assertions on these topics found in popular books written by such authors as Howe and Strauss (2000) have been based on limited profiles of Millennial Generation students who come from affluent suburban areas around large cities and whose parents are likely to have an above average socioeconomic status (SES). As these samples do not adequately represent members of the Millennial Generation from inner city and rural populations, scholars in the field have criticized such claims (Reeves & Oh, 2007). Other research studies have focused on exploring the characteristics of college students, but the students sampled in these studies are primarily (1) from large research universities, (2) able to afford a college education, (3) owners of at least one computer and one cell phone and (4) likely to become white collar knowledge-sector employees. As discussed by Kennedy and colleagues (2009), demographic variables such as being a domestic or international student and socio-economic status influence differences in technology use among college students. If people from groups representing greater diversity in terms of location, ethnicity, nationality, SES and job categories are included in new studies of these kinds, the understanding of generational characteristics, particularly regarding their technology use and the uses of these technologies for formal and informal learning, should be strengthened.

Technology Integration

As noted above, both optimists and skeptics about the Millennial Generation agree on the importance of meaningful technology integration in education and training. Some members of the Millennial Generation are truly Digital Natives who have the ability to identify the purposes and functions of different media and use them at a sophisticated level. Many others in this generation have merely had more exposure to media and may have also developed a greater preference for digital technologies and social media than previous generations. No matter what perspective we have about this generation, no one will deny that we live in a digital era in which technology has become, and will continue to be, present in virtually every aspect of our lives. While some authors are promoting ways of thriving in our digital times (Rheingold, 2012), others are counseling how to reduce our dependency on twenty-first century Internet technologies (Carr, 2011).

How does technology influence the learning and performance of Millennials? Although many educational technology researchers have made a great effort to enhance instruction, learning, and performance, critics such as Bauerlein (2008) have raised serious concerns about the intellectual deficits of today's students in almost every subject because of their extensive use of technology. Bauerlein (2008) analyzed several national assessments and large survey results such as the SAT, ACT, National Assessment of Educational Progress (NAEP), National Survey of Student Engagement (NSSE), Kaiser Family Foundation Program for the Study of Entertainment Media and Health, American Time Use Survey by the Bureau of Labor Statistics (ATUS), Survey of Public Participation in the Arts by the National Endowment for the Arts (SPPA) and Geographic Literacy Survey by National Geographic. As a result of his analysis, he concluded:

> …in sum, while the world has provided them extraordinary chances to gain knowledge and improve their reading/writing skills, not to mention offering financial incentives to do so, young Americans today are no more learned or skillful than their predecessors, no more knowledgeable, fluent, up-to-date, or inquisitive, except in the materials of youth culture. They don't know history or civics, economics or science, literature or current events. They read less on their own, both books and newspapers, and you would have to canvass a lot of college English instructors and employers before you found one who said that they compose better paragraphs. In fact, their technology skills fall well short of the common claim, too, especially when they must apply them to research and work place tasks. The world delivers facts and events and art and ideas as never before but the young American mind hasn't opened (pp. 8–9).

A number of authors of popular books and researchers report that today's generation uses technology mostly for entertainment, social connection with their friends, and a few learning tasks requiring fairly simple technical skills such as writing with Microsoft Word (Bauerlein, 2008; Caruso & Kvavik, 2005; Kennedy et al., 2009). Although today's society demands that its members have higher levels of professional competencies and continue with their professional development more than ever before, some critics argue that the minds and intellects of students and young adults are moving in the opposite direction (Bauerlein, 2008; Carr, 2011; Jackson, 2009; Turkle, 2011). Therefore, the efforts of educational technologists to work with K-12 teachers and college faculty must be increased if today's students are to achieve twenty-first century outcomes of learning and be prepared as competent professionals in their future careers.

First, it is important to help educators select and integrate technologies by considering their potential contribution to pedagogical effectiveness instead of making assumptions about the preferences of younger generations. Second, it is critical to help educators and learners use technology as cognitive tools (Jonassen & Reeves, 1996; Kim & Reeves, 2007) to improve academic work and develop intellectual skills such as critical thinking, problem solving, information literacy, and collaboration. Younger generations must be guided to use emerging technologies for more productive intellectual and career development so that they do not confine using technology primarily to entertaining themselves and staying current with their own youth culture (Head & Eisenberg, 2010).

Curriculum Development

Although the International Society for Technology in Education (ISTE) (2011) addresses *Digital Citizenship* as its fifth National Educational Technology Standard (NETS) for students, what is seriously missing in today's curriculum is teaching younger generations to live as well-rounded digital citizens. As mentioned above, a number of studies noted that the ways the Millennial Generation uses technology are limited. For every age, such as agricultural, preindustrial, and industrial ages, education contributed to preparing citizens who are responsible for and can fulfill the needs of the society. Compared to the speed that digital technology has been transforming our life styles, much of what we teach still remains in a pre-digital age. Not only how we teach, including technology integration, but also what we teach, in terms of curriculum, should be reconsidered. For example, Digital Citizenship might encompass what Rheingold (2012) identifies as five fundamental digital literacies in the twenty-first century: (1) attention or mindfulness, (2) participation, (3) collaboration, (4) critical consumption of information, and (5) network smarts.

According to Ribble, Bailey, and Ross (2004), "digital citizenship can be defined as the norms of behavior with regard to technology use" (p. 7). They identified nine areas of digital citizenship: etiquette, communication, education, access, commerce, responsibility, rights, safety, and security. In consideration of Digital Citizenship, there is an obvious need for more research and development to support effective media education (Jenkins, 2009). Many topics can be developed as a part of a new curriculum to prepare this Millennial Generation as well as the new generation (dubbed Generation Z) currently being born for productive participation in the Digital Age and beyond. For example, schools should teach students about cyber safety to protect themselves as well as others, along with the etiquette and ethics appropriate for communication in cyber space (Hanewald, 2008; Mishna, Cook, Saini, Wu, & MacFadden, 2011).

Perhaps the curricular area in most need of innovation concerns information literacy. Many authors have discussed this deficiency (Bauerlein, 2008; Coinsidine, Horton, & Moorman, 2009; Head & Eisenberg, 2010; Oblinger & Oblinger, 2005). Not only do today's students read less and write less well when compared to previous generations (Bauerlein, 2008) but they also lack literacy about technology and media (Coinsidine et al., 2009). Their information, technological, and media literacies should be enhanced (Eisenberg, 2008). Being literate in these areas is not only fundamental for students to grow up as well-rounded members of a digital world, but it also fosters their development in other areas, including critical and creative thinking, and technical, research, and problem solving skills.

Future Research Agenda

The ongoing arguments about the implications of generational differences, including the characteristics of the Millennial Generation and the still emerging Generation Z, herald many opportunities for future research. First, to strengthen generational theory and its application, researchers must examine generational differences and characteristics across different groups including SES, ethnicity, nationality, and gender. Although many current claims are still weakly supported, it has been a positive development that more scholars have raised concerns about extending and enhancing research in this area.

Second, exploring how Millennial Generation K-12 teachers and college professors differ in their technology integration from previous generations of educators can also clarify the debate on the preferences and abilities of the Millennial Generation. When the Digital Natives vs. Digital Immigrants debate emerged a decade ago, representatives of the Digital Natives had just begun entering colleges and workplaces. However, now older members of this generation are already working as teachers and trainers. If they are truly Digital Natives and possess attributes unlike those of Digital Immigrants, the way they integrate technology in their teaching and training would likely be different from that of previous generations.

Third, educational design research (McKenney & Reeves, 2012; van den Akker, Gravemeijer, McKenney, & Nieveen, 2006) is a much-needed approach to investigate a number of topics in this area. For example, design research can be used to support teachers and faculty members' effective technology integration in teaching various performance standards and subjects. Additionally, educational design research can be used to develop the new curricula as suggested above. Finally, design research can be useful in identifying how to accommodate generational differences during the instructional design process. As educational design research aims for an actual transformation through outcomes of both transferable, practical interventions and reusable design principles, this research approach can contribute to the advancement in and transformation of practice and theory in this area.

Conclusions

Compared to the speed with which the newer generation students and young adults are exposed to and use media, the speed of transition in both research and educational practice is glacially slower. The current situation certainly presents serious concerns. We should be worried not only because technology integration is less common and effective in education than it should be, but also because the ways in which today's students use technology and the amount of time they spend using that technology are far from ideal. Moreover, with respect to both media education and information literacy, a gap clearly exists between what today's learners have been taught and what they should have been taught. Our current educational systems do not sufficiently teach or guide our students about how to live in a society tremendously transformed by technology. Technology has become a central part of virtually everyone's life and has transformed reading, writing, communicating and even thinking for most people (Collins & Halverson, 2009). However, the new generation has not had sufficient opportunities to competently adapt to those changes and become adept with digital technologies and media for learning and living.

We live in an era in which lifelong learning is required, as well as enabled, via the use of emerging technologies. Using technology for learning should be as central a part of modern life as it is for amusement and social communication. Important research questions remain unanswered. How can new and emerging generations effectively use technology for their learning and development while they are in the educational system and throughout their lives? What are the real effects of the increasingly digital world on teaching and learning?

Twenge (2006) wrote, "You can't blame someone for absorbing culture around him… Just trying to see things from their perspective will help a lot" (p. 216). The uppermost mission of education, particularly K-16, is preparing younger generations for the future. The important question is whether we educators are helping today's Digital Natives and tomorrow's still undefined generation become competently equipped for their future in this rapidly changing digital age, where even toddlers' favorite toys have become smartphones (Stout, 2010). Instead of debating the real characteristics of the Millennial Generation or criticizing the abilities or technology use of various generations, the authors of this chapter believe that now is the time for moving forward toward the next step, which is substantial action for a real change in the education and lives of all learners. For that change, the roles and responsibilities of the educational technologist are profound.

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Measuring Technology Readiness and Skills

67

Rhonda Christensen and Gerald A. Knezek

Abstract

Traditional and emerging forms of assessment for measuring technology readiness are presented in the context of society's need for assessing twenty-first century skills. Workforce preparation is identified as a driving force for new forms of assessment, while rapid advances in information technologies offer opportunities for new techniques to emerge. Recent approaches to learning, such as digital game environments, demonstrate that alternative forms of assessment are emerging to fulfill these changing needs. In this chapter the need for technology readiness is introduced in the context of assessing twenty-first century skills. Conceptual and practical considerations are addressed within the categories of foundation skills, technology applications, attitudes toward technology, communicating with technology and digital citizenship. A presentation of emerging assessment techniques leads to discussion of the importance of technology readiness for preparing a productive workforce. In addition, this chapter includes prospects for forms of assessment unique to new digital media.

Keywords

Technology readiness • Twenty-first century skills • Digital literacy

Introduction

Over the past 20 years we have changed the way we access, learn, and communicate information. We have increasingly become more dependent on technology. We use technology to find jobs, read news, plan trips, purchase products, communicate with friends and colleagues, watch movies, play games, and more. However, an increased exposure to and even use of technology does not necessarily lead to an increased ability to use it effectively. Economists at MIT have noted that information technology may be advancing faster than the labor market can keep up, creating inflated unemployment (Talbot, 2012). "Students will spend their adult lives in a multitasking, multifaceted, technology-driven, diverse, vibrant world – and they must arrive equipped to do so" (Partnership for 21st Century (P21), 2003, p. 4). Educators are preparing students for a future that is not well defined. It is important to emphasize lifelong learning skills and self-directed learning with the ability to select and use the appropriate tools to complete the job or task required.

In our twenty-first century society the amount of available information is increasing at an astronomical rate. Jukes (2011) labeled this phenomenon *digital bombardment*. One case in point cited by Jukes is the enormous growth of Google. Google began in 1996 with an index of 25 million pages. In 2010 the number of pages that Google indexed had grown to 40 billion—1,600 times the size of Google when it began (Jukes, 2011). Innovative forms of assessment that utilize new media, such as digital badging systems, appear to be expanding at similar exponential rates.

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What Is Technology Readiness?

Technology readiness involves more than just technology literacy skills. It involves the ability to choose the appropriate tools for the task at hand in order to be productive citizens. Technology plays a major role in the definition of twenty-first century skills, critical thinking, problem-solving, communication, and collaboration. As observed by Resta, Searson, Patru, Knezek, and Voogt (2011), "An important change has occurred in the way new digital tools and collaborative environments have enhanced learning, moving from an emphasis on reproducing information to content creation and sharing in virtual environments." This set of skills is commonly referred to as digital literacy.

Digital literacy is a broad concept that has several aspects: technological literacy, Information and Communication Technology (ICT) literacy, and information literacy (Resta et al., 2011). "Digital literacy includes the confident use of ICT for work, learning, communication, and leisure and is considered one of the eight essential skills for lifelong learning" (Resta et al., 2011, p. 3). According to the New Media Consortium (NMC) Horizon Report (2012), digital media literacy is a key skill in every discipline and profession (Johnson, Adams, & Cummins, 2012). To compete in the global knowledge economy, successful workers will need to have multiple literacies. According to Spector (2012) these include digital literacy, information literacy, visual literacy, and technology literacy. "In addition, successful knowledge workers will need to be creative and critical thinkers, and have good communication and self-regulation skills" (Spector, 2012, p. 134).

Critical thinking is an essential skill both in school and beyond the classroom. With the massive amount of information and human connections available via the Internet, today's learners must have the capacity to critically judge which parts are trustworthy. "Today's citizens must be active critical thinkers in order to compare evidence, evaluate competing claims, and make sensible decisions" (P21, 2007b, p. 13). According to a survey of 431 human resource officials, critical thinking is the most important among a dozen valuable twenty-first century skills (Casner-Lotto & Barrington, 2006).

Problem-solving involves collaboration and communication. According to a report by the Partnership for 21st Century Skills, "Communication skills are especially critical in the expanding service economy – estimated to be 81 % of jobs by 2014" (P21, 2007b, p. 17). Today's technology enables citizens who are not in the same location and do not know each other to collaborate, regardless of time and space, for a common goal. "Successful problem solving in the 21st Century requires us to work effectively and creatively with computers, with vast amounts of information, with ambiguous situations, and with other people" (P21, 2007b, p. 14).

As a result of the projected needs of our society, many national and international groups have created lists and descriptions of twenty-first century skills that address the needs of preparing students to contribute to a global, collaborative workforce. These groups have found overlapping commonalities in their list of skills. All of these lists involve a very different set of skills than were required just a decade ago. What does not appear in any of the skill sets is rote memorization. What does appear directly or indirectly is the need for critical thinking, problem-solving, and effective communication. The facts-based knowledge and skills of the previous generation of schooling are no longer sufficient for today's students. Students need to become lifelong learners. Therefore, it is important that they learn how to learn so they can adapt to an ever-changing technological society and economy.

In order to address these needs, professional associations such as the International Society for Technology Education (ISTE) have revised their student standards to include higher order skills while retaining basic/minimum skills (technology operations and concepts). Countries such as Brazil, Canada, Costa Rica, China, India, Malaysia, Mexico, and The Philippines have used the ISTE standards as a basis for their own standards (Knezek, 2011). The ISTE National Educational Technology Standards for Students (NETS•S) include the following:

- Creativity and Innovation.
- Communication and Collaboration.
- Research and Information Fluency.
- Critical Thinking, Problem-Solving, and Decision Making.
- Digital Citizenship.
- Technology Operations and Concepts.

Another example of a framework for developing and maintaining twenty-first century skills is the European Commission's TENCompetence project. The TENCompetence project created infrastructure for lifelong competence development in Europe. The project developed improved new innovative, pedagogical approaches, assessment and organizational models, and created a technical infrastructure to integrate existing models and tools into a common framework (Schoonenboom et al., 2008).

In addition, Spector (2012) suggested that the P21 framework shown in Table 67.1 places a premium on independent, higher-order reasoning skills necessary for productive citizens in the twenty-first century. These higher-order reasoning skills span three major categories of learning and innovation skills; information, media, and technology skills; and life and career skills.

Table 67.1 Framework for skills necessary for productive citizens in the twenty-first century (from Spector, 2012)

Learning and innovation skills	Creativity and innovation Critical thinking and problem-solving Communication and collaboration
Information, media and technology skills	Information literacy Media literacy ICT literacy
Life and career skills	Flexibility and adaptability Initiative and self-direction Social and cross-cultural skills Productivity and accountability Leadership and responsibility

Both the P21 framework and the ISTE NETS emphasize critical thinking, problem-solving, communication, collaboration, and digital literacy.

What Are the Components of Technology Readiness?

Baker (2011) pointed out that the concept of twenty-first century skills likely encompasses specific sets of skills within different domains such as cognitive skills, social development skills, and intrapersonal skills. The skills directly relevant to the use of technology can be identified by selecting those aligned with frameworks such as the ISTE NETS•S. Ways of determining cognitive and social as well as technology readiness can be identified by merging concepts from the ISTE NETS•S with a broad array of characteristics necessary for twenty-first century learning. The major components described here are foundation skills, applications, and attitudes. Also addressed are digital citizenship and effective communication. Each of these components is discussed in the context of techniques for their assessment.

Foundation Skills: Technology Productivity Tools

Technology Literacy Tests

Thousands of eighth grade students across the USA are given comprehensive exams for technology literacy each year, but it is unclear as to how these assessments are used, other than to comply with a federal law. In the USA, The Enhancing Education Through Technology Act of 2001, issued by the US Department of Education, established requirements by which states must report the technology literacy of all eighth grade students (*Taking a good look at instructional technology*, 2007). The Chicago-based Mid-Continent Research for Education and Learning Laboratory (McREL), over the decade since the law's enactment, has examined and linked to more than one dozen different eighth grade testing systems spread across the 50 states in the USA (McREL, 2010). Implementations range from "none at all" for some states, to extensive reporting and tracking in others. They range from a straightforward *Test of Computer Skills* (North Carolina) to authentic performance of computer skills (Florida), to comprehensive assessment of student, teacher, and administrator skills (Montana) (McREL, 2010). The most widely used in the USA is TAGLIT, a suite of online assessment tools designed to provide educational institutions effective data to evaluate technology use and integration in the teaching and learning environment. TAGLIT is based on the National Educational Technology Standards for the USA. The tools include assessments for school leaders, teachers, and students. For example, to receive funding through the US Enhancing Education through Technology, Title II, Part D program, schools must collect data about their eighth grade students' level of technology literacy. TAGLIT is one of the online assessment tools that allow local school entities to assess their students.

Technology Driver's Licenses

Some groups have developed "driver's licenses" to award to individuals who have gone through an assessment of their technology skills. In Europe the European Computer Driving License Foundation (ECDLF) has created a program for teachers and students. ECDLF's certification programs are delivered in 148 countries around the world in 41 different languages to individuals and organizations. According to the ECDLF (2011), "Students with ICT skills will enjoy an enriched educational experience and will be better prepared for life, work, and further learning. ICT skills enable teachers to use technology more effectively in the teaching process, thus achieving educational goals more efficiently, and in doing so saving time, and increasing productivity in the classroom." To earn the certification, the candidate must successfully pass a test in seven modules. These are:

1. Concepts of information and communication technology (ICT).
2. Using the computer and managing files.
3. Word processing.
4. Spreadsheets.
5. Using databases.
6. Presentation.
7. Web browsing and communication.

Applications: Selecting and Applying Appropriate Tools

The goal of technology literacy is not to have basic skills but to apply those skills for productive endeavors. Once students have the basic knowledge and skills of technology use, it is important that they are able to select the appropriate tool for the job/assignment that is required of them. The goal is to teach students to transfer basic technology skills to solving problems; creating, producing and contributing to future job skills; or even for applying their skills to produce future products in school. For example, once students know the basics of what spreadsheet applications can do, they may find ways to communicate data visually for their history class. Students who have learned how to critically evaluate sources on the Internet are better prepared to produce a quality research paper for their English class.

Selecting and applying appropriate technology tools has been addressed at the international level. The Organization for Economic Cooperation and Development (OECD) Programme for the International Assessment of Adult Competencies (PIAAC) (OECD, 2010) identified problem-solving skills in technology-rich environments as one of the four core skills to be possessed by adults in 24 participating countries. According to OECD, "…in the information age – an age in which the accessibility of boundless information has made it essential for us to be able to work out what information we need, to evaluate it critically, and use it to solve problems" (p. 7).

Attitudes: Motivation and Engagement of the Learner

Since the early 1980s researchers have agreed that the successful use of computers and technology for learning is dependent on positive attitudes toward technology (Lawton & Gerschner, 1982). As observed by Marshall and Cox (2008), over the past quarter century a large number of research studies have been conducted into attitudinal and motivation/personality factors toward IT in education. Many of these contained attitude surveys consisting of questions about fear of computers, extent of liking technology, attitudes toward using technology in school, and so forth—and have shown strong links between pupils' and teachers' attitudes and the effect on IT use and learning (Marshall & Cox, 2008). In the area of engineering education, the criteria for lifelong learning includes both the "will do" and "can do" attitudes encompassing not only the skills the learners must have but also the willingness attributes that are critical for self-directed learning (Litzinger, Wise, Lee, & Bjorklund, 2003).

Additional topics have emerged in recent years that enrich technology use beyond basics and transcend most uses of technology. These focus less on the technology itself and more on the information produced by the new information technologies. Two that are widely agreed as having universal importance are digital citizenship and effective communication.

Digital Citizenship

As important as teaching students how to use technology effectively is preparing them to use it appropriately. Digital citizenship is a critical part of technology use for students. With the ability to share information instantly, technology users must be aware of the consequences of the information they share in the world. It is left to parents and teachers to help students navigate through the living Internet and social networking activities, using a moral compass that protects students from making mistakes that could last a lifetime. Not only do students need to be aware of protections to safeguard their physical and psychological safety, but their identity and reputation may also be at risk. Digital literacy, as previously described in this chapter, is an important foundation for digital citizenship.

Effective Communication

In addition, communication is also a critical piece of information technology use. Students must learn to use the appropriate technology to communicate with the specified audience and to collaborate with peers both locally and globally to be successful in the twenty-first century workplace. One important foundation of effective twenty-first century communication is digital visual literacy—"the ability to critically analyze digital visual materials, create effective visual communications, and make judgments and decisions using visual representations of thoughts and ideas" (Martin, Gibson, & Friesen, 2008, p. 1). According to Lester (1994–1996), "We are becoming a visually mediated society. For many, understanding of the world is being accomplished, not through words, but by reading images" (p. 2). Being able to analyze information presented in a visual format is increasingly becoming an essential skill for twenty-first century learners.

Impact of Student Technology and Readiness Skills

Technology is rapidly evolving, and hence so must the assessment of readiness and skills also evolve to be at a broader level than just measuring basic computer competencies. Students must not only learn to use information technology (IT) but also use IT to learn (similar to reading literacy). Students need to be prepared to use technology for learning. Therefore, most technology standards assume that students are technology literate in a wide variety of skills by the end of eighth grade. According to Erstad (2008), "the increased implementation of new digital technologies in school settings not only makes us view traditional ways of assessment in new ways but also raises new issues of assessment" (p. 181). "With spending on assessment development in the USA alone expected to grow into the billions of dollars this decade, it is vital that our investment focuses… on preparing today's children to face the challenges of tomorrow's complex communities and workplaces" (P21, 2007a, p. 2).

The US Department of Labor projected as early as 2001 that eight of the ten fastest growing occupations in the USA would require "technology fluency" (Ellis, 2001). More recently, Lacey and Wright (2009) have projected that jobs involving networking technologies related to the Internet will increase by 53.4 % between 2008 and 2018. The Institute of Electrical and Electronics Engineers (IEEE) Technical Committee on Learning Technologies has concluded that twenty-first century technology literacy skills go far beyond simply technology competence. Their recommendations for advanced learning technology competence include the five domains of knowledge competence, process competence, application competence, personal/social competence, and innovative/creative competence (Spector, 2012). While technology skills are one critical component, there is a much broader repertoire of skills necessary to be productive in the workforce of the twenty-first century.

What Techniques Have Been Used to Assess Technology Readiness and Skills?

Several types of assessment have been used for measuring technology readiness and skills in the past. Many new types are emerging for twenty-first century learners, especially as a result of the affordances provided by new technologies. These forms of assessment include a wide range of methods that vary in expense, invasiveness, and difficulty. The most frequently used methods are discussed in detail in this section. These are paper-based, computer-based and adaptive, performance-based, observation, rubric, portfolio, self-assessment, and embedded assessments.

Pencil/Paper Testing

When technology skills first became required knowledge and skills for students, there were typically only paper-based tests to assess how much students knew. However, the questions for these assessments tended to be multiple-choice in nature. Multiple-choice assessments are not well suited for determining expertise in higher-level applications of technology skills.

Computer-Based and Adaptive Testing

There are both computer-based software packages and Internet-based online services that assess student skills and knowledge. Many of these also create remediation modules based on performance. For example, the Skills21 program (EdTech Systems, 2010) offers online interactive assessment items that simulate technology literacy situations and produce progress reports identifying strengths and weaknesses. The Tech Skills Student Assessment (Atomic Learning, 2012) aims to gauge technology skills levels by going beyond measuring the ability to simply perform a task, and instead focuses on measuring one's ability to apply technology. Both Skills21 and Tech Skills Student Assessment are based on the NETS•S by ISTE. The iSkills package by the Educational Testing Service, aims to help ensure students are ready for success in the twenty-first century by measuring their critical thinking and problem-solving skills in a digital environment (EdTech Systems, 2010).

Performance-Based Assessment

This is a competency-based method that allows direct verification of the acquisition of skills. It is a valid way of assessing skill development but can be more subjective and typically requires allowing extra time for production of the product plus verification of completion of the task. According to a report on quality performance assessment, high-quality performance assessments are defined as, "multi-step assignments with clear criteria, expectations, and processes that measure how well a student transfers knowledge and applies complex skills to create or refine an original product" (Brown & Mevs, 2012).

Observation Assessment

Observations occur in a natural learning environment. These can be informal or formal depending on the type of information being gathered. Observation measurement instruments to assess student learning often contain data such as frequency and duration of an indicator of student learning. Observations may contain some bias by the observer or may be altered by the fact that someone is being observed.

Rubric

This type of assessment typically communicates the expectations prior to the initiation of the activity. A rubric contains the criteria that will be used to evaluate the activity. Rubrics can make a subjective assessment more objective. According to Dodge (2001), rubrics focus on measuring a stated objective (performance, behavior, or quality) and have the common characteristics that they use a range to rate performance, as well as contain specific performance characteristics arranged in levels indicating the degree to which a standard has been met.

Portfolio Assessment

This typically includes a collection of student work samples compiled over time. This type of assessment allows for a more broad and longitudinal view of learning development. However, it is costly in terms of time and effort on a teacher or evaluator's time.

Self-Assessment

This form of assessment typically involves self-reflection and goal setting toward more refined performance in the future. Self-assessment has low overhead in terms of requiring few additional resources but also works best with highly motivated individuals and teacher guidance.

Embedded Assessment (Usually for Formative Assessment)

This form of assessment has the outcome indicators gathered by the delivery system during the process of completing the task. Embedded assessment fits well with a formative evaluation (designed to improve the instructional process) and it normally requires extra development work before learners can start using the system.

Formative and summative assessments are two traditional categories of assessment that are blurring with the availability of technology enhancements. Formative assessment traditionally has a goal of improving the learning and instruction while summative is in place to judge whether good outcomes have been achieved by use of society's space, time, and money resources. As noted in the Second Information Technology in Education Study 2006 (SITES), several countries reported a shift toward more formative assessment when information technology was introduced (Law, Pelgrum, & Plomp, 2008). This enables a focus on the development of workforce preparation skills. Hickey and Itow (2012) have pointed out that new opportunities exist to assess the abilities of new disruptive technologies such as one-to-one devices (e.g., smartphones) to transform educational systems. Many countries are currently using technology to carry out summative assessment in a cost effective manner, but new opportunities exist at the formative and transformative levels. These opportunities are described more fully in the Emerging Assessment Techniques section.

Combining Multiple Types of Assessment

Given that no one form of assessment works for every situation and every learner, a better overview of the depth and breadth of learning might be gained by using more than one type and then combining the information for a more complete evaluation of the learner. One emerging form that typically includes multiple types of assessment is project-based portfolio assessment. As the name implies, portfolio assessment involves gathering and reviewing a collective body of a student's work based on products or artifacts produced. Project-based portfolio assessment involves both portfolio assessment and performance-based assessment as defined in the previous section. Two systems combining more than one of these assessment types, each of which has appeared since 2000, are described here for purposes of illustration. The first example, TechYes, incorporates performance-based assessment, portfolio assessment as well as self and peer assessment. The second example is an emerging form of assessment incorporating performance-based assessment, rubrics, self-assessment, and embedded assessment.

TechYES

TechYES is a program that focuses on students earning a certification by completing project-based learning activities demonstrating authentic student technology literacy and assessment (Becker, Hodge, & Sepelyak, 2010). In the classroom, students mentor other students who are in turn illustrating their technology literacy through hands-on learning projects. TechYES technology literacy is based on the following learning approaches grounded in research findings (Becker et al., 2010).

- Project based learning is effective. Doing projects using technology shows that students know and understand technology as opposed to simply learning out-of-context technology skills.
- Authentic assessment is accurate and assists in modifying practice. Student achievement can be assessed better and relevant feedback provided if the evaluators know the student and the assessment is based on student-produced work rather than tests.
- Peer mentoring is effective. Students learn from their peers in a noncompetitive learning community better than they do in a completely teacher-directed classroom. In addition, the benefits to the peer mentors are well documented.
- Students can be agents of positive change. Students can be accountable for their own learning when given well-designed opportunities and trusted to take that responsibility seriously.

Systems such as TechYes address most of the components necessary for comprehensively developing and verifying mastery of twenty-first century skills. However, questions remain as to whether large-scale implementation of such a system is sustainable in a typical educational environment. In particular, peer reviews must be read and judged by teachers or other qualified personnel in order to arrive at a peer-supported, expert conclusion.

In summary, TechYes is an example of using multiple forms of assessment incorporating performance-based assessment, portfolio assessment as well as self and peer assessment (GenYES, 2011). An example combining other forms of assessment is provided in the following paragraphs.

Digital Badging

Digital badging systems are a second example of a method that combines multiple assessment strategies, such as self-assessment, rubrics, performance-based assessment, and embedded assessment. The foundation of this movement is generally credited to Baker (2007) who gave a presidential address to the American Education Research Association entitled "The End(s) of Testing." Gee (Global Kids, 2012) has pointed out the popularity of using badges for educational games such as iCivics in which students learn to be engaged, intelligent citizens. According to Digital Media Learning (2012), "A badge is a validated indicator of accomplishment, skill, quality or interest" (p. 1). Badges have a long history dating from scouting to more recent intensive use in the online gaming community. They are rapidly gaining attention in education and training as a means of indicating competency or achievement (Robles, 2011). In the USA, the MacArthur Foundation announced in 2011 that it was dedicated to supporting new ways of using badges for assessment. Their Digital Media and Learning Competition is part of MacArthur's $85 million initiative to recognize new ways students learn (MacArthur Foundation, 2009–2011).

Hickey and Itow (2012) pointed out that the use of digital badges generally falls into one or more of three goal categories:

1. Using badges to show what somebody has done or might be able to do.
2. Using badges to motivate more individuals to do or learn more.
3. Using badges to transform or even create learning systems.

They further contended that these three goals correspond with three assessment functions (or purposes):

1. Summative functions, often called assessment OF learning.
2. Formative functions for individuals, often called assessment FOR learning.
3. Transformative functions for systems, sometimes calling assessment AS learning.

Hickey and Itow (2012) concluded that different assessment functions generally follow from different theories of knowing and learning, and therefore, the relationship between assumptions about learning and assessment practices is often in tension. In particular:

1. Summative functions generally follow from associationist views of learning as building organized hierarchies of specific associations (Learning is acquiring "more stuff.").
2. Formative functions follow from constructivist theories of learning as constructing conceptual schema in order to make sense of the world.
3. Transformative functions follow from sociocultural theories of learning as participating in social and technological practices.

Therefore, the intended use of badges can have a tremendous impact on choice of appropriate teaching/learning strategy and assessment technique. For example, direct instruction might typically match up with material well suited for summative assessment, while discovery learning might be more appropriate for motivating deeper learning well suited to formative refinement. So-called *disruptive* approaches to learning through technologies (Sharples, Taylor, & Vavoula, 2007), such as putting an Internet-connected laptop in the hand of every child in a school, are more likely to spawn totally new avenues for learning, and therefore are more likely to warrant assessment of readiness to use the technology in a transformative manner.

Research is beginning to emerge from the scholarly community showing that the use of badges can promote greater motivation and attention as well as produce higher mastery of content. For example, in a study that examined the issue of incentives and competition, Hickey, Filsecker, and Kwon (2009) contrasted two versions of the curriculum in a learning game, one with badge recognition as incentive for better performance and one without badge recognition. Students in the badge/public recognition condition showed significantly larger gains in understanding, as well as larger gains in achievement. Furthermore, students in the badge/public recognition condition showed slightly higher intrinsic motivation during the game and slightly larger gains in interest toward solving problems (Hickey et al., 2009). The latter findings indicate that in addition to achievement, attitudes are an important factor in learning with digital media.

Thus, it appears that badges can be effective in motivating students to master the twenty-first century skills discussed in this chapter. Clearly new information technologies are a medium through which systems such as badges become practical to be implemented and maintained on a broad scale, and therefore, the ability of learners to navigate their way through a technology-based assessment system such as badges will itself be an indication of their technology readiness. This would be a transformative assessment (assessment AS learning) according to the system of summative, formative, and transformative functions developed by Hickey and Itow (2012).

What Conceptual and Practical Considerations Exist in These Assessment Approaches?

A variety of assessment techniques exist for determining whether students have the required technology skills for learning. However, there are barriers to including these in classrooms, such as cost, time, and expertise. For these reasons, it is also important to note that often one approach alone is not adequate for measuring a student's technology knowledge and skills. Therefore, teachers may choose to use multiple measures to get a more complete assessment. Table 67.2 lists different types of assessments that are used in education. Also included are the advantages and disadvantages of each type. Traditional paper and pencil testing may assess quickly and inexpensively, for example, but it is difficult to measure twenty-first century higher order skills such as communication and collaboration through paper and pencil tests. Similarly, embedded assessments may be unobtrusive and able to measure higher order skills, but they may also be difficult for classroom teachers to create.

Table 67.3 illustrates visually that any given type of assessment technique is not likely to be capable of covering all levels of twenty-first century skills as defined by a framework such as the ISTE's NETS•S. On one hand, only *Performance* and *Observation* have the potential to span all areas. On the other hand, *Technology Operations and Concepts* can be assessed using any of the common techniques at our disposal. This analysis implies that as societies move away from twentieth century skills assessment, toward twenty-first century skills assessment, there will have to be (a) massive resource investments in time and labor-intensive techniques such as *Observation* or *Authentic Performance*, or else (b) societies will need to plan to switch techniques as students move from lower-order to higher-order twenty-first century skills. Perhaps some combination is in order with variations depending on local cultural norms and the level of development sought by society as an outcome. The level of development currently existing in the local environment may influence the optimal choice as well. For example, authentic performance through the apprentice model has worked well for vocational training in most societies for centuries. It is less clear that it is practical for every person engaged in creative and innovative work to have a shadow and take on a mentor role. Consequently, embedded assessment ought to be utilized much more, and undoubtedly will be, as the power and sophistication of computer-based assessment systems continues to increase.

Table 67.2 Advantages and disadvantages for particular types of assessments

Type of assessment	Advantages	Disadvantages
Traditional pen/paper testing	Inexpensive and quick	Does not typically assess twenty-first century skills
Computer-based and adaptive	Allows multiple levels for different students	Expensive; does not typically assess twenty-first century skills
Performance (of real-world tasks that demonstrate application of required knowledge and skills)	Useful and shows what a student can do	Expensive and time-consuming
Observation	Experts can make judgments based on their knowledge	Expensive and time-consuming
Rubric	Allows students to know what is expected	Takes time to create and often not aimed at higher order skills
Portfolio	Can measure a broad range of technology skills	Requires a great deal of time to evaluate
Self	Self correction can occur; much like real world	Need to teach skill of self-assessing
Embedded	Unobtrusive	Difficult to create

Table 67.3 Suitability of common assessment techniques for NETS•S skill categories

	Creativity and innovation	Communication and collaboration	Research and information fluency	Critical thinking, problem-solving, and decision making	Digital citizenship	Technology operations and concepts
Portfolio	✓	✓				✓
Traditional pen/paper						✓
Observation	✓	✓	✓	✓	✓	✓
Rubric		✓	✓	✓		✓
Performance	✓	✓	✓	✓	✓	✓
Self					✓	✓
Embedded		✓	✓			✓

Broadening the Focus, from Learner Skills to the Teaching/Learning and Performance Environment

Current scholarly thinking favors the ecological perspective of teaching and learning (Davis, 2009), in which all items within the learning environment are potentially considered. In keeping with the spirit of this perspective, 70 international scholars in the field of ICT in education gathered in the Hague, Netherlands, during 2009 to develop a “call for action” list of agenda items that addressed specific issues regarding ICT in Education in the twenty-first century (Voogt, Knezek, Cox, Knezek, & ten Brummelhuis, 2011). The basis for the discussion was the scholarly findings of the International Handbook of Information Technology in Primary and Secondary Education, a synthesis of research in the field of ICT in education (Voogt & Knezek, 2008). The main action points developed by this group were as follows:

- Formalizing a vision for the role of ICT in twenty-first century learning.
- Identifying the conditions for realizing the potential of multiple technologies to address individual student needs.
- Developing a better understanding of the relationship between formal and informal learning.
- Recognizing the implications of technology for student assessment.
- Accepting the need for distributed leadership models and models for teacher learning to successfully integrate technology in schools.
- Realizing the potential of ICT for digital equity
- Developing a list of essential conditions to ensure benefit from ICT investments.

Note that the fourth and seventh bullets deal directly with readiness (essential conditions) and assessment of skills.

Emerging Assessment Techniques

Baker (2011) described the principles that support new types of assessments, which include embedded assessment, student driven goals (personal learning), multiple pathways to reach benchmarks and an emphasis on applying learned concepts to new situations under varying conditions. Great future potentials for measuring technology readiness and skills lie in adaptive assessment techniques incorporating universal design, and in embedded and performance assessment.

The types of assessments previously listed included paper and pencil, computer-based and adaptive, performance based, observation-based, rubrics, portfolio, self-assessment, and embedded assessment. Practical considerations relevant to any type of assessment chosen for technology readiness may include time, technology, human resources, scoring, cost, universal design, and remediation. Depending on available time and resources, trade-offs exist in making choices for the type of assessment best suited to match the current need.

Most educators do not feel they have time to create new forms of assessment. However, if they consider the assessment as an integral part of the learning activity, it becomes embedded in the planning process. Wiggins (Wiggins & McTighe, 2005) indicated it is important for teachers to consider assessment before they begin planning specific activities for lessons or projects, with the understanding that both activities and assessments must be based on the overall goals and objectives for the curriculum. This approach is also known as *backward design* (Edutopia, 2012).

Several forms of assessment are rapidly growing because technology provides the affordances for implementing these techniques. Adaptive testing, embedded assessment, and performance-based assessment are three of the forms that are addressed.

Adaptive Testing

Adaptive testing uses statistical information about the test items to adapt selection of the next item to the test taker’s ability (van der Linden & Glas, 2010). “In essence, computer-adaptive testing decreases the number of items to which an examinee must respond before a reliable estimate of their ability is reached” (Russell, 2006, p. 80). Benefits of adaptive testing include accommodations for special needs students, efficient testing administration, organization of data, and immediacy of results (Thompson, Thurlow, & Moore, 2003). Disadvantages include costs related to extensive development time and availability of expertise in Item Response Theory and other quantitative methods that form the basis of the science of adaptive testing. It is usually not practical for a classroom teacher or even a school leader to develop and manage an adaptive testing environment, and hence these services will be amortized on a cost-per-student basis.

Embedded Assessment

This approach integrates measurements into the activities and provides the ability to assess student progress and performance within typical classroom activities. Embedded assessment is built-in to the activities. The students often do not even realize they are being assessed. It is a more formative approach in which the assessment occurs during the learning activity and is often a view of the actual process of learning. Researchers at the University of California–Berkeley created a system of embedded assessment for a science curriculum. They concluded that this type of system provided a more systematic approach to the gathering and interpretation of assessment information (Wilson & Sloane, 2000).

In the games and simulations environment, embedded assessment takes a specific form known as stealth assessment. Characteristics of stealth assessment include extracting ongoing information from the learner, making accurate inferences of competencies and reacting in immediate and helpful ways. Stealth assessment uses the sophisticated processing power of technology to implement machine-based reasoning techniques and dynamically assess the user's competence.

Performance Assessment

This type of assessment is also known as authentic assessment and is increasingly well suited to technology skills as computers and other IT devices continue to become more ubiquitous. Performance assessment requires the learner to demonstrate his or her knowledge and skills. It is a better measure of a student's ability to integrate multiple subjects' content and/or their ability to work with other students. In this type of assessment the learners are active participants. One type of online program that provides performance assessment of technology skills is learning.com. It provides both an assessment and a learning environment to enhance technology skills that are scenario-based. Students login through their school-provided login to be authentically assessed on technology skills. One barrier to wider use of performance assessment is the need for human (qualitative) judgment that the assigned task has been completed in an acceptable manner.

Model-Based Assessment

This type of assessment integrates representations of mental models and internal cognitive processes with tools that are used to assess learner progress and provide reflective feedback during instruction. Model-based assessment rests on two foundations: mental models research and systems thinking as well as concept maps and belief networks. The goal is to assess the quality of internal constructs and processes based on external representations. Online model-based tools such as the Highly Interactive Model-based Assessment Tools and Technologies (HIMATT) are being used to make this approach to assessment feasible (Shute, Jeong, Spector, Seel, & Johnson, 2009).

Summary and Conclusions

Preparing students to be successful in the twenty-first century requires ensuring students have the essential skills to be productive citizens. A key component of these skills is the use of information and communication technology. In the words of J.W. Marriot, Jr., Chairman and CEO of Marriott International, Inc.:

> To succeed in today's workplace, young people need more than basic reading and math skills. They need substantial content knowledge and information technology skills; advanced thinking skills, flexibility to adapt to change; and interpersonal skills to succeed in multi-cultural, cross-functional teams (Casner-Lotto & Barrington, 2006, p. 24).

It has been estimated that as many as 85 % of all jobs in the future will require the use of technology in some capacity (Manyika et al., 2011). This will not be an option, but a necessary proficiency. Ensuring readiness for using technology as an integral component of formal and informal learning, of job performance, and of life as a productive citizen—in addition to being able to assess progress along these growth paths—is an essential component of the future of our world. Tom Kucharvy, CEO of Beyond IT, a market strategy and consulting firm, wrote, "virtually all high-value knowledge jobs will also require at least basic quantitative, statistical and IT skills. IT, in fact, will increasingly have to become the second language for almost all 21st century knowledge workers" (Kucharvy, 2010, n.p.). It is important that future citizens be ready to acquire and refine these skills in order to assume productive roles in our society. Assessment is a key component to ensuring that our students are prepared with twenty-first century skills to not only compete for jobs but to create the next economy of the future. Numerous methods exist to allow us to assess readiness in different environments.

Society's need for assessing twenty-first century skills creates dilemmas in school environments regarding how to view technology readiness. Workforce preparation has become the major driving force for new forms of educational assessment, while rapid advances in information technologies have created opportunities for new techniques to emerge. Newer approaches to learning, such as digital game environments, have demonstrated that alternative forms of assessment are emerging to fulfill these changing needs. The need for technology readiness introduces unique assessment challenges and opportunities because demonstrated use of the medium of assessment (digital technology) often validates proficiency in the skills being assessed. Such examples illustrate emerging new forms where completing the task is demonstrated proficiency. This new form is called transformative assessment. One can envision the day when (with respect to technology skills) successful performance of a job is the assessment.

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Technology Integration in Schools

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Randall S. Davies and Richard E. West

Abstract

It is commonly believed that learning is enhanced through the use of technology and that students need to develop technology skills in order to be productive members of society. For this reason, providing a high quality education includes the expectation that teachers use educational technologies effectively in their classroom and that they teach their students to use technology. In this chapter we have organized our review of technology integration research around a framework based on three areas of focus: (1) increasing access to educational technologies, (2) increasing the use of technology for instructional purposes, and (3) improving the effectiveness of technology use to facilitate learning. Within these categories, we describe findings related to one-to-one computing initiatives, integration of open educational resources, various methods of teacher professional development, ethical issues affecting technology use, emerging approaches to technology integration that emphasize pedagogical perspectives and personalized instruction, technology-enabled assessment practices, and the need for systemic educational change to fully realize technology's potential for improving learning. From our analysis of the scholarship in this area, we conclude that the primary benefit of current technology use in education has been to increase information access and communication. Students primarily use technology to gather, organize, analyze, and report information, but this has not dramatically improved student performance on standardized tests. These findings lead to the conclusion that future efforts should focus on providing students and teachers with increased access to technology along with training in pedagogically sound best practices, including more advanced approaches for technology-based assessment and adaptive instruction.

Keywords

Technology integration • Educational technology • Instructional technology • Learning technology • TPACK • Educational policy • Technology-enabled assessment • Personalized instruction

Introduction

The Elementary and Secondary Education Act of 2001 mandated an emphasis on technology integration in all areas of K-12 education, from reading and mathematics to science and special education (US Department of Education, 2002). This mandate was reinforced in the US Department of Education's (2010) National Education Technology Plan.

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Under current legislation, education leaders at the state and local levels are expected to develop plans to effectively utilize educational technologies in the classroom. The primary goal of federal education legislation is to improve student academic achievement, measured primarily by student performance on state standardized tests. Secondary goals include the expectation that every student become technologically literate, that research-based technology-enhanced instructional methods and best practices be established, and that teachers be encouraged and trained to effectively integrate technology into the instruction they provide. The directive to integrate instructional technology into the teaching and learning equation results from the following fundamental beliefs: (1) that learning can be enhanced through the use of technology and (2) that students need to develop technology skills in order to become productive members of society in a competitive global economy (McMillan-Culp, Honey, & Mandinach, 2005; US Department of Education, 2010).

By most measures, the quality and availability of educational technology in schools, along with the technological literacy of teachers and students, have increased significantly in the past decade (Center for Digital Education, 2008; Gray, Thomas, & Lewis, 2010; McMillan-Culp et al., 2005; Nagel, 2010; Russell, Bebell, O'Dwyer, & O'Connor, 2003). In addition, educators are generally committed to technology use. Most educational practitioners value technology to some degree, yet many researchers and policy analysts have suggested that technology is not being used to its full advantage (Bauer & Kenton, 2005; Ertmer & Ottenbreit-Leftwich, 2010; Overbaugh & Lu, 2008; Woolf, 2010). Even at technology-rich schools, effective integration of technology into the instructional process is rare (Shapley, Sheehan, Maloney, & Caranikas-Walker, 2010). To fully understand this criticism requires in-depth consideration of the goals and criteria used for evaluating technology integration.

Most efforts to integrate technology into schools have the stated goal of appropriate and effective use of technology (Center for Digital Education, 2008; ISTE, 2008; Niederhauser & Lindstrom, 2006; Richey, Silber, & Ely, 2008); however, many current efforts have focused predominantly on gaining access to and increasing the extent of technology use. For example, in 1995 Moersch provided an extremely useful framework describing levels of technology integration—a tool that is still being used (see http://loticonnection.com). Like other indicators, the Levels of Teaching Innovation (LoTi) Framework tends to rely on access to and pervasive innovative use of instructional technology as an indicator of the highest level of technology integration and literacy. To some degree frameworks of this type assume that using technology will in itself be beneficial and effective. Clearly, effective and appropriate use of technology does not happen if students do not have access to learning technologies and do not use them for educational purposes; however, pervasive technology use does not always mean that technology is being used effectively or appropriately, nor does pervasive use of technology necessarily lead to increased learning. The field of adaptive technologies is one area where educational technology holds much promise. It is widely believed that intelligent tutoring systems could be used to enhance a teacher's ability to teach and test students but advances in this area have failed to produce the same kinds of formative and diagnostic feedback that teachers provide (Woolf, 2010). As a result, recent efforts to identify appropriate and effective uses for technology have focused more on the pedagogically sound use of technology to accomplish specific learning objectives (see for example, Koehler & Mishra, 2008).

To better orient our understanding and evaluation of technology integration efforts at both classroom and individual levels, integration might best be viewed as progressive steps toward effective use of technology for the purposes of improving instruction and enhancing learning. The current status of technology integration efforts could then be evaluated by the degree to which teachers and students (1) have access to educational technologies, (2) use technology for instructional purposes, and (3) implement technology effectively to facilitate learning (Davies, 2011). After first defining technology and technology integration, this chapter uses this framework for understanding and evaluating current technology integration efforts in schools, along with the challenges associated with technology integration.

Defining Technology and Technology Integration

Efforts to describe and critique current use of technology must recognize that not everyone shares a common understanding of what technology is and what technology integration means. For many, *technology* is synonymous with computer equipment, software, and other electronic devices (US Department of Education, 2010; Woolf, 2010), while *technology integration* means having and using this equipment in the classroom. However, these definitions are rather narrow. Interpreting technology integration to mean simply having access to computers, computer software, and the Internet has led critics to identify the mandate to integrate technology into schools as a simplistic solution to a complicated endeavor (Bahrampour, 2006; Cuban, 2006a; Warschauer & Ames, 2010). Similarly, defining technology simply as electronic devices tends to place an unwarranted emphasis on using digital technologies in schools regardless of the merits for doing so (Davies, Sprague, & New, 2008). However, most technology integration efforts do intentionally focus on attempting to establish innovative and creative best practices as they progress in gaining access to new and developing digital technologies (ISTE, 2008; Woolf, 2010).

For this analysis we define *technology integration* as the effective implementation of educational technology to accomplish intended learning outcomes. We consider *educational technology* to be any tool, piece of equipment, or device—electronic or mechanical—that can be used to help students accomplish specified learning goals (Davies et al., 2008). Educational technology includes both instructional technologies, which focus on technologies teachers employ to provide instruction, and learning technologies, which focus on technologies learners use to accomplish specific learning objectives.

Increasing Access to Educational Technology

Teachers find it particularly challenging, if not impossible, to integrate technology when the technologies they would like to use are either not available or not easily accessible to them or their students (Ely, 1999). Fortunately, by most measures the availability of technology in schools has increased significantly in the past decade (Bausell, 2008). In 2009, Gray et al. (2010) conducted a nationally representative survey of 2,005 public schools across 50 states. A total of 4133 surveys were administered with a response rate 65 %. From these results they estimated that 97 % of teachers in the USA had access to one or more computers in their classroom every day (a ratio of approximately five students per computer on average). In addition, these authors reported that 93 % of schools had access to the Internet.

However, 60 % of teachers providing data for this report also indicated that they and their students did not often use computers in the classroom during instructional time. In fact, 29 % of the teacher respondents reporting daily access to one or more computers also reported that they rarely or never used computers for instructional purposes. A study conducted by Shapley et al. (2010) suggested that teachers most frequently use the computer technology they had for administrative purposes (e.g., record keeping), personal productivity (e.g., locating and creating resources), and communicating with staff and parents. Students' use of technology was most often for information gathering (i.e., Internet searches) or for completing tasks more efficiently by using a specific technology (e.g., word processing, cloud-based computing) (Bebell & Kay, 2010; Davies et al., 2008; Stucker, 2005).

Thus while the availability of technology in schools may have increased in recent years, measures of access likely provide an overoptimistic indicator of technology integration. In fact, some feel that for a variety of reasons the current level of technology access in schools is far too uneven and generally inadequate to make much of an impact (Bebell & Kay, 2010; Toch & Tyre, 2010). While some question the wisdom and value of doing so (Cuban, 2006b; Warschauer & Ames, 2010), many believe we must strengthen our commitment to improving access to technology by making it an educational funding priority (Livingston, 2008; O'Hanlon, 2009).

One-to-One Computing Initiatives

The primary purpose of one-to-one computing initiatives is to increase access to technology in schools. Essentially this means providing each teacher and student in a school with individual access to an Internet-enabled computer or to a laptop (tablet PC or mobile computing device) for use both in the classroom and at home (Center for Digital Education, 2008). Such access implies that schools would also provide and maintain the infrastructure needed to support these technologies (i.e., networking and Internet access). While the number of these programs has increased worldwide, growth has been slow, largely due to the cost of implementation and maintenance (Bebell & Kay, 2010; Greaves & Hayes, 2008; Livingston, 2008). In practice, major one-to-one computing programs in the USA require large federal or state grants, which are often directed at Title I schools in areas characterized by high academic risk (Bebell & Kay, 2010; Shapley et al., 2010). Often these programs partner with equipment providers to alleviate implementation costs (including training and support) as well as maintaining and upgrading equipment. These partnerships have resulted in several pockets of technology-rich schools around the nation, some of which have demonstrated excellence in integrating technology effectively. More often one-to-one computing programs have provided equipment to schools, but students' access to it could not be considered ubiquitous, nor has having access to more computer equipment dramatically changed the instruction in most classrooms (Penuel, 2006; Ross, Morrison, & Lowther, 2010; Warschauer & Matuchniak, 2010).

Evidence of academic impact that can be attributed to one-to-one computing initiatives has been mixed. A few studies have provided evidence that infusing technology into the classroom has closed the achievement gap and increased academic performance (Shapley et al., 2010; Zucker & Light, 2009); however, Cuban (2006b) reported that most studies have shown little academic benefit in these areas, and Vigdor and Ladd (2010) suggested that providing ubiquitous computer access to all students may actually widen the achievement gap.

Other studies have suggested that additional benefits derived from technology integration might include increased access to information, increased motivation of students to complete their studies, and better communication between teachers and students (Bebell & Kay, 2010; Zucker, 2005). However, such studies often referred to the "potential" technology has for increasing learning, acknowledging that any scholastic benefit technology might produce depends on factors other than simply having access to technology (Center for Digital Education, 2008; McMillan-Culp et al., 2005; Woolf, 2010).

Open Educational Resources

An important factor associated with access is the issue of educational resource availability: i.e., having access to technological tools without access to the educational resources needed to utilize those tools effectively. Much of the current work in this area has focused on developing research-based instructional resources such as online courses and instructional materials that can be used in the classroom to improve student achievement. This can be costly and time consuming. Facing budget cuts and restrictions in funding, many schools need freer access to educational resources.

The Open Educational Resource (OER) movement is a worldwide initiative providing free educational resources intended to facilitate teaching and learning processes (Atkins, Seely Brown, & Hammond, 2007). A few examples of OER initiatives include the OpenCourseWare Consortium (http://www.ocwconsortium.org), the Open Educational Resources Commons (http://www.oercommons.org), and the Open Learning Initiative (oli.web.cmu.edu/openlearning), along with Creative Commons (creativecommons.org), which provides the legal mechanism for sharing resources. Since one of the largest impediments to technology integration has been cost (Greaves & Hayes, 2008), some policy analysts have identified the need to provide free educational resources as essential to the success of any technology integration mandate; but this idea has been controversial because it means individuals must be willing to create and provide quality educational resources without compensation. Wiley (2007) has pointed out that as the OER movement is currently an altruistic endeavor with no proven cost recovery mechanism, the real costs associated with producing, storing, and distributing resources in a format that operates equally well across various hardware and operating system platforms constitute a sustainability challenge for the OER movement. The topic of open education is discussed more completely in another chapter of this handbook.

Increasing Instructional Technology Use

Even when schools have adequate access to educational technologies, teachers and students do not always use them for instructional purposes. Efforts to improve technology use in schools have typically focused on professional development for teachers. In addition, both social and moral ethical issues have been raised.

Professional Development as a Method for Increasing Technology Use

Much of the research on increasing technology use in schools has focused on training those preparing to become teachers, although discussions regarding professional development for current classroom teachers are becoming more common. Harris, Mishra, and Koehler (2009) suggested that most professional development in technology for teachers uses one of five models: (a) software-focused initiatives, (b) demonstrations of sample resources, lessons, and projects, (c) technology-based educational reform efforts, (d) structured/standardized professional development workshops or courses, or (e) technology-focused teacher education courses. According to these authors, there is, as yet, very little conclusive evidence that any of these models has been successful in substantially increasing the effective use of technology as measured by increased learning outcomes. Research on technology integration training for teachers has typically focused on either (a) the effectiveness of the professional development training methods or (b) the desired objectives of the professional development.

Technology integration professional development methods. Many methods have been utilized to provide professional development to teachers on technology integration issues. We highlight three methods on which the research evidence seems strongest: (a) developing technological skills, (b) increasing support through collaborative environments, and (c) providing increased mentoring.

Skill development using technology. Some scholars have focused on using technology to mediate professional development. Technology integration practices are modeled by using blogs and other forms of Internet communication (Chuang, 2010; Cook-Sather, 2007; Gibson & Kelland, 2009); video-based self-assessment (Calandra, Brantley-dias, Lee, & Fox, 2009; West, Rich, Shepherd, Recesso, & Hannafin, 2009); electronic portfolios (Derham & DiPerna, 2007); and individual response systems (Cheesman, Winograd, & Wehrman, 2010). These approaches are intended to help teachers gain experience and confidence with technology, as well as provide them with models for how it might be used effectively.

Collaborative environments. Other scholars have found that increasing collaboration among teachers learning to integrate technology can improve professional development outcomes. In an article on technology integration, Macdonald (2008) wrote that “to effect lasting educational change” collaboration for teachers needs to be facilitated in “authentic teacher contexts” (p. 431). Hur and Brush (2009) added that professional development needs to emphasize the ability of teachers to share their emotions as well as knowledge. Most collaborative environments typically only emphasize knowledge sharing when emotion sharing may be linked to effective professional development. An increasingly popular medium for enabling this collaboration and development of emotional safety is online discussions and social networking. While this trend needs more research, positive effects have been indicated. For example, Vavasseur and Macgregor (2008) found that online communities provided better opportunities for teacher sharing and reflection, improving curriculum-based knowledge and technology integration self-efficacy. Also, Borup, West, and Graham (2012) found that using video technologies to mediate class discussions helped students feel more connected to their instructor and peers.

Mentoring. Similar to research on teacher collaboration, some scholars have discussed the important role of mentoring in helping teachers gain technology integration skills. Kopcha (2010) described a systems approach to professional development emphasizing communities of practice and shifting mentoring responsibilities throughout various stages of the technology integration adoption process. Kopcha's model was designed to reduce some of the costs associated with teacher mentoring—a common criticism of the method. In addition, Gentry, Denton, and Kurz (2008) found in their review of the literature on technology-based mentoring that while these approaches were not highly used, technology can support mentoring and improve teachers' technology integration attitudes and practices. The authors noted however that many of these effects were self-reported, and not substantiated through direct observation, nor was there any evidence of subsequent effect on student learning outcomes.

Goals of technology integration professional development. In addition to a variety of methods and approaches to providing professional development on technology integration issues, researchers have found that the goals and objectives of the professional development have also varied. Perhaps the most common objective has been to change teachers' attitudes towards technology integration in an effort to get them to use technology more often (e.g., Annetta, Murray, Gull Laird, Bohr, & Park, 2008; Lambert, Gong, & Cuper, 2008; McCaughtry & Dillon, 2008; Rickard, McAvinia, & Quirke-Bolt, 2009). This has included efforts to change teachers' ability to use specific technologies (through skill development) and thereby to improve their technology integration self-efficacy (e.g., Ertmer & Ottenbreit-Leftwich, 2010; Overbaugh & Lu, 2008). It has also included changing teachers' attitudes regarding the pedagogical value of using technology in the classroom (Bai & Ertmer, 2008; Ma, Lu, Turner, & Wan, 2008). In many of these studies, increasing positive teacher attitudes was seen not only as a way to increase technology use but as an important and necessary step towards increasing effective technology integration (Ertmer & Ottenbreit-Leftwich, 2010; Palak & Walls, 2009).

Ethical Issues Affecting Increased Technology Use

Because education is a human, and thus a moral, endeavor (Osguthorpe, Osguthorpe, Jacob, & Davies, 2003), ethical issues frequently surface. Technology integration has caused major shifts in administrative and pedagogical strategies, therefore creating a need for new definitions and ideas about ethical teaching and learning (Turner, 2005). Although some have cautioned that ethical issues should be considered before implementing technology-based assignments (Oliver, 2007), the pressure to increase access to and ubiquitous use of technology has often outpaced the necessary development of policies and procedures for its ethical use (Baum, 2005), creating challenges for administrators and teachers who are integrating it in schools. In many cases unintended negative consequences and ethical dilemmas have resulted from inappropriate use of technology, and addressing these issues has required that restrictions be applied. Scholars have specifically mentioned the issues related to technology-based academic dishonesty, the challenges of technology accessibility for all students, and the necessity for developing standards for ethical technology use.

Technology-based academic dishonesty. According to Akbulut et al. (2008), the most common examples of academic dishonesty include fraudulence, plagiarism, falsification, delinquency, and unauthorized help. Lin (2007) added copyright infringement and learner privacy issues to the list of unethical behaviors. Many researchers have discussed the potential for technology to increase these kinds of academic dishonesty and unethical behaviors. Of concern to many teachers is that technology provides easy access to information, giving students more opportunities to cheat (Akbulut et al., 2008; Chiesl, 2007). King, Roger, and Piotrowski (2009) found that the vast majority of undergraduate business students in their study considered it easier to cheat online than in a traditional classroom setting. Scholars also believed that the increasingly social and collaborative nature of the Web creates a greater acceptance of cheating by students (Ma et al., 2008). Baum (2005) reported, "Many computer-savvy kids as well as educators, administrators and parents are unclear about what is and what is not ethical when dealing with the World Wide Web" (p. 54). Greater opportunities and relaxed attitudes about cheating have led to issues of plagiarism, among other challenges (de Jager & Brown, 2010; Samuels & Bast, 2006). However, other research has contradicted these conclusions, arguing that online learning does not necessarily facilitate greater dishonesty. For example, Stuber-McEwen, Wiseley, and Hoggatt (2009) surveyed 225 students and found that students enrolled in online classes were less likely to cheat than those in regular classes, leaving the question of whether the online medium facilitates greater cheating still unanswered.

Accessibility. Accessibility of educational technologies has been recognized as one of the most prominent ethical concerns facing schools (Lin, 2007). In support of this notion, Garland (2010) suggested that one of the school principal's most important roles is ensuring ethical technology use and guarding against inequities in technology access between groups of students. However, scholars are not consistent on how accessibility might be a problem. Traxler (2010), for example, has suggested that unequal access to technology creates a digital divide that can impede the social progress of some student groups, contributing to a potential nightmare for institutions. In contrast, Vigdor and Ladd (2010) pointed out that providing all students with ubiquitous access to educational technology would increase not decrease the achievement gap. In addition to enabling all student groups to have access to the same educational technologies, institutions must also increase access to assistive technologies for students with disabilities (Dyal, Carpenter, & Wright, 2009).

Developing ethical use behaviors. A quick search of the Internet using the keywords "appropriate technology use policy" reveals a plethora of documents from schools stipulating the expectation that students use technology for appropriate educational purposes only. Although technology has the potential to benefit students in their educational pursuits, making technology ubiquitously available to students and teachers has the obvious risk that technology will be used inappropriately on occasion. Thus, most K-12 schools find it necessary, as a moral imperative, to monitor Internet use and restrict student access to this technology and the information the technology may provide.

Researchers have suggested several possible methods for developing students' ability to use technologies more ethically. Bennett (2005) suggested using the National Education Technology Standards (NETS•S) as a guide (see ISTE, 2008b); however, while instructive, these standards are not specific enough to inform direct strategies. Including ethical training in teacher professional development has also been explored (Ben-Jacob, 2005; Duncan & Barnett, 2009). Some academics feel it is the teacher's responsibility to create a safe and ethical learning environment with and without technology (Bennett, 2005; Milson & Chu, 2002). Several researchers have suggested classroom strategies for teachers. For example, Kruger (2003) recommended teaching by example and working cyber ethics into assignments and discussions. Baum (2005) echoed these ideas, adding that teachers should create acceptable use policies with students and involve them in making pledges concerning their ethical behavior. Ma, Lu, Turner, and Wan (2008) added that effectively designed activities that are engaging and relevant to students' interests encourage more ethical technology use. Still other scholars have suggested using technology to combat technological-based dishonesty through anti-plagiarism software (Jocoy & DiBiase, 2006) or the use of webcams to verify that online students who complete the work are the same students enrolled in the courses (Saunders, Wenzel, & Stivason, 2008). In addition, instructors can make it a personal goal to stay abreast of technological developments and their potential ethical implications (Howell, Sorensen, & Tippets, 2009). Finally, some researchers have suggested building a supportive social community characterized by a culture of academic honesty (Ma et al., 2008; Wang, 2008) because "students who feel disconnected from others may be prone to engage in deceptive behaviors such as academic dishonesty" (Stuber-McEwen et al., 2009, p. 1).

Despite the concern expressed and implied in these suggestions, it is apparent that as a society we have been slow in developing the ethics, norms, and cultural practices needed to keep pace with technological advances (Traxler, 2010), leaving many teachers unaware of proper "technoethics" (Pascual, 2005, p. 73). As we continue to increase access to and use of technologies, it will become paramount to address these and other ethical considerations if we are to succeed in promoting effective and sustainable technology integration.

Increasing Effective Use of Technology

Researchers have reported that even when teachers and students have sufficient access to educational technologies, adequate training in technology use, and confidence in their abilities to apply it, not all of them actually use technology in the classroom, and those who do may not always use it effectively (Bauer & Kenton, 2005; Choy & Wong, 2009; Overbaugh & Lu, 2008; Shapley et al., 2010; Van Dam, Becker, & Simpson, 2007; Woolf, 2010; Zhao, 2007). For example Choy and Wong (2009) found that student teachers who had received technology integration training indicated they were more likely to use technology in their classrooms; but in practice they used technology in teacher-centered functions rather than in more effective student-centered pedagogies.

The complex and dynamic nature of the teaching and learning process contributes to the difficulty of effective technology integration. For example, experts and stakeholders do not always agree on what to teach and how to teach it (Woolf, 2010). Also, given the complexity of most educational tasks, the certainty of accomplishing specific learning goals with or without technology is often low (Patton, 2011). Thus, establishing research-based technology-enhanced instructional methods and best practices is challenging. However, emerging research into the effective use of technology has identified some best practices by considering issues such as (1) the need to focus on pedagogically sound technology use, (2) ways to use technology to personalize instruction, and (3) benefits of technology-enabled assessment. An additional area of concern is the need for systemic changes at the organizational level.

Need for Pedagogically Sound Technology Integration Practices

A major criticism of current teacher professional development efforts is that many of them have emphasized improving teachers' attitudes toward technology integration and increasing their self-efficacy without a strong enough emphasis on pedagogically sound practice. Some scholars have indicated that professional development goals must shift to emphasize understanding and utilizing pedagogically sound technology practices (Inan & Lowther, 2010). For example, Palak and Walls (2009) explained that "future technology professional development efforts need to focus on integration of technology into curriculum via student-centered pedagogy while attending to multiple contextual conditions under which teacher practice takes place" (p. 417). Similarly, Ertmer & Ottenbreit-Leftwich, 2010 argued that "we need to help teachers understand how to use technology to facilitate meaningful learning, defined as that which enables students to construct deep and connected knowledge, which can be applied to real situations" (p. 257). According to Cennamo, Ross, and Ertmer (2010), to achieve technology integration that targets student learning, teachers need to identify which technologies support specific curricular goals. Doing so would require understanding the technological tools themselves, as well as the specific affordances of each tool that would enable students to learn difficult concepts more readily, hopefully resulting in greater and more meaningful student outcomes (Ertmer & Ottenbreit-Leftwich, 2010).

An emerging framework for professional development technology integration that attempts to help teachers focus more on learning is Technological Pedagogical Content Knowledge (TPACK). This framework is discussed elsewhere in this handbook, but it is worth mentioning here in that it has been proposed as a guiding framework for training teachers and evaluating effective technology integration efforts (Harris et al., 2009). Koehler & Mishra (2008); (see also Koehler, Mishra, & Yahya, 2007) developed the concept of TPACK as a specific type of knowledge necessary for successful teaching with technology. TPACK is the intersection of three knowledge areas that individual educators might possess: content knowledge, pedagogical knowledge, and technological knowledge. Teachers are expected to be knowledgeable in pedagogical issues related to teaching and learning (PK). They are also required to have in-depth content knowledge of the subjects they are to teach (CK). In addition, they are expected to have technological knowledge in general (TK), along with an understanding of how specific technologies might facilitate student learning of specific content in a pedagogically sound way (TPCK). TPACK proponents argue that teachers must understand the connections between these knowledge areas so that instructional decisions regarding technology integration are pedagogically sound and content driven.

Since TPACK emerged as a theoretical framework, researchers have explored its potential professional development applications (Cavin, 2008), as well as ways to assess teachers' abilities and skills in this area (Kang, Wu, Ni, & Li, 2010; Schmidt et al., 2009). However, work in this area is still ongoing, and methods and principles for creating effective TPACK-related professional development and measurement should continue to develop as an area of research.

Need for Technology-Enabled Personalized Instruction

Most educators hope to personalize instruction for their students, which generally includes identifying the needs and capabilities of individual learners; providing flexibility in scheduling, assignments, and pacing; and making instruction relevant and meaningful for the individual student (Keefe, 2007). The goal of personalizing instruction usually means rejecting the "one size fits all" model of education and replacing it with customized instruction. The idea of personalized or differentiated instruction is not new (Keefe & Jenkins, 2002; Tomlinson, 2003); however, the potential for technology to facilitate differentiation is appealing to many educators (Woolf, 2010).

Many factors are required for technology-enabled personalized instruction to become a reality. Access to the mobile devices needed for ubiquitous individualized instruction would need to be more prevalent (Hohlfeld, Ritzhoupt, Barron, & Kemker, 2008; Inan & Lowther, 2010; Nagel, 2010). And few of the many existing educational software programs are designed to provide differentiated instruction, monitor student progress, and assess student achievement on a comprehensive set of learning objectives (Fletcher & Lu, 2009; Ross & Lowther, 2009).

Critics of educational initiatives that use technology as a primary means of instruction contend that computers do not teach as well as human beings (Kose, 2009; Owusua, Monneyb, Appiaha, & Wilmota, 2010). We do not have the type of artificial intelligence needed to replicate all that teachers do when providing instruction (Woolf, 2010). However, hybrid courses (blended learning) are now utilizing technology (like intelligent tutoring systems) but maintaining face-to-face aspects of the traditional classroom (Jones & Graham, 2010; Yang, 2010).

Much of the educational software currently being used in schools focuses on content delivery (with some pacing flexibility and assessment) or on knowledge management systems using information communication technology, but not necessarily customization that tailors instruction to the individual needs of the learner. Computer software used in

K-12 education has primarily involved drill and practice for developing reading and mathematics skills (i.e., computer-based instructional products). Improving basic word processing skills (i.e., typing) is also a prevalent technology-facilitated instructional activity taking place in schools (Ross et al., 2010). These educational software programs are intended to supplement the work of teachers rather than replace them and are typically not integrated directly into classroom instruction.

Some intelligent tutoring systems (also called intelligent computer-assisted instruction or integrated learning systems) have been studied and made available to schools (Conati, 2009; Lowther & Ross, 2012; Vandewaetere, Desmet, & Clarebout, 2011; Yang, 2010). These systems have been designed to customize instruction for individual students, but many challenges are involved with their use (Conati, 2009; Yang, 2010). They are not widely implemented in schools as many are in a developmental stage, they are limited in scope, and they are quite expensive (Conati, 2009; Cooper, 2010; Lowther & Ross, 2012; Yang, 2010). In most cases these systems attempt to differentiate instruction but fail to rise to the level of adaptive intelligent tutors. The current efforts to personalize instruction with technology have focused on managing learning (e.g., providing instruction, practice, and summative testing) because programming intelligent formative and diagnostic assessment and feedback into these systems has proven to be a daunting challenge (Woolf, 2010).

Need for Technology-Enabled Assessment

Assessment is an important aspect of differentiated instruction that can be strengthened by technology. The primary focus of summative standardized testing in schools has been accountability (US Government Accountability Office, 2009); but the true power of assessment is obtaining diagnostic and formative information about individuals that can be used to customize instruction and remediation (Cizek, 2010a; Keefe, 2007; Marzano, 2009). For this critical purpose, technology has the potential to be extremely valuable.

Summative assessment and accountability efforts. Since 2002 the cost of testing in schools has increased significantly (US Government Accountability Office, 2009). Testing costs result primarily from accountability mandates that emphasize increased achievement on state standardized tests. With the current imperative to adopt common core standards and establish national online standardized testing in the USA, the need for technology-enabled assessment will only increase (Toch & Tyre, 2010), including the use of computer-adaptive testing techniques and technologies. The major concern with these initiatives is that schools are not now, nor in the immediate future will they be, equipped to handle the requirements of large scale online testing in terms of access to computers and the Internet, as well as the networking infrastructure needed (Deubel, 2010; Toch & Tyre, 2010).

Formative and diagnotic assessment efforts. One of the greatest benefits of online testing is the potential for teachers and individual students to get immediate results (Deubel, 2010; Toch & Tyre, 2010). State standardized testing in its current form does little to improve learning for individual students, as the lag time between taking a test and receiving the results prevents the information from being useful. In addition, most standardized assessments are not designed to help individual students (Marzano, 2009). Embedding assessment into the learning activities for both formative and diagnostic purposes can be facilitated by using technology, but the ability to do this is at the emergent stage. Critics of technology-enabled assessment have pointed out that the tools required to accomplish this type of testing are far from adequate.

The benefits of having computerized assessment systems in schools may be compromised by a lack of quality. For example, while assessment vendors claim high correlations between the results of computer-scored and human-scored writing tests (Elliot, 2003), critics have described serious flaws in the process (McCurry, 2010; Miller, 2009). Writing software using computer scoring can be programmed to identify language patterns, basic writing conventions, and usage issues; the software cannot, however, read for meaning, creativity, or logical argument (McCurry, 2010), which are more important aspects of literacy development. Thus, the accuracy and validity of computer-scored writing assessments are suspect. At this time, schools using these technologies are forced into a tradeoff between quality assessment and practicality (Miller, 2009). However, computer-scored writing assessment is an area of great interest in schools.

Another criticism of current assessment trends relates to how tests are developed and used. Diagnostic formative assessments should be narrower in focus, more specific in content coverage, and more frequent than the summative standardized testing currently being mandated for accountability purposes (Cizek, 2010b; Marzano, 2009). For this type of testing to become a reality, students would need better access to personal computers or mobile devices, school networks, and the Internet (Toch & Tyre, 2010). In addition, instructional software would have to be aligned with approved learning objectives (Cizek, 2010b). Assessment would need to be integrated into the learning process more thoroughly, with instructional software designed to monitor and test the progress of students and then provide prompt feedback to each individual learner (Marzano, 2009). We expect teachers to provide formative assessment and feedback to their students, but teachers are often overwhelmed by the task. Technology has the potential to facilitate learning by enabling this process, but greater advancements in this area are needed to make this a workable reality (Woolf, 2010).

Need for Change at Systemic Level

While TPACK and other pedagogically driven technology integration efforts are an improvement in the drive towards more effective use of educational technologies, to focus on pedagogically sound technology use alone would be insufficient for lasting change. Many teachers and educational technologists have learned that even when teachers adopt technologies and learn how to use them in pedagogically appropriate ways, they are hampered in their integration efforts by the educational system. Thus, as Sangra and Gonzalez-Sanmamed (2010) argued, true technology integration is possible only when systemic changes are made in the way we teach and provide education (see also Gunn, 2010). Teacher-level implementation of technology is not always the most significant predictor of student achievement. For example, Li (2010) made observations and conducted focus group interviews with students, teachers, and school stakeholders in a school in Hong Kong. The author found that changing teachers' conceptions did not necessarily impact outcomes without an accompanying increase in "social trust, access to expertise, and social pressure" (p. 292) in a way that empowered the teachers to take risks and supported their pedagogical changes. These findings suggest a great need for social support for whatever educational initiative is being implemented. And Shapley et al. (2010) suggested that students' use of laptops outside of school to complete learning tasks may be the strongest predictor of academic success. Thus, possibly the most important indicator of whether an educational initiative will be effective is the individual students' desire and effort to learn (Davies, 2003).

The importance of social and organizational structures is further confirmed as many teachers and educational technologists have encountered barriers to effective implementation at the administrative, collegial, parental, or community level. Drawing on evidence from higher education institutions in the UK, Australia, and New Zealand, Marshall (2010) reported that "university culture and existing capability constrain such innovation and to a large extent determine the nature and extent of organizational change" (p. 179). Marshall also argued that without strong and supportive leadership, rather than being a catalyst for more effective instruction, educational technologies reinforced the status quo of existing beliefs and practices (see also, Ely, 1999). Similarly, in their study of faculty adoption of course management technologies, West, Waddoups, and Graham (2007) found that the attitudes of peers, administrators, and even teaching assistants were often more influential than the perceived quality of the tool and the availability of technical support on campus.

Much discussion of systemic change is occurring in the field of educational communications technology. It appears that these efforts will become more critical as "educational performance based on the learning outcomes of formal schooling in a future knowledge society could be significantly different from that of today" (Kang, Heo, Jo, Shin, & Seo, 2010–2011, p. 157), requiring new and evolving uses of technologies, curriculum, and systems to facilitate these changes (Facer & Sandford, 2010).

We find it surprising that scholars appear to be lagging in this effort to understand systemic influences on technology integration. As Tondeur, van Keer, van Braak, and Valcke (2008) reported, research on technology in schools is focused mostly on classroom rather than organizational variables. Additionally, there seems to be a major gap in the literature regarding the development of a technology integration framework that, like TPACK, is pedagogically driven but sensitive to systemic variables. We are unsure what an "organizational TPACK" model would look like, but we believe this to be a potentially fruitful research endeavor for the next decade.

Conclusions

Legislative mandates for schools to utilize educational technologies in classrooms are based on the belief that technology can improve instruction and facilitate learning. Another widely held belief is that students need to develop technology literacy and skills in order to become productive members of society in a competitive global economy. This chapter explored school technology integration efforts as progressive steps: increasing access to educational technologies, increasing ubiquitous technology use, and improving effective technology implementation.

Over the past decade, one-to-one computing programs have been the most prominent initiatives used to increase access to technology in schools. These initiatives are designed to increase the availability of primarily digital technologies and related software for teachers and students. The biggest access obstacle has been the cost of obtaining and maintaining technology resources. The Open Educational Resource (OER) movement is attempting to alleviate some of the cost associated with providing quality educational resources, but OER programs struggle with sustainability issues. The cost of providing and maintaining technology as well as the way federal programs fund technology initiatives have often resulted in uneven levels of access, creating pockets of technology-rich schools.

While technology availability in schools has increased significantly over the past decade, measures of access likely provide an overenthusiastic impression of progress in effective technology integration and use. Having greater access to and improved use of technology (i.e., computer and Internet availability) has not always led to substantial increases in learning. Typically, studies refer to technology's potential for increasing learning but acknowledge that any scholastic benefit depends on factors other than simply having technology access.

Once schools have access to educational technologies, the focus of technology integration often turns to increasing technology use. Researchers have reported that even when teachers and students have sufficient access, they do not always use technology for instructional purposes. Issues that hinder technology use in schools include social and moral ethics, like the question of inequitable access to technology for all students, which causes some teachers to avoid requiring students to use technologies to do assignments at home. Many schools also find it necessary to restrict the use of various technologies due to potential negative consequences and ethical dilemmas, considering it a moral imperative to monitor Internet use and limit student access to this technology.

In an effort to increase technology use in classrooms, most schools encourage teachers to participate in professional development activities. The most common goal for teacher development has been to change teachers' attitudes towards technology integration and to strengthen their abilities to use specific technologies. A major criticism of these efforts is that they do not provide a strong emphasis on practice that is contextually based and pedagogically sound. TPACK proponents argue that teachers must understand the connections between the specific affordances of various technologies and the ways each tool might best be used to facilitate specific content learning.

However, efforts to establish research-based technology-enhanced instructional methods and best practices encounter many challenges. Given the contextual complexity and extraneous factors that affect most educational endeavors, our ability to accomplish specific learning goals with or without technology can be difficult. But researchers warn that pedagogically sound practice must be implemented before substantial increases can be made in the effectiveness of technology use in schools. Specific areas where technology has the potential for improving instruction and learning include personalizing instruction and improving assessment. But by most accounts, given the current state of technology, our ability to customize instruction and assessment effectively with technology would require better technology access, tools, and methods.

In conclusion, future efforts to improve instruction and learning using educational technologies will still need to focus on providing students and teachers with ubiquitous access to new technologies and educational resources. However, pedagogically sound best practices will need to be established, and professional development will need to focus more on using technology to improve learning—not just on changing teachers' attitudes and abilities in general. Substantial systemic changes will likely need to be made in educational systems, administration, and resources in order to support teachers in making these types of transformations. The development of adaptive intelligent tutors is an area of great potential. Technology enabled assessment will be an especially important area of research and development in this regard. In addition to these efforts we would need more discussion on pedagogically oriented systemic changes that can support frameworks such as TPACK at the organizational level.

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69 Synthesis of Recent Literature on Educational Technologies in Medical Curricula

Tiffany A. Koszalka, John W. Epling, and Jennifer Lynn Reece-Barnes

Abstract

A recent call for medical school reform in the USA has sparked a renewed interest in the use of educational technologies to help enhance and standardize the complex medical curriculum. Medical school goals focus on preparing medical students to be physicians who connect multiple knowledge bases to clinical experiences, develop professional competencies, and continually self-assess knowledge and learning needs. Educational technology has been suggested as a critical factor in meeting these goals. Although there is a growing presence of technologies in medical schools, recent educational technology studies in medical education outlets overwhelmingly appear to be solo pilot efforts that are evaluative in nature and primarily describe uses and perceived value of technology. Few report widely studied technology phenomena and produce evidence-based results powerful enough to support uses of technology to inform curricular reform. Medical education scholars have suggested that more interdisciplinary and rigorous empirical studies are required to determine how educational technologies may enhance the efficiency and quality of medical curricula. This chapter describes the evolving process of educating physicians and provides a synthesis of recent themes in the medical school educational technology literature covering areas of adoption of educational technology innovations, technology support structures, design and development challenges, and recent research. Conclusions suggest future research that by nature is collaborative, interdisciplinary, multi-institutional, and aligns with curriculum enhancement themes.

Keywords

Medical education • Technology integration • Medical school reform • Instructional design

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Introduction

Medical education scholars agree that medical schools must prepare new physicians who can connect formal medical knowledge to clinical experiences, integrate the multiple knowledge bases required to practice medicine, interact with multiple specialists to diagnose and treat patients, develop habits of inquiry, track and further develop their professional competencies, and be able to assess their own learning (Cooke, Irby, & O'Brien, 2010). However, there is disparity between current medical school practices and the way each school prepares medical students to achieve these learning outcomes and become practicing physicians. Ellaway (2010) suggested that appropriate and efficient uses of emerging technologies could be helpful in improving and standardizing learning within a complex medical education curriculum.

Scholars and practitioners interested in the benefits and challenges of emerging educational technologies have worked for decades to study many of these same educational goals in other professions. Recently, Larsen, Visser-Rotgans, and Hole (2011) studied the use of online learning in the development of knowledge and competencies of social services professionals. Wu and Koszalka (2011) explored how distributed teams of senior engineering students, with preparation in different specialties, collaborated on engineering design diagnostics and problem-solving in an online multiuser virtual environment. Pinkwart, Harrer, and Kuhn (2010) investigated how digital tools supported the development of inquiry skills during individual and group learning activities on calculating statistical probabilities. Poldoja, Valjataga, Tammets, and Laanpere (2011) tested the use of Web-based self and peer assessments on developing teacher educational technology competencies. Gogus, Koszalka, and Spector (2009) explored how technology tools helped measure learning progress in the complex domain of environmental sciences.

Scholarship in medical education also reports on educational technology initiatives. However, studies in medical education rarely referenced the rich body of educational technology research and/or used rigorous study methodologies as defined by social sciences domains. Teaching physicians are more accountable for increasing clinical productivity, serving patients, helping to achieve standardization and quality in medical education, and teaching than they are in publishing medical education research (Chen, Bauchner, & Burstin, 2004). Thus, medical education literature is relatively bereft of controlled studies, randomized trials, and attention to the essential learning outcomes needed to truly evaluate and enhance education with technology.

Scholars have suggested that medical education research should receive a higher priority and be more multi-institutional and interdisciplinary in order to reduce medical educators' time away from patient and educational responsibilities while still producing empirical data that can inform technology's role in meeting medical school's ambitious and necessary goals (Carney et al., 2004; Chu, Zamora, Young, Kurup, & Macario, 2010; Eysenbach, 2008; Gagnon et al., 2009). Thus, it appears there are opportunities for educational technology scholars to seek partnerships with the medical education community to pursue deeper understanding of the roles technology can play in learning and productivity in medical schools.

Unquestionably, the rapid emergence and ubiquitous nature of technology in society has touched the health care community. Electronic Medical Records (EMR), for example, provide instantaneous access to information that has changed the practices of physicians while providing valuable point-of-care information (Dansky, Gamm, Vasey, & Barsukiewicz, 1999). Robots help increase the accuracy of surgery (Gerhardus, 2003). Internet resources help better educate patients and their physicians (Wald, Dube, & Anthony, 2007). Increases in the uses of these technologies in medical practice has aided in diagnosis, treatment, and communications with patients and collaborating health care providers. However, few of these technologies, or others (e.g., tablets, mobile technologies), are integrated into medical school curriculum. The use of technology in learning is not emphasized, nor is it strategically and consistently implemented and supported to scaffold student learning (Ellaway, 2011). The call for medical education reform has raised questions about best practices of technology integration and how technologies might help in the effort to standardize and improve medical education.

The remainder of this chapter synthesizes recently published works in medical education outlets in an attempt to describe the current state of technology use and its impact on becoming a physician. The next section begins with a brief description of the medical education process and the role educational technology has played in training physicians.

Becoming a Physician

Learning to become a physician and maintaining credentials in this profession is a life-long journey. Students who enter medical school find out quickly that learning to practice medicine requires immersion in the hard sciences and math, skills in the *practice-of-medicine* (e.g., patient exams, use of medical equipment), and mastery of soft skills like communication, collaboration, teamwork, and relationship building (Cooke et al., 2010). Medical students are assessed for empathy, reflective practice, learning preferences, problem identification and solving, social consciousness, and societal participation (Carraccio & Englander, 2004; Hoff, Pohl, & Bartfield, 2004; Miflin, Campbell, & Price, 2000; ten Care, Snell, Mann, & Vermunt, 2004). These learning, practice, and assessment activities in US medical schools generally occur within a *2-by-2* curriculum model.

In the first 2 years, medical students build a solid background in the basic sciences of medicine (e.g., biochemistry, anatomy, physiology). The final 2 years include clinical duties in traditional departments of medicine like internal medicine, family medicine, surgery, pediatrics, and obstetrics. Over time, this model has changed where introductory courses in medical interviewing, physical examination, ethical and social issues, and clinical experiences are now presented in the first 2 years. *Back to basic* science electives have been added in later clinical years to refresh knowledge prior to licensing examinations and start of residency.

In the last decade, there have been other disruptions to the traditional *2-by-2* model by shortening the preclinical years and taking the basic science content out of traditional academic department courses to integrate it into clinically sensible modules, usually by organ system. There is now an emphasis on early clinical experiences, longitudinal study of pervasive content (e.g., ethics, public health, medical information skills), and more authentic, competency-based, and well-planned assessment methods. These changes have been in response to transformations in medical practices.

Preparing Medical Students for Medical Practice

Medical school curricula have generally struggled to keep up with the changes occurring in medical practice. The widespread, incentivized adoption of Electronic Medical Records (EMR), patient portals, and new methods to communicate with and manage patients has strained the ability of medical schools to keep pace. These changes require a more active, outreach-oriented style of analyzing and managing patient needs that is unfamiliar to traditionally trained physicians. In addition, basic mastery of the stream of continuously updated medical knowledge requires new methods for organizing, retaining, and accessing information needed while seeing a patient (Mostaghimi et al., 2006).

Only recently has the literature suggested that technology tools be strategically integrated into the teaching, learning, and assessment processes of medical school to support new medical practice requirements. Currently, although simulations are prevalent in medical schools, the most popular uses of technology have been little more than replacements for existing modes of communication and record-keeping with only weak endorsements for other roles that technology might play.

Potential Role of Emerging Educational Technologies

Medical curriculum is abundant in opportunities to integrate educational technologies to support complex, changing, and varied information-rich learning environments. In reality, technologies have been integrated slowly into various aspects of medical schools. With the possible exception of simulations, integration has often been haphazard, without regard to learning and instructional principles, with only a few instances suggesting technology use for a direct educational purposes (Ellaway et al., 2011; Khogali et al., 2011).

Exploring the Range of Educational Technology in Medical Education

We conducted a simple article title scan across issues of eight medical education journals published in 2011 to understand the emphasis on educational technology research. Our title scan identified themes published over the last year. Abstracts were read occasionally to clarify whether certain words in the title indicated digital technologies or some non-digital technique. For example *simulation*, is often used to describe a face-to-face (non-technology-based) staged teaching situation during educational sessions.

The eight journals included four primarily focused on medical education and four medical practice journals with an allocated section for education. There were 1,966 articles in these journals. Sixty-six (3 %) focused on technology uses in medical education. Twenty-three of the 66 were classified as conceptual works. Seven appeared to be evaluation studies. Five were survey research. Ten were research trials or pilot studies. Twenty-one were opinion articles.

Given the nature of the profession, it was understandable that a majority of the articles focused on teaching medical content and procedures. Educational technology topics that were covered included topics like: social media, podcasting, simulations, pedagogy, tele-medicine, virtual surgery, digital virtual patients, distance education, support, and cost effectiveness. Most titles classified as research tended toward level 1 evaluation data (i.e., feelings, perceptions), although some suggested measures of learning gains.

This initial review supports conjecture that little reported empirical research exists that unpacks the complexity of educational technology in medical education. This review however, neglects to identify related articles in other outlets (e.g., other medical education journals and conferences, educational technology and instructional science journals and conferences, educational psychology outlets). Our findings may also suggest there has not been significant motivation in publishing or studying the use of technology to support learning in medical education over the past year. In fact, conducting educational technology research is not well supported in medical schools given the priorities of teaching physicians, namely, patient care and educating medical students (Chen et al., 2004). What is clear is that educational technology has made its way into medical curriculum, but it has not necessarily been integrated in strategic and meaningful ways (see Table 69.1).

Table 69.1 Classification of educational technology articles in 2011 medical journals

	Number of articles	Number of ed tech articles	Percentage of ed tech	Conceptual reviews and how to	Eval	Survey research	Research trails	Opinion	Topics
Journal of Pediatrics (quarterly)	642	6	1	1				5	Social media; computerized patient training; tech integration; importance of technology skills; video; tele-education
Academic Medicine (monthly)	386	13	3	3		1	2	7	Tech-supported simulations; online forums; simulation meta-analysis, IT benefits/challenges; virtual patients
Annals of Internal Medicine (twice monthly)	378	6	2				1	5	IT and reforming education; up-to-speed on EMR/IT; social media in edu/practice; interactive video
Medical Teacher (monthly) 1.982 5-year impact	232	24	10	10	7	3	2	2	Virtual patients, podcasting, computer-based testing, digital pen, emedical teacher; virtual surgery
Family Medicine (monthly)	112	2	2	1			1		How to develop; electronic quality patient mgt systems; interdisciplinary teams in medical education
Education for Primary Care (monthly)	89	6	7	6					Tech cost-effectiveness, use of EMR, e-learning sites, case-based simulations, using World Café
Annals of Family Medicine (quarterly)	70	5	7	2			1	2	Tech in practice, tech in med ed; prof development apps; synchronous tools in learning/practice; electronic med records training
Teaching and Learning in Medicine (quarterly) 1.051 5-year impact	57	4	7			1	3		Simulations; mannequins, online assessment/feedback, Web-based assessment tool validation
	1966	66	3	23	7	5	10	21	

Recent Literature in Medical Education and Technology

It is not clear *how* and *when* technology is helping or hindering the complex process of learning to be a physician. Thus, a more in-depth review was warranted to see what educational technology initiatives have been proposed, implemented, and researched in recent years. Identifying patterns of value and impact across these initiatives, and across the many specialties of medicine, may help support future technology decisions and further overall understanding of education technology's role in enhancing the quality of medical curricula. Identification of these themes may also draw the attention of educational technology researchers interested in collaborating with medical schools to develop more rigorous studies aimed at further understanding the phenomena of educational technologies.

Methodology for a Narrative Review and Critique of Current Literature

We conducted a review of several educational technology works published in medical education outlets over the last decade. The work began with key word searches (e.g., educational technology, instructional technology) that yielded several hundred papers in medical education library databases and open Internet searches. A coding scheme was developed to label works as conceptual, process, or research focused. Papers were identified that fit into each of these categories and that represented newer to older publications (within established dates), individual and meta-analysis works, and different types of technologies (e.g., simulations, distance education, Web tools) used in different medical education contexts (e.g., teaching, practice) and disciplines (e.g., internal medicine, pediatrics, surgery). This sample was not meant to be all-inclusive or provide a basis for generalizing findings. We were not conducting a meta-analysis. Rather, this narrative review represents a synthesis of a broad collection of works in several medical education contexts and disciplines, showing the breadth of medical education scholarly work devoted to educational technology.

Following a brief overview of *conceptual thoughts* of medical education scholars gleaned from this literature and an example of a well-established line of research in educational technology, a narrative review is offered on the selected papers describing themes in educational technology literature.

Conceptual Thoughts on the Value of Educational Technologies

One question continually raised in the medical education literature is when and how technology can be used to enhance teaching and learning in complex medical curricula (Cooke et al., 2010; Ellaway, 2011; Gattoni & Tenzek, 2010). Sandars (2011), for example, posited that educational technology can engage medical students in learning content and procedures. Dror, Schmidt, and O'Connor (2011) suggested that technology can be valuable in developing cognitive abilities, while Fryer-Edwards et al. (2006) conceptualized technology as a tool for prompting reflection. Ellaway (2010, 2011) developed a different conceptualization by grouping technology uses into functional categories like (1) *research*—access to multiple forms of information, (2) *convenience*—digital services and social media to maintain human mediated contact, and (3) *tracking*—storage of information for access and analysis.

Conceptual thoughts about increasing information access, communication, and storage have likely led to the automation of traditional or *safe* teaching and learning activities in medical education and provisions to provide open access to more information. Other medical educators appear to be seeking different types of value from technology, perhaps more in technology's ability to *disrupt* the status quo of medical education and increase the curriculum's quality and efficiency by using technology to further engage medical students in new ways—moving from memorizing toward prompting higher levels of engagement and better thinking qualities in students (Cooke et al., 2010; Ellaway, 2010, 2011). See Stead (2006) regarding *safe* and *disruptive* use of technologies.

Others have suggested that specific technologies can add value to student learning. Social media technologies can enhance communication among medical students and faculty (Eysenbach, 2008). Semantic networking tools can enhance assessment of learning progress in the complex domain of medicine (Koszalka & Epling, 2010). Distance education technologies can support learning of time-challenged physician-in-training (Koszalka & Olson, 2009; Larsen et al., 2011). Thus, educational technologies are perceived as providing powerful solutions to many medical school challenges. The literature often describes the characteristics of a specific technology's use or reports student feelings about a technology through individual, un-replicated studies; yet few offer empirical evidence on learning or productivity of medical students across curricula or institutions.

An example of a well-established line of technology research. One exception is the well-established literature of simulation-based medical education. Recently McGaghie, Issenberg, Petrusa, and Scalese (2009) and Cook et al. (2011) provided meta-analyses summarizing key characteristics of successful technology-simulations and providing some evidence of impact on learning and medical practices. For example, simulations were found to improve mastery learning. However, questions were raised as to the learner's ability to transfer simulation learning to practice environments (McGaghie et al., 2009). Cook et al. (2011), in their comprehensive review of over 600 simulation studies, suggested that *better learning outcomes* were often found in simulation versus non-simulation learning situations. Both works, however, noted that learning was rarely defined consistently and the variety of conditions in the reviewed investigations (e.g., topics, learners, instructional designs, research methods, and outcome measures) led to high inconsistencies in results across studies. Both also mentioned that methodology weaknesses suggested limitations in the studies. Future research was recommended to clarify *when* and *how* simulations might be used most effectively.

Glimpses of *how* to use technology to support deep learning are beginning to emerge in the investigations of integrative designs (i.e., prompting thinking and learning in context). For example, virtual patient simulations (Bowdish, Chauvin, Kreisman, & Britt, 2003), technology-based reflection activities (Sanders & Murray, 2009), and comment-supported virtual learning objects (Harden et al., 2011) show promise in engaging medical students in more complex and contextualized situations over the traditional lecture, case review, or computer-based instruction. Many technology initiatives, however, have failed to move students to the next step of understanding basic content as a critical and holistic aspect of the everyday medical practice (Bowdish et al., 2003). Conceptually, technology integration efforts seem fruitful; however, the field's understanding of their adoption and full integration into medical curriculum remains fuzzy.

Research on Medical School Adoption of Educational Technology

Although reports of educational technologies are plentiful, literature has acknowledged little about the technology adoption process or rates of technology adoption on a system-wide-scale, either by discipline or medical institution. Fall et al. (2005) shared results on a multi-institutional development and implementation study on computer-assisted learning programs in pediatrics clerkships. This study impacted over 8,000 medical students across 50 medical schools. Cost effectiveness, consistency of content delivered, value noted by clerkship directors in helping meet required accreditations, and student acceptance were all cited as successes (see www.clipcases.org). Berman et al. (2009) described a study on Web-based virtual patient cases across six medical schools' pediatric clerkship programs. Results suggested that medical students positively perceived technology and their perceptions were positively correlated with their satisfaction and thoughts about the effectiveness of their learning. Neither study, however, provided direct indications of how and when the cases were used (or fully adopted) within the curriculum nor were measures of learning presented. Recommendations suggested a balanced approach among technology-based learning activities and other medical student requirements (e.g., clinic time, reading). Berman et al. (2011) agreed that widespread use of technology-aided instruction requires both well-integrated modules that complement existing instruction and multi-institutional collaborations focused on the technology integration initiative.

As suggested by adoption of innovation literature (see Rogers, 2003), it is important for stakeholders to develop knowledge about an innovation and its value before subsequently developing a positive attitude toward it and eventually adopting it (Ely, 1999; Koszalka, 2000, 2003; Moser, 2007). Medical education scholars concur that stakeholder measures of readiness to adopt (e.g., knowledge, perceived value, attitude) can indicate probabilities for the spread and sustainability of technology initiatives (Zayim, Yildirim, & Saka, 2006). McGee and Kanter (2011) suggested that successful adoption in medical schools is also indicated by the use of good project selection criteria, theory-based design, a robust technology development process, thoughtful implementation, and strategic evaluation. Issenberg (2006) posited that systemic curricular change begins with institutional decisions to pursue an innovation (e.g., technology), individual stakeholder (e.g., faculty) knowledge and attitudes toward the innovation, and a history of successes integrating and supporting the innovation.

Cuban (2012) argued that using technology devices effectively to customize content and learning experiences for the learner could systemically change an education system by wiping schools out of existence. But, he contended that it will not happen because of educators who are resistant to dropping traditional models of teaching, the insistence of separating students into grade levels, and the greater social beliefs that traditional schools are necessary; the system of stakeholders is not ready for such systemic change.

Medical education faces similar issues in its effort to fully integrate technology across the curriculum, rather than merely using simulations, for example, as add-on practice sessions. The well-documented technology-supported simulation and PBL movements have provided models shown to support medical student learning (AK, 2011; Cook et al., 2011; Hoffman, Hosokawa, Blake, Headrick, & Johnson, 2006; McGaghie et al., 2009). These models, with up-and-coming research on mobile technologies (Ally, 2009; Koszalka & Ntloedibe-Kuswani, 2010), social networking tools (Chu et al., 2010; Eysenbach, 2008), digital information and consulting resources (Snasel, Platos, & El-Qawasmeh, 2011), and other emerging technologies, may be able to inform designs that support medical curricula transformations and improvements. However faculty preparedness and readiness to accept and use these new tools are critical to the success of implementing these technologies.

It does appear, however, that initiatives with interdisciplinary teams are making progress in curriculum improvement efforts. Educational research suggests that strategic initiatives in technology integration are more likely to succeed if they begin with interdisciplinary teams of content and educational technology specialists as well as others with reputations for being innovative and partnering with those who are resistant (Reiser & Duffy, 2007). One indication of medical school movements toward interdisciplinary teams (e.g., primary and specialty physicians, medical researchers, nurses) to guide educational technology integration is the recent appearance of the term *instructional rounds* on Web sites that report efforts in transforming medical curricula. These *rounds*, like traditional patient rounds in hospitals, include collaborative reviews by multidisciplinary specialists who provide feedback on science or medical content, pedagogy, or technology during collaborative working sessions. Such work can bring potential integrators from the periphery of practice into the center of technology integration. See University of Virginia, University of California–San Francisco, University of Massachusetts medical school Web sites.

Even with the appearance of small- and large-scale technology initiative reports and emerging terms suggesting progress, there is no indication how ready medical educators are to integrate technology or which technologies might be most well suited across, or for each aspect of, medical school. One factor that influences adoption, integration, and sustainability of technology initiatives is technology support (Reiser & Duffy, 2007).

Research on Infrastructure and Support Mechanisms

Infrastructure. Infrastructure literature focuses on both the physical structures and digital resources being developed in medical schools to support learning. Candler and Dewayne-Andrews (2004), for example, described how technology was integrated into the physical structures of a medical university. Their definition of support focused on the placement of equipment like digital response systems, computers, and Internet access points. Similarly, Candler and Dewayne-Andrews (2004) and McGee & Kanter (2011) discussed infrastructure in terms of its function to support medical students in developing and practicing clinical skills in common and high risk/rare procedures. Ruiz, Mintzer, Leipzig, and Rosanne (2006) added to the conversation by describing infrastructure as a means for fostering a culture of curricular innovation. McGee & Kanter, (2011) suggested that technology labs were particularly supportive in the development and implementation of technology resources. Others posited that labs became a tool in themselves to encourage participation of medical faculty, staff, and students in technology initiatives and promote wide-scale uses and adoption (Cook, 2005, 2006; Cook & Dupas, 2006; Kern, Thomas, Howard, & Bass, 1998).

Infrastructure for medical learning support also includes Web sites of medical resources developed, digitized, posted, and used for classes and as references while in clinical settings (Candler & Dewayne-Andrews, 2004). Digital tools are professed to allow medical students access to up-to-date information sources. They also offer opportunities for self-paced practice prior to patient encounters. Although some have argued that these infrastructure components enhance learning (Candler & Dewayne-Andrews, 2004; McGee & Kanter, 2011), few have reported data on when, how, and how well these resources were being accessed and used and whether they were having impact on the quality of learning and practice.

Support Mechanisms. Support mechanism literature primarily describes models for sustaining technology initiatives on medical school campuses (Souza, Kamin, O'Sullivan, Moses, & Heestand, 2008; McGee & Kanter, 2011). Support for technology initiatives is generally provided through technicians commonly organized into Educational Technology Units (ETUs). Research on the organization of ETUs suggested that when ETUs were centralized, included sufficient staffing and leadership aligned with educational goals, cultivated relationships across the medical school, involved medical students in educational technology teams, and provided educational technology services to faculty and students technology initiatives were more successful than those ETUs that were decentralized and less able to support stakeholders (AAMC-IIME, 2008; Bolman & Deal, 2003). Thus, the organization of support mechanisms played a major role in use and adoption of technology innovations. Only anecdotal observations and conjecture were presented to support these claims, thus raising questions about the characteristics of *successful adoption*. Studies like Berman et al. (2009), however, described approaches that can aid in the development of support mechanisms for technology implementation beyond a single institution.

Together, infrastructure and support mechanisms can provide a foundation upon which to develop, disseminate, and support technology initiatives. However, the design of an intervention is also key to its adoption.

Research on the Design and Development of Technology Resources

The body of literature in technology integration overwhelmingly suggests that resources must be well designed and well integrated into the curriculum to support expected learning outcomes. Willcockson and Phelps (2010), for example, cited Bates and Poole (2003), Kirkpatrick (1994), and Wang (2008) when suggesting a model for implementing technologies into medical education. Their focus was to keep *learning* central to decisions about which, and how, technology should be used in learning. They suggested embracing learning theories that help match technology features to learner characteristics and expected learning outcomes. Others have suggested that well designed instructional materials that follow established models and theoretical principles, are more likely to stimulate and enhance reasoning and learning processes (Adams, Rodgers, Harrington, Young, & Sieber, 2011; Fall et al., 2005). Design literature generally suggests that designing and integrating technology resources is much more complex than simply following a model. Pedagogical perspectives, technology infrastructure and support mechanisms, interdisciplinary team expertise, technology standardization, faculty motivation, are but a few of the challenges (Ruiz et al., 2006).

Published reports on development efforts also suggested that interdisciplinary teams were better able to define high quality design, development processes, and measures for instructional products (Adams et al., 2011; Mostaghimi et al., 2006). These collaborations were particularly valuable in developing assessment and evaluation tools that provided data helpful in improving products and providing evidence of impact (Edelbring et al., 2012; Orchard, Curran, & Kabene, 2005). Educational technologists also were reported to have the competencies necessary to design complex technologies like *interactive video* (visual with prompts, cues, and testing), *simulations* (digital virtual patients that allow students to explore, practice, test, and observe effects) and *gaming* (rich environments, with time constraints and authentic distractions, means to engage multiple players in authentic tasks), that were often missing in medical educators (Dror et al., 2011).

Medical education technology resources have generally been informed, at least in theory, by educational research and collaborative partnerships. However, little is published on how well these resources or environments meet quality design or integration criteria. Literature on the decisions surrounding design choices was scarce, although there appeared to be interest in identifying supportive theories, models and partnerships to support educational technology initiatives.

Research on Educational Technology Uses and Impact

The research in educational technology uses and impact is broad. Studies have investigated the use and impact of information technology resources, virtual patients, interactive video, social networking tools, simulation, learning objects, and a range of pedagogical approaches.

Smaller, descriptive studies abound in telling how medical students used social networks and other online resources (Sanders & Murray, 2009), comparing technology to non-technology instructional interventions (Bowdish et al., 2003), correlating technology uses to learners' cognitive abilities and learning preferences (Dror et al., 2011; Halbert, Kriebel, Cuzzolino, Coughlin, & Fresa-Dillon, 2011; Khogali et al., 2011), measuring frequency of technology uses (Chu et al., 2010; Khogali et al., 2011), collecting data on completion rates of instructional activities (Koszalka & Olson, 2009), and gathering data on medical student feelings about online resources and the flexibility they provide (Cook, Levinson, & Garside, 2008; Leong, Baldwin, Usatine, Adelman, & Gjerde, 2000). Researchers have also investigated the use of technologies to support the development of reflective practices in medical students (Fryer-Edwards et al., 2006) and use of automated concept mapping tools to measure learning progress in medical diagnostics (Koszalka & Epling, 2010).

Some scholarship synthesizes multiple studies across medical schools. For example, in reviewing 9 years of published scholarship in the *Journal of Medical Internet Research* Eysenbach (2008) described multiple benefits of Web tools. Common themes identified in Eysenbach's review included easier access to medical information, improved communication among colleagues and patients, and provision of authentic virtual practice environments. Further, Eysenbach found that many articles suggested that collaborative tools provided opportunities for medical students to collaborate among themselves, learn from each other, and refine their own communication and expression skills. These ideas align with recent descriptions of how medical students should be prepared for medical practice (Cooke et al., 2010).

Harden et al. (2011) recently reported positive results for a large-scale study investigating learning objects. Learning objects are self-contained, entities that can be used, reused, or referenced to support learning (Wiley, 2002). While educational research suggested that the results of learning object integration has been disappointing (Wiley, 2002), medical education has met with success by adding commentary to each digitized learning object. Harden et al.'s (2011) findings suggested that the commentary prompted interaction and reflection and provided advice that led to successful widespread integrated and stand alone uses of these digital resources.

e-Learning and distance learning is also rapidly becoming popular in medical schools (Dror et al., 2011). Olson, Mata, and Koszalka (2013), for example, integrated video-based lectures, digitized medical papers, and self-assessment quizzing with feedback into distance education replacing over 120 lecture sessions with focused self-paced study units. Data collected suggested that students completed more of the self-study units than attended the previous lecture sessions. Online resources were deemed more flexible, easy to access before a patient consult, and able to provide enough information and practice to prepare for case-based class sessions (Olson, Mata, & Koszalka, 2013).

Overall, this narrative review suggested both broad application of technologies and emerging designs of technology interventions that included more self-assessment, activity, feedback, flexibility, and rich context in which medical student could learn. There is evidence that medical education researchers have tapped into educational technology research, conducted small-scale projects, and summarized their own bodies of literature, indicating interest in technology solutions. Newer and older technologies are being integrated and tested, yet little is known about which technologies are best used in different aspects of medical education. Guidelines to support the widespread use of these technologies are lacking, except perhaps in the use of simulations. New mobile technologies, social networks, and other online technologies are becoming part of the everyday practices of medical students, yet there seems to be no definitive research investigating the impact they have on learning or productivity. What is apparent is that a variety of technologies are being used.

Synthesis of Themes Across Conceptual Thoughts and Research

Conceptual thoughts suggest that there is educational value in technology and research reports that medical students, in general, have found technology-based resources and environments helpful in their learning. However, few studies reported any differences in overall learning between technology- and non-technology supported instructional interventions, with the exception of simulation research. This is not surprising given Clark's (1983) work and adult learning theory (Knowles & Associates, 1984) suggesting that adults seek information they need to learn, regardless of the delivery mechanisms.

However, medical education researchers themselves profess that there is a lack of rigor in the research, suggesting a lack of evidence to fully understand *how* and *when* different types of technologies are most successful in supporting specific types of learning in medical school. Constant changes in medical practices, appearances of new technologies, and demands for medical faculty to maintain patient and teaching responsibilities may affect the prevalence of literature on new educational technology initiatives (Chen et al., 2004; Ellaway, 2011).

Discussion

It has been suggested in educational technology literature that wide-scale readiness of the K-12 education system is required for successful reform (Cuban, 2012). The same is likely true for medical schools. However, medical education literature does not make it clear how widely used resources are in learning and how deeply different technologies are embedded into medical curriculum; conjecture suggests that few technology applications are directly focused on learning (Ellaway, 2010). Few proposed initiatives exist that provide specific ideas on how to successfully integrate educational technology as part of improving medical education.

Readiness. The challenges medical schools face are in understanding the level of readiness for wide-scale adoption of educational technology and determining which technologies are best suited to help achieve goals in preparing physicians. As found in the failures of the K-12 technology interventions, implementing technology interventions in medical schools is most likely going to require both professional development of faculty and changes in their mindset from status quo teacher-centered pedagogies to more thoughtful student-centered pedagogies and from technology-driven decisions to learning and practice gap-driven technology decisions. Medical educators, like most faculty in universities, are subject matter experts, rarely versed in instructional design and educational technology sciences. Training and partnerships with educational technology scholars could relieve this tension.

Mindset. A overarching mindset about technology as a delivery tool in the process of learning seems to be holding strong in the current research. With the exception of simulations, a majority of recent technology uses appear to be for accessing information (Internet-based sites and tools); few require students to think critically. As suggested in the educational media and technology literature (see Jonassen, 2005; Jonassen, Campbell, & Davidson, 1994; Jonassen, Carr, & Yueh, 1998) a perspective, or mindset, of learning *with* (technologies to enhance level of engagement with and thinking about content) versus learning *from* technology (memorizing information from viewing digitized materials) changes the entire conception of designing curriculum. The questions of design become those of automating existing resources and strategies (*safe* learning) or using technologies to encourage new relationships in education (*disruptive* learning) where learners use the tools that help them organize information in meaningful ways, manipulate information and interact with people and new information in authentic ways, and enhance social connectedness with others with whom they can learn (Jonassen et al., 1994; Stead, 2006).

An important aspect of changing mindset is professional development. Only anecdotal references were made to medical faculty acceptance of new technologies; little was mentioned about their technology competencies. Although laden with patient and teaching responsibilities, faculty need to develop their own competencies in using these new tools. One of the failures in the K-12 education system was the lack of professional development to help educators determine how to effectively integrate technology into their teaching (Grabowski, McCarthy, & Koszalka, 1998; Lawless & Pellegrino, 2007; Majumdar et al., 2005). Although not emphasized in all research, Berman et al. (2011) suggested that medical faculty were ready and have been implementing technology. It is advisable that efforts be taken to help all medical educators develop the competencies to integrate new technologies in meaningful ways to support student learning.

Support. In efforts to enhance technology support infrastructures and mechanisms, medical schools may benefit from developing better connections across medical institutions. These collaborations can provide interdisciplinary expertise, distribute effort in development and dissemination activities, and provide a powerful network for systemic change. Examples of multi-institutional collaborations are becoming more plentiful. Such collaboratories may have a greater chance of securing funding given their potential to be sustainable and produce higher impact from sharing resources across national groups (NIH, 2012; NSF, 2011). However, evaluation systems collecting and tracking data on successes, impact, and sustainability are required. Similar collaboratories in US K-12 technology integration are supporting systemic efforts to enhance science education, nationally (Hsu & Sharma, 2006). Collaboratories can support progress toward enhancing education by strategically and collaboratively planning testing strategies, sharing data collection tools, and offering wide-scale study results. Recent medical simulation, PBL, and learning objects integration research have suggested such models.

Future Research

Areas currently being researched only begin to scratch the surface of exploring the use of technology in medical education. There is a large base of research on the more popular simulation technologies and literature is beginning to emerge on new Web, social media, and handheld technologies. Yet, broad knowledge of the value of technology integration in medical curricula continues to be elusive. Future scholarship should begin to focus on the uses of these technologies in direct support of the rich context of medical student learning (e.g., which technologies, how within given contexts). New research questions, rigorous methodologies, and valid instruments need to be identified or developed to support evidence-based curriculum reform.

Adoption studies. Research surveying medical educators across the country about technology competencies, level of engagement with technologies, and attitudes toward various technology resources could help clarify the state of readiness to support local and national technology integration initiatives. Results may indicate needs, areas of success and resistance, and faculty professional development opportunities.

Broad understanding. Questions need to be developed like which technologies are being most commonly used across the medical curriculum, which have the greatest abilities to support skill development, which best scaffold development of deep understanding, and how can technologies be best used to encourage self-assessment and ongoing competency development. Taking advantage of the synthesized works in both medical education and educational research may help validate medical education literature, provide better interpretation of findings, and support educational technology decisions. A review might also be conducted to identify the characteristics of best practices of technology uses in medical schools. This includes developing an understanding of medical faculty and student technology competencies. Learnings from this type of review may help establish networks among research and development groups and help in the planning of strategic goals and determine projects ready for larger dissemination efforts.

Methodology, validation, and measurement. This literature rarely presented results related to learning outcomes. To enhance research quality medical educators might seek partnerships with educational technology scholars. These partnerships may enhance questions and lead to the use of previously validated instruments that collect data exploring participant changes in motivation, thinking, recall, and application of new knowledge. These partnerships may also make it more feasible to conduct replication studies across medical disciplines (e.g., surgery, internal medicine, pediatrics), which can extend results and spawn further studies on anomalies.

Conclusions

This research synthesis does not represent all educational technology literature in the medical education profession published over the last decade. There are other efforts at domestic and international medical schools investigating education technology. This chapter focused on synthesizing a broad sample of works that have been published primarily in US medical education journals and key texts over the last decade. The literature is varied; however, rarely have research studies focused on learning outcomes in the presence of technology.

There are many opportunities for educational researchers to engage in this rich environment. Areas on adoption of innovations, support strategies and mechanism for technology initiative, curriculum transformation and leadership, impact of educational technologies on learning, and others are ripe for collaboration and rigorous studies. And, it appears that medical schools are interested in collaborative, multi-institutional studies that align with and support proposed reform themes. Educational technology researchers and developers can certainly add value to, and benefit from, such collaborations and extend the body of evidence suggesting that educational technologies can provide value and change the circumstances of learning, when integrated effectively and efficiently into medical curricula.

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Technology Integration in Multicultural Settings

70

Konrad Morgan

Abstract

This chapter presents an exposition of how multicultural factors influence the design of electronic learning systems to support educational goals and improve learning outcomes for students from diverse cultures. The chapter reviews the specialized literature related to the intersection of the disciplines of multicultural education and instructional design to show how to make best use of instructional settings to support and respect the many cultures that are represented within the modern classroom. The chapter concludes with some suggested future directions for research with a specific recommendation that instructional designers embrace the powerful user configuration features now available in digital and social media to empower learners to modify both technologies and learning environments to support their own cultural learning needs to utilize the affordances available.

Keywords

Culture • Multicultural • Multicultural learning • Individual and group differences • Innovative technologies

The Growing Importance of Multicultural Inclusion Within Education and Learning

Educators in the twenty-first century are faced with learning paradigms that include large diverse student groups that are independent of geographical location and homogeneous communities. Recognition of education as a basic human right, that should be available to all, has transformed educational settings into domains where educators have learners from many backgrounds, countries and—by necessity—diverse cultures. The educator and the instructional designer are faced with a new reality where the learning materials, systems and the innovative technologies used to support individual learning must also respect and support diverse cultures.

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This chapter provides a review of research that addresses this challenge and discusses how emerging technologies can be used to provide engaging and effective learning materials and solutions that are culturally sensitive. One of the emerging solutions to this complex challenge is the ability of the latest technologies to allow users enormous control in configuring the ways in which these systems behave and the ways in which learning materials can thus be self-configured to closely match the cultural expectations of the learner.

How Can Multicultural Education Be Integrated into Learning Situations?

Before discussing the technological aspects of multicultural learning we must examine the pedagogical frameworks that have been developed to address multicultural education. Gay (2010) and McShay (2005) contended that in order for multicultural education to succeed there must be critical considerations in four areas: (a) learner self-knowledge,

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so they understand and respect their own culture; (b) cultural differences, so learners are aware of how the culture of others differs from their own; (c) knowledge of pedagogical skills for diverse learners, so the educator can identify the most appropriate approach to present learning materials; and (d) community involvement practices to reinforce the understanding of different cultures and the importance of respecting them. (For a complete review of culturally relevant pedagogy see Chapter 28 in this volume.)

Technological Learning Solutions Need to Be Culturally Sensitive

Over the past decades researchers have addressed the issue of how cultural differences affect the impact of information and communications technology (ICT) on different user populations. They have shown that the cultural background of a user not only impacts the effectiveness of their use of technology but that use of a culturally sensitive design improves the rated satisfaction and performance of information systems (Chisholm, 1998; Morgan & Morgan, 2003; Munoz, 2002). They have shown this effect in a variety of computer systems but none have a greater impact than in training and education.

Such educational systems are developed with the specific purpose to broaden the users' experience, knowledge and competence. If a clash occurs between the culture of the user and the culture that has been implicitly designed and built into the system, then the user feels alienated very rapidly. Typically, these problems result in users feeling isolated from the system and they often then decide to drop from classes that force them to experience using that system (Drabinski, Clark, & Roberts, 2011).

Ironically, very few educational technologists or designers are aware that they are designing for a specific culture or cultures when they implement a digital learning environment. Many educational technology theorists even have implicit western cultural perspectives built into their models of how users interact using new communication and education technology. This, in turn, affects how an entire generation of educational technology designers view productive interaction methods or what they assume is the basis for all successful learning (Stafford-Levy & Wilburg, 2001).

Often, the users of learning systems are unaware that the reason for their dissatisfaction with a system may be due to the mismatch between the culture that has been embedded within the system they are using and their own experiences and background. The user assumes the problem lies with his or her ability or intelligence and simply withdraws from the class that uses that system. The educator often also assumes a student withdrawal from a class is due to individual preference and the problem of digital culture clash remains hidden (Drabinski et al., 2011).

Multicultural Differences in Digital Learning Systems

Studies such as those of Ferdig, Coutts, DiPietro, Lok, and Davis (2007) provide us with a view of the different perceptions that exist among students with regard to science and science-based education across a range of countries and cultures. Research into cross-cultural differences in attitudes towards technology using the Technology Acceptance Model (TAM) and its acceptance across different countries (Schepers & Wetzels, 2007) found significant differences in acceptance of technology related to the cultural characteristics of nations.

Educators should keep this finding in mind when designing course materials or educational technologies that will be used by persons where a particular technology may have not been well established. An example often found is that the emerging technology of tactile interaction with a screen or touch pad still may not have reached significant market penetration in some regions of the world and students from those regions may struggle with learning situations that have integrated such technologies (Cardoso de Castro Salgado, Sieckenius de Souza, & Faria Leitão, 2011).

Solutions to the Challenges of Supporting Multicultural Learners in Electronic Education

Fortunately, over the past few years there has been growing recognition of the importance of culture in information systems design (Day, 1996) and educational technology (Marinetti & Dunn, 2002; Simons, 2000). Some of these researchers have recognized a need for methodologies to assist pedagogical designers and educators when dealing with multicultural audiences and have proposed design frameworks to help designers respect the cultural difference of their users (Simons, 2000). However, the major challenge for instructional designers seeking to address using educational technology in multicultural settings has been that traditional electronic learning systems were rather inflexible in their user interface and had limited scope for configuring the ways in which learners used the educational materials being presented. If an instructional designer wished to provide more than one method of presenting the user interface or learning materials, it involved extensive reworking of the system and the learning materials (Morgan, 2006). Within the last decade innovative technologies have increasingly allowed for more user control over the user interface and the ways in which learning materials can be presented. As a result, instructional designers are now able to begin addressing Gay and McShay's four multicultural challenges by empowering user self-configuration of a system.

Research Challenges Associated with Emerging Hardware Technologies in Digital Education

Tactile interfaces. The increasing adoption of tactile interfaces on consumer products has caused a small revolution in the ways that learners can interact with technology (Faculty Focus 2nd Annual Survey, 2010). The use of gestures and hand movement in manipulating virtual digital objects has allowed for a much more naturalistic digital environment where biological affordances (Gibson, 1977; Norman, 1999) can be utilized and complex command syntaxes can be replaced with simple finger and hand movements (Price & Rogers, 2004). The research challenge for instructional designers with this range of technologies is that, often, western cultural behaviors have been integrated into the designs. So users are expected to flip virtual pages from left to right and scan text from top left to bottom right of a digital document. Designers then struggle to integrate such technologies to cultures whose languages do not conform to these directional standards, such as Arabic where the written document flows from right to left or some Asian cultures where documents are read from the bottom up. For those students who come from largely oral cultures such interface design metaphors can be very challenging (Gonzalez & Jinyu, 2011).

Gesture and movement. There has also been an emerging technology derived from the gaming console industry for gesture or movement as a form of technology interaction. Such technologies can provide extremely realistic training scenarios and have proven very popular with those learners who have already learned the interaction metaphor from previous game console use. The research challenge for educational designers with this type of interactivity is to design with the realization that in some cultures it is regarded as inappropriate for some users to move their bodies in such a manner that would draw attention to themselves or others (Savin-Baden et al., 2010).

Mobile devices. One of the major changes in technology use for education over the past decade has been the increasing use of mobile devices for providing interactive free roaming information and study opportunities (Looi et al., 2009; Squire & Klopfer, 2007). These include providing and exchanging text, sound and video based materials in real time (Lazzari, 2009) with geographical independence. These capabilities have freed the learner from the confines of a classroom and have made the world a learning environment. However, mobile technologies have also raised challenges for multicultural education where the affordances of time and space independence allow users to share negative materials and comments with alarming ease and speed. There have been well-publicized cases, such as that of Phoebe Prince, in which students have ended their lives tragically because of the misuse of postings on social media sites and the cultural peer pressure that becomes involved. The next generation of instructional designers must find some culturally acceptable mechanism to enforce some boundaries or safeguards to try and avoid such tragedies and misuse of these technologies (Ferdon & Hertz, 2007).

Robots. As we have discussed in the section related to tactile- and gesture-based interaction there is an increasing tendency for the interface between the digital world and physical worlds to become blurred. The other technology that is becoming more widespread as an interaction method is that of robotic entities who can physically or verbally interact with users and move objects in the real world and digital world (Verner et al., 2010). The speech and/or movement of such robots are most frequently seen in the form of interactive toys but there are also educational uses for such tools. The appearance, speech forms and movements that such robots make have quite obvious cultural implications that need extensive further research in order to make these technologies effective in multicultural educational settings.

Research Challenges Associated with Emerging Software Paradigms in Digital Education

Simulation and virtual reality based learning environments. A growing body of research is showing that virtual reality and simulation can provide highly effective means to train students from diverse cultural backgrounds (Tiernan, 2010; Yen & Lee, 2011). Gay's (2010) and McShay's (2005) reviews of diversity training and multicultural educator training suggests that simulations can be useful for training practical skills that can then be applied to any cross-cultural simulation design. This is obviously a highly productive area of research for instructional designers seeking to produce effective multicultural systems.

Social media supporting collaborative multicultural learning. The most dramatic change in educational software paradigms that has occurred recently is the use of social media within the educational process. Many educators are adopting social media tools to engage their students and to enhance open communication within a cohort of learners who may be geographically or temporally distant. These allow groups to develop levels of social cohesion that would be difficult using more traditional methods (Eteokleous, 2011). When the tools such as Twitter and Facebook are integrated into course management software and instructional systems, the effect on motivation can be as these technologies allow the educational setting to become mobile and to fit within the very flexible lifestyles adopted by many students dramatic (Faculty Focus 2nd Annual Survey, 2010).

However, as we have already highlighted in the previous section on mobile technology, there are some risks associated with this technology as it is very hard to control the content that will be posted and how the social groups created by such tools will use the capabilities of the technology. At their best, these tools allow improved communication and an independence from temporal and geographical separation. At their worst, they can encourage bullying and isolation against those who are identified as not being part of the majority culture represented within the online community. Strict codes of user behavior, close monitoring of contributions and interactions, and—most importantly—raised awareness of the importance of respecting those who do not conform to the majority's cultural and behavioral norms are suggested as possible mechanisms to address the dangers of using Social Media in educational settings (Tynes, Garcia, Giang, & Coleman, 2011).

Conclusions

The complex and fascinating areas we have discussed in this chapter are rich with future potential for researchers and for practitioners who are seeking to explore how technology can be utilized to support the goals of multicultural education. Social media combined with the emerging technologies of tactile and gesture interfaces can be used to present real-world, situated learning that is mobile and responds to the immediate learning goals of a wide variety of learners from multiple cultures who can learn not only some relevant skill but also that the world of learning and life is made richer and more valuable by respecting the cultures and values of others.

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Section IX

A Look Forward

M. David Merrill and Jan Elen

This concluding section of the *Handbook* is focused on the future of educational technology research and development. This section comprises four chapters that deal, respectively, with (a) the philosophy of science as it pertains to educational technology research, (b) information and communication technologies (ICT) in developing countries, (c) educating instructional designers and teachers, and (d) fostering research in educational technology. This section, which is new to this edition, is followed by an epilogue that builds upon the Forward by Youqun Ren and Chap. 1 by Joost Lowyck.

In an important sense, this final section of the *Handbook* suggests that the future of the discipline depends on (a) maintaining the scientific integrity of educational technology research, (b) reducing the digital divide using appropriate technologies, (c) developing the next generation of teachers with competence in instructional design and technology integration, and (d) providing sufficient funding support for relevant educational technology research.

The chapter by Cilesiz and Spector presents an argument that research involving educational technologies is influenced by developments in cognitive science, information technology, and psychology, among other disciplines (see also Spector, 2012). The resulting implications for research include a need to broaden scientific approaches to accommodate the fact that technologies are deployed in actual settings, and, as a consequence, inquiry needs to take the natural settings in which those technologies are used into account. An appropriate perspective within the philosophy of science is a constructivist epistemology that is consistent with phenomenological research, both of which are elaborated by the authors in this chapter.

Robert Kozma and Wayan Vota address the issues involved when introducing educational technologies into developing countries. Kozma and Vota note that the prevailing view of many developing countries is that education, especially education well supported by appropriate but inexpensive technologies, is directly linked with economic development and social progress. This echoes a similar conclusion in the chapter by Luschei on educational costs and benefits. Kozma and Vota also discuss policy implications and the need for ongoing research in developing countries.

Ellen Hoffman examines degree programs and the professional preparation of K-12 teachers with regard to competence in designing instruction and integrating technology into learning. She notes that as learning and instructional paradigms have evolved and technologies have proliferated, properly preparing teachers for technology-enhanced classrooms has grown increasingly challenging. While there is little evidence to date of an impact of a systematic approach to instructional design on teachers, there is evidence that teachers can benefit from more knowledge about effective instructional design and technology integration practices.

The final chapter by Martin Oliver about fostering relevant research on educational communications and technology presents an argument for placing priorities on relevant research likely to have a significant impact on teaching and learning. Historically, educational technologists have promised more than they have delivered (Spector, 2012). There is a need to focus research and funding on those technologies most likely to have sustained and measureable outcomes. Likely candidates in the digital age include technologies that foster the development of communities of practice and that encourage participatory design. Specific needs for future

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research and development include ways to improve peer review processes and accelerate the exchange of knowledge about what works when and why. The author also emphasizes the need for design-based research, a topic which is treated in several other chapters in this *Handbook*.

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* An asterisk next to a reference entry throughout this Handbook indicates a reference that the author(s) considers to be central to the topic.

71 The Philosophy of Science and Educational Technology Research

Sebnem Cilesiz and J. Michael Spector

Abstract

Educational technology—the study and practice of using technology to support learning and instruction—is influenced by developments in various fields such as cognitive science, information and communications technologies, and psychology. To address the broad range of questions that make up the domain of educational technology research, a variety of approaches to scientific research are relevant. To facilitate the pursuit of a diverse research agenda relying on various approaches, we discuss scientific research in the domain of educational technology, present three philosophical approaches to scientific research that are relevant to educational technology research (namely, postpositivism, constructivism, and phenomenology) along with examples, and then discuss the larger landscape of approaches to scientific inquiry. With this, we aim to contribute to expanding the domain and diversity of scientific approaches within the discipline of educational technology, thereby informing and improving subsequent educational technology research.

Keywords

Constructivist epistemology • Philosophy of science • Scientific inquiry • Phenomenology • Postpositivist science • Research paradigms

Introduction

It was once noted that educational research has had little impact on improving learning on a large and sustained scale (Suppes, 1978). We believe similar concerns might be valid about educational technology research today. This is why we think it is appropriate to revisit the landscape of scientific inquiry within the context of educational technology research and why we hope that doing so will inform and improve subsequent educational technology research. Philosophy of science raises critical questions that inform educational technology research, including the following:

(a) Is there a proper domain of "educational technology research"? If so, how might that body of research be characterized and distinguished from other bodies of research that might also inform or influence educational technology practice?
(b) What critical features of research are commonly found in educational technology research? What forms of research and scientific perspectives are relevant to educational technology research?

We structure our discussion of the philosophy of science and educational technology research around these two broad questions. First, we attempt to define a domain of educational

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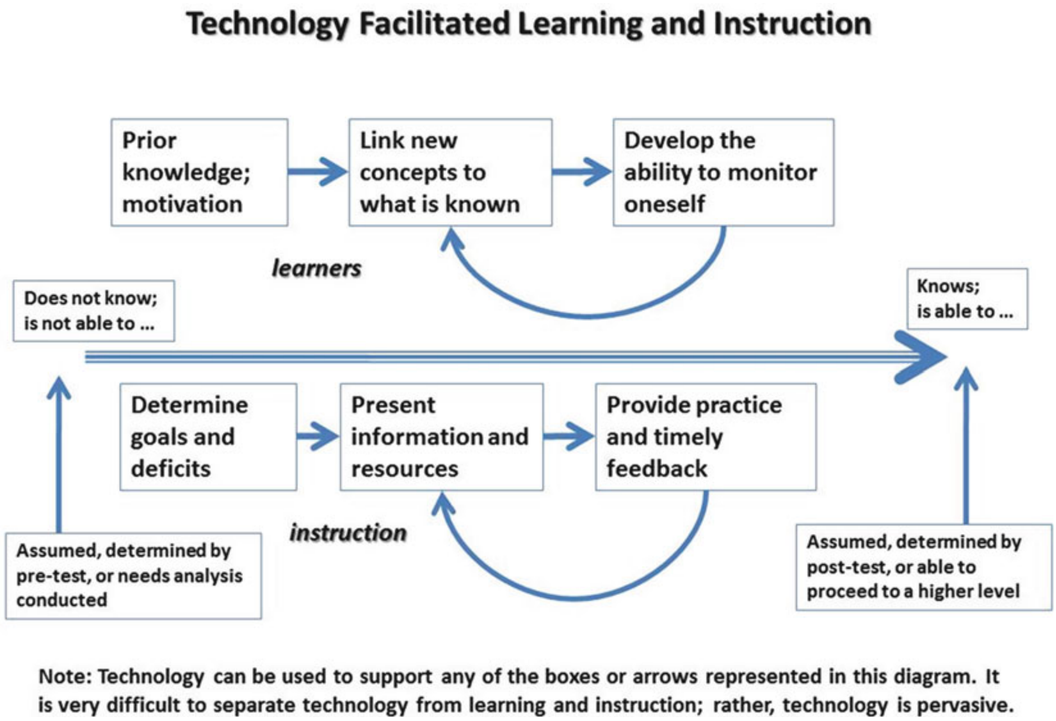

Fig. 71.1 Research on technology in learning and instruction (adapted from Spector, 2012)

technology research and define what constitutes scientific research. Second, we present three philosophical approaches to scientific research that are relevant to educational technology research, including examples. The first two approaches to scientific inquiry (i.e., postpositivism and constructivism) are the dominant approaches to address common research topics in educational technology. The third approach, phenomenology, is chosen as an example of a research approach that is currently not widely used, yet has the potential to address important questions in educational technology. Third, we place these scientific perspectives in the context of the landscape of approaches to scientific inquiry and discuss the current status and future potential for expanding the domain and diversity of scientific approaches within the discipline of educational technology.

We begin by defining the domain of scientific research in educational technology. Educational technology is defined as "the study and ethical practice of facilitating learning and improving performance by creating, using and managing appropriate technological processes and resources" (Januszewski & Molenda, 2008, p. 1). This definition can be interpreted in a number of ways; Fig. 71.1 depicts a provisional attempt to indicate the constructs that might properly constitute the core focus of scientific inquiry in educational technology, specifically research that is directly related to the practice of educational technology. Because one can use technology to support any and all of the boxes and arrows, in this and similar diagrams that represent learning and instruction, one could conclude that the focus could be on the efficacy or usefulness of those technologies. For example, one might use a pedagogical agent to help improve a learner's motivation (see, e.g., Kim, Keller, & Baylor, 2007); educational technology research pertaining to such a virtual agent might involve its impact on student achievement or attrition in online and blended learning environments.

One can conceivably ask many different kinds of questions about a variety of technologies used to support and facilitate learning and instruction. How these questions are formulated, and the approach to and process of resolving these questions depend on a clear definition of and approach to scientific inquiry.

Any discussion of the philosophy of science is related to a discussion of research itself. In the most ordinary sense, research is aimed at answering a question or resolving a problem. This broad definition of research would include a simple Internet search to find an isolated fact, such as the name of the person who wrote a book entitled *The Conditions of Learning*, because it involves an inquiry, an inquiry process, and a resolution. However, whether it qualifies as scientific research depends on how scientific research is defined. Not only is the definition of scientific research complex, but it is further complicated by its association with disciplinary traditions, politics, and historical contingencies. Not surprisingly, in the history of education as academic field, what counts as scientific research has always been contested (Lagemann, 2000); this longstanding contest is echoed in recent controversies surrounding national educational policies regarding the definition of scientific inquiry and its consequences for educational research (Denzin, 2009; Feuer, Towne, & Shavelson, 2002; Howe, 2009). Although it is contested by some (e.g., Denzin, 2009), the definition of scientifically based research provided by The American Educational Research Association (AERA) is used widely in the field. This definition includes eight characteristics: (a) logical, evidence-based reasoning, (b) appropriate methods for the questions posed, (c) observational or experimental designs that provide reliable and generalizable results, (d) data and analysis to support findings, (e) detailed elaboration of procedures used, (f) peer review, (g) dissemination of findings, and (h) access to and replicability of findings (AERA, 2008). This definition may be used widely because it is relatively broad and accounts for the fact that the nature of questions and problems studied are related to the kinds of research appropriate to study them.

Another essential characteristic of scientific research is its communal nature; researchers have questions and present findings that others can use and evaluate. Scientific research is also cumulative and progressive; it has the aim to improve knowledge over time as deeper and deeper insights into phenomena are gained and shared. For an inquiry to be considered scientific it is essential for it to be structured so that others can participate at some point—for example, by replicating the study, by critiquing the findings, or by extending the research in another direction. The notion of publicly accessible discourse is what helps to make science cumulative and progressive. Sharing ideas, which requires commonly understood discourse within a context of commonly understood frameworks, is essential for scientific progress. Thus, accepted ways of talking about the key questions and methods used to investigate those questions are essential for the progress of science.

Scientific inquiry is typically classified into three general types: basic research, applied research, or development research (e.g., NSF, 2012). Basic research questions are aimed at developing a fundamental understanding of new or unusual phenomena with no particular application in mind (e.g., What are the observable limits of working memory and do they vary based on age, experience, etc.?) and are typically explored using experimental research methods. Applied research questions aim to understand the extent to which the means intended to achieve a particular purpose are effective (e.g., To what extent does experience in using an interactive simulation in the domain of environmental planning improve the quality of decision making and problem solving in that domain?). Development research is aimed at understanding the use of particular systems and products, especially those that are new and innovative (e.g., How, when, and why do teachers make use of an option to personalize learning activities in a particular learning support system?). Some development research questions involve feasibility studies while others involve descriptive studies of the use of a new system. Often times, a new system is not used in the field in ways that designers originally envisioned, although this may not detract from its overall usefulness. Most educational technology research falls into the latter two categories—applied and development research. (For an overview of research designs for the most common research issues in educational technology, see Ross et al., 2007).

Research questions in the domain of educational technology can be explored using inquiry approaches that involve the characteristics of scientifically based research according to AERA, NSF, and other reputable sources. The particular approach to scientific research depends on the question asked and the purposes of research. Below we discuss three major approaches to scientific inquiry, which are appropriate for investigating questions in educational technology.

Postpositivist Science

According to this approach to scientific research, also called the hypo-theoretical model, scientific inquiry consists of a cycle involving such elements as (Duschi & Hamilton, 1992; Nagel, 1994; Scriven, 1960):

- Noticing an unusual phenomenon or encountering a new situation with unexplained attributes
- Reviewing relevant research and forming an initial hypothesis to explain the unusual phenomenon or as yet not understood situation
- Testing the hypothesis in some way, taking a closer look at the phenomenon or situation, and refining the hypothesis
- Sharing findings with others, reexamining assumptions and underlying theories, and possibly repeating the cycle

Although scientists may not always strictly follow these steps, but may rather jump from one activity to another or pursue multiple avenues of inquiry in parallel, forming and testing hypotheses are essential to postpositivist scientific inquiry. To clarify the process, let us begin with examining scientific hypotheses. What makes a statement or hypothesis a scientific statement or hypothesis in the postpositivist sense is that one could examine the facts and collect empirical data to determine whether the statement is true or false—put differently, whether the hypothesis was supported of falsified (Popper, 1963). Popper (1963) argued that the notion of falsifiability was a stronger notion than that of verifiability, meaning empirical observations could more easily serve as counterevidence to a hypothesis. This also implies that a scientific claim has to run the risk of being shown to be false or unjustified under public scrutiny. This model of scientific inquiry is referred to as the postpositivist model. In order for scientific progress to occur, there needs to be scientific discourse among people; if two individuals are engaged in an

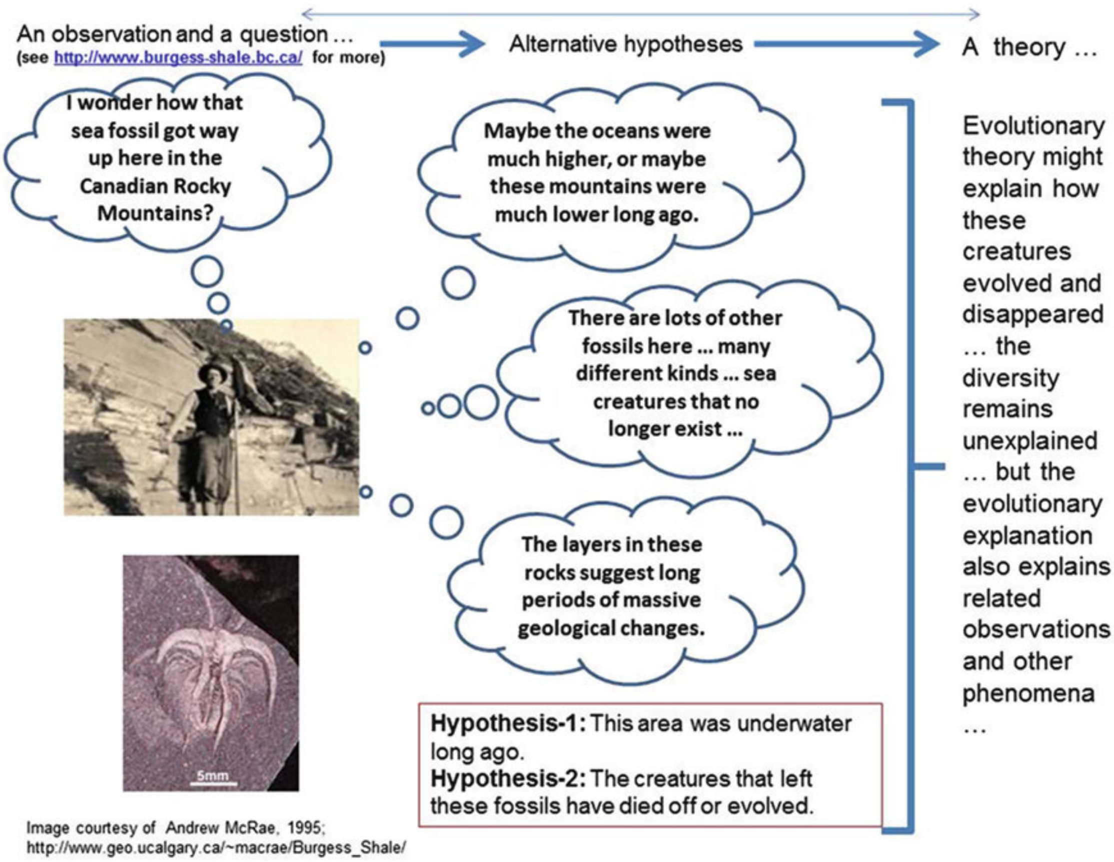

Fig. 71.2 A representation of forming scientific hypotheses (adapted from Spector, 2012)

apparently scientific discourse about something they must both allow any observations to count against their claims. Suppose someone finds unusual fossils in the Canadian Rocky Mountains (see Fig. 71.2).

One might ask how the fossils got there. Another might answer, for example, that God had put them there. Such a response is neither refutable nor verifiable and is therefore not suitable for scientific discourse. For the discourse to be a scientific discourse, a different kind of response is required. Perhaps this matter was not a mountain thousands of years ago, but had been under water in the middle of an ocean. This could raise the question of whether the Earth can really change that radically. Such a possibility is supported by other evidence at other locations. For example, geological evidence suggests that the Grand Canyon did not start out as a canyon a mile deep but that it took millions of years to form. If such changes are possible, then perhaps millions of years ago, the area in which the fossils were found in Canada was under water. For further investigation, the fossils are sent to a reputable and experienced marine biologist, who reports that there is no living creature that matches the fossil. This is additional evidence that the fossil was left behind a long time ago—so long that the species has died off. The claim that species disappear is acceptable as there are familiar examples of endangered species within our common experience today. Carbon dating may provide further evidence that the fossil is very old. In sum, evidence can be collected and observed by a group of investigators to confirm, or potentially refute, the hypothesis in question.

A postpositivist understanding of scientific inquiry assumes that observations and the formation of hypotheses can be objective, provided principles of scientific inquiry are followed. However, values, predispositions, and habits influence the observations we make and the hypotheses we form. Nevertheless, in order to make progress in understanding our world, we need a commonly accepted language to discuss findings and formulate hypotheses, and we need a commonly accepted framework within which to proceed. A constructivist epistemology takes these into account in its approach to scientific inquiry.

Constructivist Epistemology

The terms constructivism and constructionism are frequently used to refer to an epistemology (i.e., beliefs about knowledge and how we come to know) or a learning theory (i.e., a theory about how people learn). In various streams of literature, it is possible to find either word referring to either concept. Adding to the confusion is the fact that these words are sometimes used interchangeably to refer to the same concept. To clarify our focus here, we would like to distinguish between the epistemology and the learning theory. The latter concept is based on Papert's (1980) belief that knowledge is effectively developed through the construction and manipulation of objects, artifacts, or even concepts (for a discussion of constructivism as learning theory in educational technology see, e.g., Duffy & Cunningham, 1996; for an overview of various philosophical perspectives and their relationship to theories of learning see Schuh & Barab, 2007). Here, we use the word "constructivism" to refer to the former concept, constructivist epistemology. Constructivism as an epistemological position is often linked back to Piaget's (1950) basic idea that learners construct knowledge through active involvement with and interpretation of that individual's experiences, as well as to similar positions in the works of Kant and others centuries earlier. Relatedly, social constructionism maintains that reality is constructed through social interaction (Berger & Luckmann, 1967). One foundation for constructivist epistemology can be found in the work of the Austrian philosopher Ludwig Wittgenstein. In the *Tractatus Logico-Philosophicus* (Wittgenstein, 1922), Wittgenstein makes the apparently simple observation that we picture facts to ourselves. We create internal representations of things we experience—especially puzzling things or things we have not previously experienced. We construct internal representations that serve us as interpretations of our experiences. This is something a person does naturally and often without any conscious or deliberate effort, as part and parcel of being human.

The second component of a constructivist epistemology can be found in Wittgenstein's posthumously published *Philosophical Investigations* (Wittgenstein, 1953), in which he introduces the concept of a *language game*. Language games involve rules which a community of users generally accept and follow, and they involve family resemblances between and among terms. Wittgenstein pinpoints forming and testing hypotheses as an example of a common language game in the scientific community. A language game not only creates internal representations of things we experience, but also enables us to talk about those representations with others. Internal representations are thereby externalized, shared, and submitted to the court of public scrutiny. The notion of a shareable language is essential if one is to avoid the solipsism (one can only know one's own thoughts) that is sometimes associated with radical constructivism. What is useful is the naturalistic approach to epistemology found in Wittgenstein and in Piaget, meaning that we naturally and without prompting create internal representations and share them with others in the form of language, drawings, constructed artifacts, and so on. Because this process is ongoing and natural, the focus is on the individual and not the outside environment. Individuals construct internal representations in any learning environment—indeed, in any environment, and they occasionally share them with others regardless of any particular aspects of the learning situation or environment. For educational researchers, what matters is the extent to which those internal representations and the sharing that involves them supports or leads to desired learning outcomes. That is something that can be measured although doing so is not always an easy task (Pirnay-Dummer, Ifenthaler, & Spector, 2010; Spector & Merrill, 2008).

Overall, constructivist epistemology has added alternative insights and a particular way of talking about (i.e., a language game) research in educational technology. Constructivist epistemology is not in direct opposition to earlier accounts of learning and instruction; rather it provides new and insightful ways to discuss core topics in educational technology, such as the conditions of learning. A typical interpretation of Gagné's (1985) work is that effective instruction includes a certain set of events (e.g., gaining attention, reminding learners, stating goals and objectives, presenting information, providing learning support, providing opportunities for practice, providing meaningful and timely feedback, assessing performance, promoting transfer of learning to new situations). A constructivist perspective on this theory would suggest that engaging learners actively in setting goals or asking learners to reflect on and assess their own progress are likely to promote learning. For example, in the product developed around Gagné's nine events of instruction called GAIDA (Guided Approach to Instructional Design Advising) (Spector, Polson, & Muraida, 1993), the nine events are not regarded as a linear sequence or a set of discrete events but characterized in terms of common clusters (set-up, primary instruction, and resolution) that could occur in any order and recur several times within a unit of instruction. While GAIDA was focused on instructional designers and instructors, the rationale provided for the design was most often focused on learners, learning activities, and how what learners did was likely to result in targeted outcomes (Spector et al., 1993).

Constructivist approaches to educational technology research are more explicitly focused on how learning develops within particular learners in various situations, considering all perspectives—the learner perspective, the instructor perspective, and the design perspective—and the interactions among these. For example, evaluating implementations of innovative educational technologies or systems is a rich area of research and overtly aims to integrate the three perspectives (i.e., learner, instructor, and design), and can do so from a constructivist perspective. Thus, we discuss program evaluation as an area of development research in educational technology and provide an example below. At the heart of program evaluation are basic questions such as whether and to what extent an intervention (e.g., an innovative technology or new learning

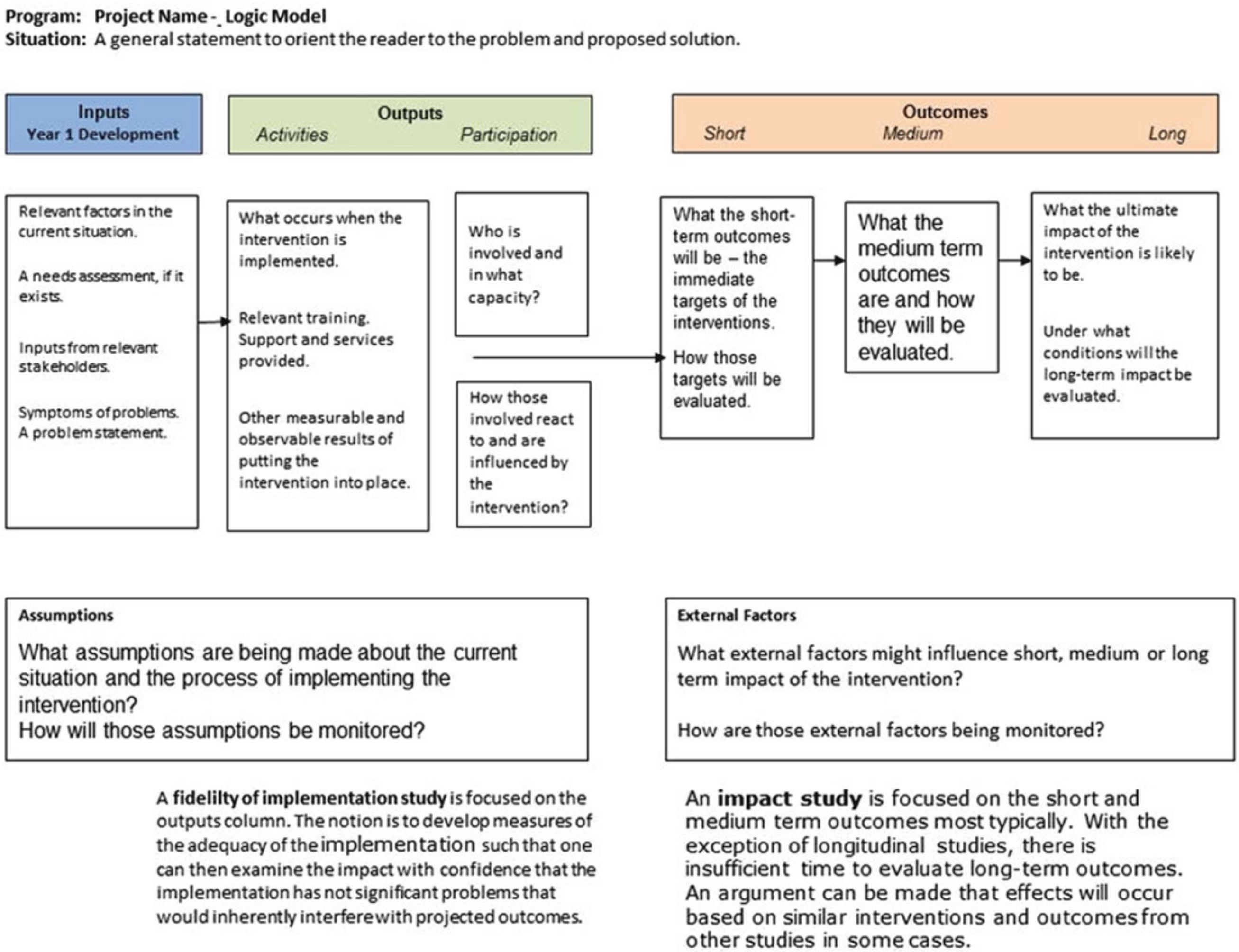

Fig. 71.3 Logic models, fidelity of implementation, and impact studies (adapted from Spector, 2012)

environment or educational system) achieves its intended aims, and why it succeeded or fell short in some way. Within a logic model (see Fig. 71.3), an evaluation study can include a fidelity of implementation study, an impact study, or both.

As Fig. 71.3 shows, a logic model portrays a current situation and the associated problem, implementation of an intervention intended to address the problem situation, and the projected or predicted outcomes and benefits of that intervention if successfully implemented. A theory of change that explains why and how the intervention would lead from the problem state to the desired outcomes is normally associated with a logic model. A fidelity of implementation study could be structured such that the results of the study reflect degrees of successful implementation (as in high, medium, low, or superior, adequate, marginal for such variables as professional development and technology support). Having such data is useful in explaining why (or why not) and to what extent significant differences were found in outcome variables. For additional detail on such studies, see the chapter by Jennifer Hamilton in this Handbook.

We would like to further explain program evaluation through a hypothetical research example. We first describe a development case and then continue on with a fictitious research example (intended for purposes of illustration) that could have been conducted as evaluation research. The setting is the US Air Force Academy (USAFA) located just North of Colorado Springs, Colorado. The time frame is the 1980s. The problem situation is that a large percentage of cadets were changing their major from aeronautical engineering to something else after taking the first aeronautical engineering course. Indeed the second author was a cadet who did just that in 1963, so this situation had been developing for some time. The Academy wanted the majority of its graduates to have a major in aeronautical engineering—that goal was not being met and had not been met for many years. A study was conducted to determine what might account for the massive rate of change in majors after the first course. First, a needs assessment was conducted that included classroom observations and interviews with cadets. The symptom (high rate of changes in major) was linked to the nature of the aeronautical engineering course. It was being taught as a drill and practice class, where students had to memorize formulas and then plug numbers into the formulas to calculate values. In the 1960s slide rules were used for those calculations; in the 1980s cadets had personal computers available, but the reports of boredom with the drill and practice nature of the course did not change.

That analysis led to the conclusion that the course was not motivating or sufficiently engaging for USAFA students. A theory of change evolved that hypothesized that allowing students to design and test artifacts would result in increased engagement and motivation and result in lower rates of change to another major. The implementation that became the focus of the intervention involved a series of increasingly challenging interactive simulations—students formed small groups and designed engines and other aircraft components and tested them to see which ones were the best according to the relevant aeronautical criteria. There was a companion textbook written to accompany the simulation-based learning environment, and all of the components were built into an electronic environment and could be searched by topic, keyword or chapter.

The implementation involved training of all aeronautical engineering faculty on the new learning environment and its intended use. Incidentally, a fire destroyed all of the textbooks before they could be delivered to USAFA. This could be categorized as an external event that might have affected the outcomes. As it happened, there was no known effect on outcomes since the entire textbook was available electronically, in a form more usable than a textbook. Typical assumptions about the timeliness of the delivery, appropriate support and so on were satisfied, although not without enormous effort on the part of USAFA faculty and support personnel. There was an analysis of outcomes, although its results were not formally reported. USAFA uses standardized end-of-course tests and had available approximately 30 years of data on the standardized test for the first aeronautical engineering course, along with a great deal of other information on USAFA cadets over that 30 year period of time. The analysis revealed no significant difference in terms of performance on the end-of-course test of the impact of the new design compared with the previous design. This outcome might be disappointing from the perspective of implementing an innovation. In fact, the test had not been changed to test the kinds of things that might have been learned in a simulation-based problem-solving environment as opposed to a drill and practice classroom environment. However, analysis on the primary outcome—those changing majors after that first aeronautical engineering course—did reveal a significant difference. The course had the desired outcome of dramatically lowering the rate of change for those dropping the aeronautical engineering major.

This development at USAFA had all the aspects of a development research project. The needs assessment was extensive and informed the theory of change based on experiential learning. A fidelity of implementation study would have made explicit the fact that much of the training and preparation occurred with rushed schedules and nonstandard training of faculty. Nevertheless, an impact study would have yielded positive outcomes. Moreover, further research could explore effects on student understanding of complex problems, using a technology such as that reported by Pirnay-Dummer et al. (2010). Then, similar implementations in other subjects as well as at other institutions could be studied. In this way, such a research project would add to the knowledge of what works in various learning situations and satisfy the requirement of scientifically based inquiry to be cumulative. Furthermore, by replicating the implementation at other institutions and with other subjects, the generalizability of the findings could be subjected to public scrutiny, another critical feature of scientific inquiry.

So far, we have reviewed the postpositivist approach and constructivist epistemology as approaches to scientific inquiry that can be used in educational technology research, providing specific examples. Indeed, these approaches can and do address common problems that lie in the core domain of research in educational technology, as we have described above (see Fig. 71.1) (Ross et al., 2007). While important and useful, these types of scientific inquiry do not address all problems relevant to educational technology. Educational technology research is also concerned with some outcomes that are not immediately measurable, such as long-term outcomes; emotional, social, cultural, political, and aesthetic qualities of experiences; and processes of teaching and learning (Parrish, 2009). Views of scientific inquiry that emphasize such foci in educational domains are important additions to established research in educational technology that intends to identify causal relationships, predict, or evaluate outcomes. To give an example of such an approach, we explain phenomenological research below. Phenomenology is especially suited to this chapter due to its origins as a philosophical analysis method. Moreover, phenomenology is a promising approach for the pursuit and advancement of educational technology research (Cilesiz, 2011).

Phenomenological Research

Phenomenology is rooted in the work of German philosopher Edmund Husserl (Husserl, 1969, 1970a, 1970b); other philosophers who built on his work include Heidegger, Merleau-Ponty, Gadamer, Ricoeur, Sartre, and Schutz. Phenomenology originated as a method of philosophical analysis and was consequently applied as research methodology in disciplines such as psychology, nursing, and education. Currently, it is both a philosophical approach and a social science research methodology, founded on a specific (phenomenological) conceptualization of experience (for a depiction of a phenomenological concept of experience see Cilesiz, 2011). In order to conduct a rigorous phenomenological study, one must understand its philosophical underpinnings and presuppositions (Giorgi, 1997), therefore we begin with a brief description of the philosophical foundations of phenomenology.

Phenomenology is based on Cartesian dualism, emphasizing simultaneously that a world of objects exists without humans' consciousness, waiting to be discovered and that the external world is not independent of cognizant minds; from the perspective of phenomenology, conscious subjects and their objects are separate, yet they interact, and meaning can be found in this relationship (Husserl, 1982). Epistemologically, phenomenological inquiry is concerned with the essences of ideas; however, essences are manifested in and can only be known through conscious experience, which has both a material dimension and an ideal dimension. Essence refers to the condition or quality of an experience that is common or universal; it is what makes an experience what it is and without which an experience would not be what it is (Husserl, 1969).

Phenomenological research aims to develop an in-depth understanding of individuals' lived experiences of a phenomenon from the perspective of those who experience it, thereby producing in-depth descriptions of essential structures of the phenomenon. In doing so, phenomenological inquiry aims to obtain descriptions of subjective experience without questioning their causes or whether they correspond to an independent reality. Consistent with this epistemological position, phenomenological research makes it possible to generate plausible insights through direct contact with phenomena rather than aiming at empirical generalizations, establishment of functional relationships, or development of theory with which to predict or control. To do justice to investigating subjective experience, a phenomenological researcher is supposed to have an unadulterated mind, refraining from any judgments about the correctness or falsity of a research participant's claims regarding his/her *lifeworld*, rather engaging in a deliberate, disciplined, and systematic effort to suspend his/her natural standpoint about the phenomenon of study (Husserl, 1969, 1970b).

How does and can the field of educational technology benefit from the pursuit of phenomenological research? In one sense, phenomenology is the study of the *lifeworlds* of individuals, meaning "what we know best, what is always taken for granted in all human life, always familiar to us in its typology through experience" (Husserl, 1970a, pp. 123–124). Technologies, old and new, are ubiquitous elements of modern life and thereby education, thus humans' experiences with technology are part of their lifeworlds. The mundane is the domain of phenomenological research, and most technologies are seamlessly integrated into people's daily lives.v Therefore, investigating people's experiences with technology, both in teaching and learning, and in everyday life, is consistent with the goals of phenomenological research. Examples of phenomenological research in educational technology include studies on adolescents' experiences of educational computer use in informal learning environments (Cilesiz, 2009) and experiences of adult first-time computer users (Howard, 1994). Cilesiz (2011) provides a discussion of the suitability of phenomenology in educational technology research and suggests several research directions for phenomenological research in educational technology. Below, we provide an example of a research scenario using phenomenology to approach an educational technology research topic.

Assume a researcher is interested in understanding the experiences of novice computer users and aims to understand the process of learning to use computers as well as the feelings associated with the process in order to develop proper support programs for such users at a community technology center. The researcher can use a phenomenological philosophical approach and research methodology. First the researcher would suspend his/her presuppositions about novice users' experiences. He/she would avoid drawing on his/her own experiences with learning to use computers, which may have been pleasant and exciting due to availability of material resources and supportive and knowledgeable parents. Likewise, he/she would refrain from drawing on his/her assumptions based on others' accounts of their experiences or knowledge from the academic literature that novice users are supposed to feel anxiety and/or ambivalence about learning to use computers. The researcher would design the study consistent with the philosophical foundations of phenomenology, recruit participants who have significant experiences of the phenomenon, and arrange interviews with them. Once data collection is underway, the researcher would continue to suspend his/her previous knowledge or assumptions about novice computer users so as to be able to hear fully the participants' experiences, avoiding any premature conclusions. He/she would retain a focus on the participants' descriptions of their experiences rather than making factual claims about these statements. For example, the researcher could state that the participants *expressed* anxiety about learning to use computers rather than stating that participants *felt* anxiety about learning to use computers. To the extent that the researcher can record whether the participants were anxious or not, these would have to depend on direct observations, and this type of researcher judgment is not consistent with phenomenological research. The researcher would collect descriptions from the participants, look for shared structural similarities in experience, and would produce a textual description of the essence of the experience of learning to use computers as the output of the study.

Conclusion

This discussion of philosophical approaches for scientific inquiry as it pertains to educational technology research has had three objectives. First, we demonstrated that consideration of philosophy of science is useful in helping to improve scientific inquiry in the area of educational technology. We provided a definition of the domain of educational technology research and described philosophies of science and scientific research as they relate to educational technology; our goal was to evoke consideration of the broad range of questions that make up the domain of educational technology research and the variety of approaches to scientific research available to address these issues. We hope that readers and researchers will be more firmly grounded in the scientific enterprise, recognizing its diversity, and, as a result, conduct more rigorous studies that add to our knowledge and push educational technology research forward. We believe our discussion emphasizing the interrelation between scientific approaches and the types of questions they can address within the domain of research in educational technology can help improve the scientific basis of the field.

Second, to facilitate the pursuit of a diverse research agenda relying on various approaches, we presented three philosophical approaches to scientific research that are relevant to educational technology research—both dominant approaches (i.e., postpositivism and constructivism) and promising approaches currently not widely used (i.e., phenomenology). We also provided examples of the types of research that these approaches could address. Different approaches to scientific inquiry are available and are suitable for different research objectives, and appropriate methods of inquiry (qualitative, quantitative, or a combination) can be identified according to specific research questions (Creswell, 2007; Crotty, 1998; Spector, 2007). Our goal was to demonstrate both the availability of various approaches to science and facilitate the identification of a suitable approach for any given question, thereby enabling researchers to reach their research goals as well as leading to the utilization of a wide variety of approaches in the field.

Our third objective was to discuss the larger landscape of approaches to scientific inquiry in educational technology. Certainly the approaches we have discussed in this chapter do not capture the paradigmatic and epistemological diversity available in scientific inquiry; it is important to place them in the context of the larger landscape of scientific inquiry. Although philosophical orientations of instructional designers and researchers in the field gravitate toward certain approaches (e.g., pragmatic) while being less accepting of others (e.g., critical) (Sheehan & Johnson, 2011), there is nonetheless some variation in approaches to scientific inquiry used in educational technology. In addition to commonly used approaches and methodologies, recent literature has discussed the use of qualitative research in general (Savenye & Robinson, 2004) as well as specific methodologies such as conversation analysis (Mazur, 2004), phenomenology (Cilesiz, 2011), and philosophical inquiry (Koetting & Malisa, 2004) in educational technology. Moreover, there are discussions around more marginal approaches such as those advocating critical theory (Nichols & Allen-Brown, 1996) or poststructuralism (Hlynka, 2004; Solomon, 2000; Yeaman, Hlynka, Anderson, Damarin, & Muffoletto, 1996) as well as those advocating a critical-realist agenda to resist the postmodern agenda (Evans, 2011). Our discussion of examples of scientific approaches as well as the larger landscape of approaches to scientific inquiry in educational technology has the intention of promoting further discussion along these lines. We believe that such discussions are fruitful as they can raise awareness of researchers regarding their contributions to the field and facilitate higher acceptance of a wider range of approaches, which in turn would advance the field as a whole and strengthen its scientific basis.

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ICT in Developing Countries: Policies, Implementation, and Impact

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Robert B. Kozma and Wayan Surya Vota

Abstract

Many countries in the developing world, including the least developed countries, are making significant investments in educational ICT (information and communication technology). Even with extremely constrained financial resources, some countries are purchasing one laptop for every primary or secondary student. This chapter examines the policies and rationales used by governments to justify these investments, the issues involved in the implementation of ICT in developing countries, and the available research on the impact of ICT investments. Policy documents from a range of developing countries are analyzed to identify key policy goals and the implementation programs authorized to accomplish these goals. The rationales include the use of educational ICT to support economic development, social progress, and education reform. Field reports from developing countries are analyzed to describe sometimes unique implementation challenges related to infrastructure, maintenance, contents, and teacher training, as well as the efforts used to address these challenges. Such challenges include limited electrical or Internet infrastructure in rural areas, limited availability of technically skilled support staff, the predominance of minority languages, and underqualified teaching staff. And finally, the chapter reviews research on these ICT efforts, including descriptive studies, classroom practice studies, and impact research. The chapter makes some concluding remarks about the current status of ICT in developing countries and research needed to determine the contribution ICT will make in these countries.

Keywords

ICT policy • ICT impact • Economic development • Education reform • Research methods

Introduction

Educational ICT (information and communication technology) in developing countries has generated a significant amount of interest in recent years, in large part due to the One Laptop per Child program (OLPC) and what used to be called the "$100 dollar computer".[1] Among the more controversial claims made by Nicolas Negroponte, Massachusetts Institute of Technology professor and the intellectual godfather of OLPC, is that by providing an inexpensive laptop for every child, a country can address its educational needs, combat poverty, and contribute to economic development.[2] On the

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[1] Initially targeted at $100 the OLPC XO machine cost at its introduction was approximately $175. http://www.olpcnews.com/sales_talk/price/laptop_olpc_xo_price.html

[2] http://www.zdnet.co.uk/news/it-strategy/2006/12/05/the-100-laptop-could-eliminate-poverty-39284994/

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power of this claim and the backing of key international figures, OLPC has established a presence in many developing countries. According to OLPC's Web site,[3] 38 developing countries are implementing OLPC or experimenting with their XO hardware and Sugar operating system. Peru and Uruguay are the largest implementers, currently deploying 870,000 and 510,000 XO computers, respectively.

Although OLPC's XO machine has gotten the most press, it is not the only program focusing on ICT in developing countries. There are now over 30 low-cost ICT devices available (Vota, 2010). And there are many other national and international initiatives that are supporting the use of computers to improve education in the developing world, sponsored by multinational organizations or private corporations. Often, these initiatives go beyond the mere introduction of computers and address other educational issues, a concern generally ignored by the OLPC program.[4] For example, World Links for Development,[5] stared at the World Bank, emphasizes both the availability of computers in schools and changes in educational practices, such as those focused on student projects and cross-school or even international collaboration. Intel's Teach program[6] focuses more on teacher's skills in integrating technology into the curriculum than on increasing the number of computers.

Within this context, even the least developed countries, such as Namibia and Rwanda, are making ICT in schools a top policy priority, despite extremely limited resources at their disposal. By comparison to Singapore, for example, with a GDP of US$ 182 billion and a per-capita GDP of $36,500, Namibia has a GDP of US$ 9.2 billion and a per capita GDP of US$ 4,267. Rwanda has a GDP of US$ 5 billion and a per capita GDP of US$ 506. Developing countries see ICT investments as a way to increase the quality of teachers, to enable more students to access educational services, or to better prepare them for a globally competitive economy. However, a critical question remains as to whether the cost-benefit ratio is sufficient, given limited resources. This question has implications for policy goals, implementation considerations, and research on impact and cost.

The purpose of this chapter is to explore the potential benefits and the challenges that ICT holds for education in developing countries. The chapter begins by examining the educational ICT policies of a select sample of developing countries in Africa, Latin America, and the Middle East. This first section analyzes policy documents to lay out the rationale that these governments have used to support the investment in educational ICT. It describes the structure of these policy documents and the programs they craft to implement policy priorities. The subsequent section describes the range of challenges and costs that confront developing countries in their effort to implement ICT in their school systems, again referencing the experiences of a range of countries. The next section reviews the limited research available on the use and impact of ICT in developing countries. The final section summarizes the previous sections and presents some concluding observations and recommendations for those countries contemplating the use of ICT in education.

Educational ICT Policies in Developing Counties

The underlying premise of OLPC is that the connection between the child and the tool is important; giving children powerful tools will enable them to develop their creativity and generate creative products (Papert, 1993). From this perspective, policy may seem irrelevant to the relationship. But policy is the mechanism by which countries set their priorities and goals and establish programs intended to realize these goals. Recently, there have been a series systematic reviews published of national ICT policies in education; many of them include policies from developing countries. Farrell and Issacs (2007a, 2007b) conducted a survey of the educational ICT policies in 53 African countries for the infoDev program of the World Bank. These reports use a common analytic format to provide detailed descriptions of each nation's policy status. At the time of the report, 36 of the 53 countries had national ICT policies in place and 12 had policies under development. Only 5 of the 53 had no national ICT policy or no plans underway, at the time. Of the 48 countries that either had a national ICT policy in place or were in the process of developing one, 39 of them had education sector ICT policies and plans in one form or another or were in the process of developing them. Another infoDev-sponsored survey of educational ICT was conducted by Gaible (2009), who also used a common format to describe the policies and programs of 16 Caribbean countries. infoDev and Price, Waterhouse, and Cooper (2010) conducted a study of ICT in India and eight other countries in south Asia. They give a brief description of the ICT policy for each of these countries.

Law, Plegrum, and Plomp (2008) have brief descriptions of the educational ICT policies of the 22 educational systems participating in their IEA study on ICT use in classrooms. Among them, only Chile, Thailand, and South Africa are developing countries. In another IEA-sponsored report,

[3] http://one.laptop.org/map; accessed March 14, 2011.

[4] http://www.olpcnews.com/use_cases/education/one_laptop_per_child_education.html

[5] http://www.world-links.org/

[6] http://www.intel.com/about/corporateresponsibility/education/programs/intelteach_ww/index.htm

Plomp, Anderson, Law, and Quale (2009) systematically review educational ICT policies of a larger set of 37 countries, using a common format across countries, similar to the format in the Farrell and Issacs report. Most of the 37 are developed countries but the review also includes policies in Brazil, Chile, the People's Republic of China, India, Malaysia, Philippines, Thailand, and South Africa.

A recent, UNESCO-sponsored report (Kozma, 2011c) focuses on ICT as a transformational lever in education. The report includes in-depth case studies of policies and programs in five countries, four of which are developing countries: Jordan, Namibia, Rwanda, and Uruguay (Singapore is the fifth country). This study is featured in this section.

Policy Rationales

A variety of rationales motive government investments in educational ICT. Kozma (2008) identifies three most often used by governments to justify the use of ICT: economic development, social progress, and education reform.

Economic development. Economic development is the most frequently used rationale for educational ICT investment. A major economic goal for most countries and especially developing countries is sustainable economic growth. Governments often argue that by placing networked computers in classrooms and including ICT in the curriculum, students will be better prepared for the globally competitive knowledge economy. But a key challenge for this policy approach is the articulation of specific ways that the educational deployment of ICT can advance these economic goals, lest the connections between the two are mere hollow platitudes. This is a particularly challenging task for developing countries, which participate only peripherally in the global economy and which are the least able to generate sustainable growth, for lack of capital, infrastructure, and human resources (Sachs, 2005).

All five of the case studies in the Kozma (2011c) book site economic development as a rationale for ICT investment (Alnoaimi, Hinostroza, Issacs, Kozma, & Wong, 2011). Singapore is an obvious example of a developed country that has used education policy and ICT to advance economic development (Wong, 2011). But Jordan (Alnoaimi, 2011) is an excellent example of the use of this rationale for developing countries. In 2002, King Abdullah II of Jordan issued the "Vision for the Future of Education in Jordan" in which education and the ICT sector would play a strong role in developing the economy of the country. Jordan has invested heavily in its education system and in its human resources with a strong emphasis on enabling a more ICT-friendly and technology aware population. The Ministry also launched the Education Reform for the Knowledge Economy (ERfKE), which has a strong emphasis on ICT.

Rwanda (Issacs, 2011b) also used the economic development rationale in the formulation of its educational ICT policy. The draft ICT policy of Rwanda, published in 2009, aims at developing a workforce equipped with ICT skills needed for employment and use in knowledge-based economy. This builds on Rwanda's *Vision 2020* document which was endorsed in 2002. One of its key objectives of the Vision is to transform Rwanda into a middle income economy with a per capita income goal of $900 USD by 2020. It also aims to develop Rwanda into a knowledge-based service hub in the African region, with high levels of savings and private investment.

Social progress. Other countries have focused more on the potential social impact of ICT and governments have justified ICT investments with policies that promote their use to make knowledge accessible to the broad population, foster cultural creativity, increase democratic participation, make government services more widely available, and enhance social cohesion and the integration of different cultural groups and of individuals with different abilities. Within education, socially oriented policies offer the prospect of student access to specialized educational services, the delivery of educational services to remote populations, increased parental participation, and connections between classrooms across cultures. As with the economic rationale, the key is to articulate specific ways that educational ICT can support these broad social goals.

Uruguay (Hinostroza, Jara, & Brun, 2011) is an excellent example of a developing country that used this rationale. An important driver of Uruguay's educational ICT, OLPC initiative—*Plan Ceibal*—was to bring equity in knowledge access that leads to equitable economic development. An important part of Uruguay's ICT policy is to provide all teachers and students in primary and, ultimately, secondary schools with personal laptops. In line with equity goals, the policy began by placing laptops in rural areas, those with least access to computing, and moved to the urban areas.

Namibia is another example of ICT policy motivated, in part, by social development issues (Issacs, 2011a). Through its education policy, the government endeavors to establish an education system based upon the principles of access, equity, quality, and democracy. The nation's educational ICT policy envisages ICT literate Namibian citizens, capable of participating in the new economies that emerge from ICTs and related developments. The goal is to leverage ICTs to facilitate teaching and learning, improve the administrative and management efficiency of the education system, and broaden access to quality educational services for all.

Education reform. ICT can play a particularly important role in supporting education reform and transformation (Kozma, 2011b; Means & Olson, 1995; Means, Roschelle, Penuel, Sabelli, & Haertel, 2004). Investments in ICT have been used to support major curriculum revisions, shifts in pedagogy, and assessment changes. The kinds of education reforms that have been associated with the introduction of ICT include curriculum reforms that emphasize high levels of understanding of key concepts within subject areas and the ability to apply these concepts to solve complex, real-world problems (Bransford, Brown, & Cocking, 2000). Other curriculum reforms emphasize what are sometimes called "twenty-first century skills," qualities that prepare students for the knowledge economy, such as creativity, information management, communication, collaboration, and the ability to direct one's own work and learning (International Society for Technology in Education [ISTE], 2007; Partnership for the 21st Century, 2005; Trilling & Fadel, 2009).

The emphasis in Jordan's policies is on both economic development and education reform, as implied by the name of their reform effort—Education Reform for the Knowledge Economy (ERfKE). Jordan's education reform is systemic, covering not only ICT but teacher professional development, curriculum and pedagogy, and assessment reform. The outcomes-based curriculum reform is moving toward a convergence with international standards in terms of basic skills, critical thinking, problem solving, decision making, numeracy, communication skills, managing information, learning continuously, entrepreneurship, adaptability, teamwork, innovation and creativity. And the assessment reform aims at measuring *knowledge economy skills*.

Multiple rationales. Apparent in the analyses above is the fact that these rationales are not mutually exclusive and are often mutually reinforcing. Many countries connect ICT policy to combinations of education reform, economic development or social development. For example, as noted above, Jordan combined ICT, education reform and economic development. Uruguay combined economic development and social development, as did Namibia and Rwanda. However, there was often a logical gap between the policy rationale—be it economic, social, or educational—and the specifics of its implementation. It is not clear from the policy formulations how it is that investment in ICT will lead to economic prosperity or social progress.

Policy Structure

Educational ICT policy can be structured quite differently from country to country. In some cases, the policy is located outside the Ministry of Education, such as in Uruguay where the policy was launched by the country's President and implemented by an authority separate from the Ministry. Sometimes the policy is integrated into an overall national economic or ICT policy, such as in Rwanda. In other countries, such as Jordan, ICT policy is integrated into a larger educational policy. And sometimes, as in Namibia, there is a separate educational ICT policy or master plan. Across all of these arrangements, there are components that are often common. In many of these cases, the policy serves two important purposes: to offer a vision and to provide programs and resources that would realize this vision.

Vision. Educational ICT is often part of a larger vision articulated for the nation's future. A country's policy vision often articulates the intended impact of the policy on the educational system and all its beneficiaries, including students, teachers, and parents, as well as its impact on the economy and society at large. This vision is often provided by a high-level national official who is the champion of the initiative and who situates the effort in a historical, cultural, political or economic context. In Uruguay and Rwanda, the country's President provided such a vision. In Uruguay, President Vázquez launched *Plan Ciebal* to provide a computer for each child and teacher, with the long-term purpose of promoting social justice and ensuring equal access to information and communication tools for all (Hinostroza et al., 2011). In the context of recovery from civil strife, Rwanda President Kagame provided a vision in which ICT is a tool to increase access to formal and informal basic education, improve the quality of education and promote independent and lifelong learning (Issacs, 2011b). In Jordan, it was the King who provided the vision. King Abdulla II envisioned a future in which Jordan's citizens have the knowledge, skills, and a lifelong learning capability to make the economy competitive in the global marketplace (Alnoaimi, 2011). Often the vision is often somewhat vague but serves as a motivator and catalyst for the more specific work of hammering out programs and resources that are need to make the initiative succeed.

Programs, and resources. The policies in developing countries cover a range of programs and resources designed to implement policy visions and priorities. Most often, they focus on infrastructure—hardware, networking, and software. Uruguay's *Plan Ceibal* initially focused on providing laptops to 362,000 primary school children and 18,000 teachers. More than 1,400 educational institutions have been connected to Internet and more than 3,000 hotspots, or Wi-Fi zones have also been deployed. Jordan's implementation program has focused on improving the student-to-computer ratio in each school, as well as providing other ICT related equipment.

But programs can also focus on teacher professional development, curriculum, and pedagogy. The Rwandan Ministry of Education and the Global eSchools and Communities Initiative developed a teacher training framework based on *UNESCO's ICT Teacher Competency Standards* (UNESCO, 2008). ICT policies sometimes limit curriculum considerations to computer science or ICT as a subject. The ICT policy in Namibia identifies three aspects to the role of ICT in the curriculum: ICT literacy skills, the study of computer science and advanced technical skill, and cross-curricula ICTs (Issacs, 2011a). Jordan is moving their curriculum toward international standards related to basic skills, critical thinking, problem solving, decision making, numeracy, communication skills, managing information, learning continuously, entrepreneurship, adaptability, teamwork, innovation and creativity.

Education ICT Implementation in Developing Countries

Implementation Challenges

When it comes to actually implementing the programs envisioned by policies, there are a number of challenges faced by all governments but particularly those in developing countries. These challenges include:

- Deploying ICT infrastructure
- Maintaining systems at the school level
- Training teachers on the usage of ICT in the classroom
- Developing relevant content
- Leveraging community inclusion to expand impact and sustainability
- Covering the total cost of ownership of ICTs

Deploying ICT Infrastructure. At the very least, ICT needs to be installed in a school in order for it to be used by teachers and students. This may seem simple, but in countries where road infrastructure is poor, not all schools are mapped, and where student populations are not precisely known, just finding all the schools and delivering the right number of computers to each can be problematic (Zimmerman, 2008). In addition, many schools in the developing world do not have electricity, do not have secure ICT storage facilities, and do not have Internet access or local ICT knowledge to support systems once in place (Farrell & Issacs, 2007a).

Peru's Una Laptop Por Niño program is a great example of infrastructure challenges. The laptops were to be deployed only to schools with electricity, yet at least 5 % of the schools that received laptops with the expectation they did have electricity, did not (Santiago et al., 2010). Many more schools were noted as having electricity did not have adequate electrical systems to handle the simultaneous charging of every student's laptop, e.g., one electrical outlet in the principals' office for example.[7] On top of this, only 1.4 % of the schools had Internet access (Santiago et al., 2010).

ICT Maintenance and Support. Once installed, ICT requires ongoing maintenance and support to ensure its proper functioning in the school environment. Peru's geography—from the Pacific Ocean, across the Andes Mountains, and into the start of the Amazon—created a logistical barrier to regular maintenance visits and support service that is compounded by Una Laptop Por Niño's focus on the more remote and underprivileged schools. In fact, it often takes 3 months just to ship spare computer parts from the capital, Lima, to regional computer repair centers.[8] Yet even Uruguay, which is one-seventh the size of Peru and has much better infrastructure, encountered maintenance issues. A 2010 study by Centro para la Inclusión Tecnológica y Social (CITS) found that 27 % of all laptops were unusable at any given time due to breakage, security locks, data storage issues, or being repaired.

In Paraguay, ParagrayEduca has an innovative solution to ICT maintenance. A repair team visits each school on a weekly basis and laptops with minor issues are repaired on the spot while major repairs are done offsite. All issues are logged to accurately track problems and solutions and fed back into the teacher training program, significantly enhancing the maintenance and repair process. Broken computers are offline for less than 1 week on average.[9]

Teacher training. The challenges in educational ICT deployment do not stop once the technology is in the classroom. Training teachers in the operation of the computers and their use in their teaching is as challenge as it is necessary. In Macedonia, the US Agency for International Development (USAID) began teacher training prior to the computers arriving in the schools. Training was comprehensive: 14,000 primary and secondary-level teachers from all 460 schools received training in basic computer use, and then in how to effectively and creatively utilize the technology in their classrooms and pedagogy. Local teachers became master trainers and teacher trainers, progressively advancing skills-development courses were offered, ranging from basic ICT skills classes aimed at enabling teachers with basic technical computer skills, to trainings aimed at integration of the technology into the curriculum. Yet Hosman and Cvetanoska (2010) found that 2 years later, 65 % of teachers had not used computers in the classroom in the 2 months prior to the study. An astounding 44 % of the teachers reported that they had never used computers in the classroom, although they reported using ICT in preparing teaching materials and tests (72 %) and for lesson-planning (63 %). Teachers cited both a lack of training and relevant content for the underutilization of the ICT infrastructure.

[7] https://edutechdebate.org/olpc-in-south-america/will-paraguayeduca-scale/

[8] http://edutechdebate.org/olpc-in-south-america/olpc-in-peru-one-laptop-per-child-problems/

[9] https://edutechdebate.org/olpc-in-south-america/will-paraguayeduca-scale/

One approach to increase ICT usage by educators is to engage teachers from the onset. In India, the IT@School program starts with the existing teacher training structure—student teachers are trained on how to use ICT to enable learning even before becoming teachers, and the training is augmented through in-service training with master trainers, who are themselves practicing teachers. With over a decade of trained teachers now in the classroom, there is already a critical mass of ICT-empowered educators.[10]

Electronic Content. Even with trained and motivated teachers, educational ICT deployments require locally relevant content and curriculum for both teachers and students. Content is a challenge, regardless of the medium. Of 19 countries analyzed in a World Bank (2008) study on secondary schools, only Botswana reports adequate textbook provision at close to a 1:1 ratio for all subjects and all grades. In the other 18 countries secondary textbooks were in seriously short supply for most. This shortage is magnified in educational ICT deployments by the relative newness of ICT tools, the complexity of digital content creation, and the overall lack of digital content in local languages (Unwin, 2007). For example, the Wikipedia's article count by language shows millions of English language articles, but the 8 million people Xhosa speakers—20 % of South Africa's population—are served by only 118 articles in their language.[11]

Faced with this challenge, Uruguay and Jordan have taken two different approaches. In Uruguay, Plan Ceibal is developing ICT content for teachers to use and encouraging teacher-produced content. Plan Ceibal developed Canal Ceibal, a special television program on using ICT for student learning.[12] The program is broadcast over the cable network and uploaded to YouTube. Teachers and third-party educational providers can submit their online resources, games, videos, tutorials, and guides to Plan Ceibal's educational portal, a collection of over 500 different objects vetted for quality and relevance. A staff of 180 at a newly created content group coordinates all of these activities.

In Jordan, the JEI supported the development of e-curricula for math, science, Arabic, EFL, civics, and ICT through a public-private partnership model that built the capacity in Jordanian ICT companies to develop educational software aligned with the national curricula. The Ministry of Education set content targets and JEI worked with private sponsors and developers, and a Ministry curriculum team to create the digital content. The result was EduWave, a national e-learning platform to supplement the national curricula and textbooks (USAID, 2007).

Community Engagement. In Jordan, the JEI shows how the private sector can be engaged to support educational ICT deployments. Forty-seven global organizations partnered with the Ministry of Education to develop the EduWave e-learning environment and equip 100 "Discovery Schools" with additional educational ICT resources (Khatib, 2007).

In Paraguay, ParaguayEduca, started as an independent Paraguayan civil society organization to promote educational ICT. Through its success with a pilot OLPC program, ParaguayEduca now has an agreement with the Ministry of Education to comanage a 1:1 deployment of almost 10,000 XO laptops and the development of educational resources and training programs tied to the national curriculum system.[13]

In Uruguay, Red de Apoyo al Plan Ceibal (RAP Ceibal) supports Plan Ceibal's implementation by educating parents and community members on the benefits of educational ICT and supporting computer repairs at local schools.[14] RAP Ceibal is unique in that it is an informal community of local groups that were not formal members of the educational community before Plan Ceibal. Yet, it is already expanding public Internet access for students and created a SMS-based support system for quick responses to computer issues.[15]

Overall Cost. But perhaps the most challenging of all for developing countries is managing the costs of their ICT investments. As the cost of personal computers has dropped, the overall cost of deploying educational ICT on a national level has also decreased. Yet beyond doubt, hardware and software are not the largest costs in educational ICT deployments. Support and training are recurrent costs that are two of the largest educational ICT deployment costs, greater than hardware and software (Vital Wave Consulting, 2008). This can best be seen in an analysis of Total Cost of Ownership (TCO) performed by Vital Wave Consulting (2008) for several types of computer configurations in Indian schools. Regardless of the type of computer hardware or software deployed, the TCO was a relatively constant $2,800 per computer over 5 years due to the labor costs involved in educational ICT deployment.

The cost of Uruguay's Plan Ceibal technology was just $276 per computer, but at 400,000 computers, that's $110 million in aggregate.[16] Anecdotal evidence shows that whichever costs are included, the overall cost is significant. Jordan's

[10] https://www.itschool.gov.in/glance.php

[11] http://meta.wikimedia.org/wiki/List_of_Wikipedias

[12] http://ceibal.edu.uy/Portal.Base/Web/VerContenido.aspx?ID=203113

[13] http://www.paraguayeduca.org/

[14] http://rapceibal.ning.com/

[15] https://edutechdebate.org/olpc-in-south-america/olpc-in-south-america-an-overview-of-olpc-in-uruguay-paraguay-and-peru/

[16] http://idbdocs.iadb.org/WSDocs/getDocument.aspx?DOCNUM=2162969

ERfKE was a $380 million program manly sponsored by the World Bank and other donors. The Jordan Education Initiative was an additional $6 million from the Jordanian government and $25 million in cash and in-kind services from the private sector to support 100 schools (Khatib, 2007).

Unfortunately, the World Bank notes that there is still very little data on the total cost of ownership for computers in developing-country contexts.[17] This makes it difficult for governments to adequately plan and budget for their ICT initiatives. Often developing countries must rely on external funds to support their efforts. Alnoaimi et al. (2011) noted that Jordan, Namibia, and Rwanda were all relying on external donors to finance their ICT plans. Private partners can also play a role in supporting these efforts, as they did in Jordan. Intel, Microsoft, Cisco, and HP all have international programs to support ICT development in schools and well as educational improvement.

ICT Research in Developing Countries

If developing countries can craft policies, mount challenges, and find the budgets, the question remains as to whether they achieve the desired impact on their education system, economy, and society. The impact of computers has been studied extensively for many decades in developed countries and an extensive literature amassed on the impact of ICT on teachers and students. The volume of this research has enabled reviews (European SchoolNet, 2006; Kozma, 2005; Zucker & Light, 2009) and meta-analyses that provide a comprehensive picture of the results of using ICT in schools (Means, Toyama, Murphy, Bakia, & Jones, 2009; Tamim, Bernard, Borokhovski, Abrami, & Schmidt, 2011). However for a variety of reasons, there is still a paucity of research studies on the educational impact of ICT in developing countries (Tolani-Brown, McCormac, & Zimmermann, 2009). The work of Fraj, Al-Quraan, Al-Dababseh, and Al-Obaidy (2010) in Jordan, Rosa et al. (2002) in Chile, and Bannerjee, Cole, Duflo, and Lindenn (2007) in India are among the few.

The dominant literature on educational ICT in developing countries is focused on the evaluation of large-scale ICT programs or initiatives and the results appear in the form of reports or conference presentations, rather than peer-reviewed journal articles. Wagner (2005) presents a conceptual model for planning the evaluation of ICT-based initiatives that maps onto the developmental trajectory of the project from implementation of the program, to its immediate influence on teacher and student practices, to impact on student learning, and ultimately to its long-term social or economic impact. The preponderance of evaluations is at the descriptive implementation end of this continuum, with few studies of the impact on student learning and none on the long-term impact.

Descriptive Reports

The infoDev reports are typical of many descriptive reports focusing on ICT use in developing countries. For example, the infoDev and Price, Waterhouse, and Cooper reports (2010) on ICT in South Asia describes the ICT initiatives and programs in each of the countries and then analyzes regional trends across these countries. The infoDev study in the Caribbean (Gaible, 2009) parallels the South Asian report. InfoDev also commissioned a preliminary evaluation of the NEPAD (New Partnership for Africa's Development) e-schools demonstration project (Farrell, Issacs, & Trucano, 2007). While not quantitative, the study did go beyond mere description to make a preliminary assessment of the project, as it was implemented in six schools in each of 16 African countries, based on a series of internal reports provided to the e-Africa Commission as part of the evaluation and monitoring process. In short, the report found that the implementation of ICT in the NEPAD e-schools took much longer than expected, particularly in some countries, due in large part of a lack of both human and fiscal resources.

Impact on Teacher and Student Practices

Most studies that go beyond mere description focus on the availability of ICT or the impact of ICT-base programs on the ways or extent to which computers are used by teachers and students. For example in an evaluation of the World Links program, Kozma, McGhee, Quellmalz, and Zalles (2004) surveyed teachers and students from schools in 16 developing African and Latin American countries. They found that World Links teachers and students more likely than nonparticipating teachers who also had access to computers to use computers to engage in a wide variety of new pedagogical practices, such as conducting research projects, gathering and analyzing information, and collaborating on projects with students in other countries. World Links students were also more likely than computer-using students in non-World Links schools to use a variety of technologies, such as e-mail, search engines, and the Internet.

Light, McMillan Culp, Menon, and Shulman (2006) evaluated Intel's Teach program, a corporate responsibility initiative to develop teachers' skills in integrating technology-rich, project-based learning activities into their teaching.[18] Launched under another name in 1989, the pro-

[17] http://www.ictworks.org/tags/michael-trucano

[18] http://www.intel.com/education/teach/index.htm

gram has since involved nine million teachers in over 60 countries. The researchers analyzed surveys of 11,780 teachers from 17 countries who had participated in the program; 12 of the 17 were developing countries. A significant number of teachers across regions reported a change in teaching practices, such that the teachers integrated student technology-based activities into their teaching. The program also resulted in an increased use of technology by teachers for lesson planning and preparation. However, there was a significant interaction such that teachers from the more-developed countries were more likely to integrate student technology activities in their teaching and more likely to use project-based approaches. Conversely, teachers from less developed countries had less access to technology and it made it more difficult for them to implement or sustain technology-rich activities after training.

Cervantez, Warschauer, Nardi, and Sambasivan (2011) examined the ways low-cost laptops were being used in Mexican classrooms. Through observations and interviews with teachers and students in five Mexican schools—2 high-SES and 3 low-SES schools—that were participating in laptop programs—either the OLPC XO computer or the Intel ClassmatePC computer—although not in a strict one-to-one mode. They found that schools changed their teaching and learning practices only after the infrastructure was in place and teachers had enough technical and pedagogical support. In low-SES schools, both those using XOs and ClassmatePCs, much more effort was needed to build an infrastructure that enabled students to access learning environments they had no access to otherwise.

Santiago et al. (2010) conducted the first phase of a multiyear study to examine the impact of the use of the OLPC XO computer in Peru, the country with the largest participation in that program. In what constituted a baseline study for a longitudinal evaluation, the researchers examined installation and teachers' and students' use of computers less than 3 months after the computers were distributed. Data were collected from qualifying schools that were randomly selected for first year participation, as well as schools that qualified but were not selected. In a quantitative study, 98 % of the treatment schools received computers and in 89 % of these, at least one teacher had received training on their use. While 95 % of the schools had electric power, only 1 % had Internet access. In observed classes, laptops were being regularly used between three times a week and daily but used within traditional teaching practices. There was a tendency for student to use the computers to transcribe texts from notebooks or chalkboards to their laptops. In the quantitative study, there was a trend that pedagogical uses decreased among those teachers who had been working with the computers for a longer period of time in their classroom; 69 % of the teachers who had the computers for less than 2 months used them 3 or more days per week while only 40 % of teachers who had the computers longer use them that often.

Impact on Student Learning

A very small number of studies in developing countries report the impact of ICT on student learning. Generally, it is the more established programs which have been in operation longer that report these results. Often these studies measure teachers' opinions about the impact of ICT on their students' learning. In the evaluation of World Links, Kozma et al. (2004) found that both participating students and teachers often than nonparticipating teachers and students reported that students learned communication skills, knowledge of other cultures, collaboration skills, and Internet skills. In addition to these self-report data, a connected study (Quellmalz & Zalles, 2000) in one country, Uganda, used a specially designed performance assessment to directly measure student learning of these skills, testing both participating and nonparticipating students. The study found that World Links schools out-performed the non-World Links schools on measures of communication and reasoning with information.

Even though the One Laptop per Child program is relatively new, there has been considerable pressure to show its impact on student learning, in part because of the grand claims made by the program. In the Santiago et al. (2010) study, preliminary assessment of student learning was taken in academic (e.g., mathematics, ICT skills) and nonacademic (problem solving skills, collaboration, etc.) areas, as well as behaviors (attendance, motivation, etc.). With less than 3 months of use, it is not surprising that there were no significant differences on these measures between treatment and control schools. However, there was a positive relationship between ICT test scores and the teachers' use of computer in class for 3 days or more per week.

Conclusions

ICT has a very high profile in developing countries. Many countries have or are formulating ICT policies that involve significant investments in hardware, software, networking, and technical support. The expectation is that these investments will result in reformed education systems, increased social equity, and economic development, as students become prepared to join the highly competitive global economy.

There is still relatively little research on ICT in developing countries. But what literature there is suggests that currently the challenges—and they are significant—far outweigh the benefits realized to date. There is not enough evidence to date to justify the great expense of one-to-one computing in developing countries. First, the purchase of computers and installation of networks are both problematic in developing countries and, by themselves, are insufficient to bring about change. Both theory (Kozma, 2011a) and initial research findings indicate that ICT policies and programs should include other, coordinated changes in areas such as teacher training, pedagogical practices, curriculum, and assessment. Additional research is needed on teacher and student practices and best practices but indications are that these can change as part of a coordinated ICT effort. As programs mature, more research will be needed on their impact on student learning. It is only after ICT programs are in place for several years, perhaps decades, that research can be conducted on long-term social and economic impact of educational ICT investments. Then will we know if the promise of ICT will be realized in developing countries. Until then, it will be important to keep a balanced perspective and take a systematic approach to ICT policy and implementation.

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73 Prospects for Instructional Design and Teacher Education

Ellen S. Hoffman

Abstract

With most academic instructional design and technology (IDT) degree programs located within education units in higher education, teacher education is a focal point for research on the classroom teacher as instructional designer and implementer of technology in K-12. Further, teacher education serves as a locus for modelling and testing theory-based teaching practice arising from the discipline. This review examines the historical foundations and recent scholarship in teacher education from an instructional design and technology perspective in US and international contexts, providing a lens to the issues of theory versus practice and evolving research paradigms. Research areas reviewed include teacher thinking and planning, novice versus expert teacher differences, the use of systematic instructional design in classroom practices, and the teacher as designer of instructional materials. Changing research approaches and constructivist philosophies have widened the understanding of teacher instructional planning and action from earlier process–product causation to a more complex, situated view of practice. From an examination of the uneasy relationship between the two disciplines, prospects for future cooperation and research are explored in terms of theory building, impacts on training, debates on the nature of design practice, and potential for shaping educational reform efforts.

Keywords

Teacher education • Preservice teachers • Lesson planning • Instructional systems design

Introduction

For over half a century, scholars in instructional design and technology (IDT) have proposed that the field has significant contributions to make to improving public education, arguing that creating more efficient and effective instruction could result from application of evidence-based principles and processes of instructional design (ID) widely used in other organizational settings. The education of classroom teachers has historically been proposed as a mechanism for school improvement by increasing teachers' skills in designing "instructional materials and programs" (Salisbury, 1987, p. 3). Among the approaches to introducing ID in teacher education are graduate programs in IDT in the USA which commonly require instructional design courses taken by teachers and preservice teacher technology courses that include ID. The use of textbooks on lesson planning based on instructional design written specifically for teachers has a long tradition (Carr-Chelman, 2011; Reiser & Dick, 1996; Shambaugh & Magliaro, 2006). While much of the literature on instructional design and schools originates in the USA, reformers in other nations have also looked to ID as a way to understand and impact teaching practice as is detailed below.

The "teacher as designer" role is one that Norton and her coauthors (2009) observe is fundamental but less visible than

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that of the school teacher directing classroom instruction and interacting with students.

> The teacher as designer recognizes the centrality of planning, structuring, provisioning, and orchestrating learning. While the role of designer may be the least observed and recognized teacher role, the intellectual analysis of construction of learning opportunities for students underpins all robust and worthwhile K-12 learning opportunities…. Thus, teachers are and ought to be designers. And they must come to understand that they are designers and learn theories and principles that guide their ability to create designs that promote opportunities to learn. (p. 53)

Studies on what teachers do in their classrooms and why in relation to the design and implementation of instruction have been shaped by larger trends in educational research, including changing epistemologies, acceptance of a wider range of research methods, new understandings of learning in cognitive psychology, and the differing purposes of the researcher(s) conducting the study (Lagemann, 2000; Rosiek & Atkinson, 2005; Willis, 2008; Zeichner, 1999). Parallel areas of current concern such as practice versus theory, expertise, training, and school reform underscore research directions by which both teacher education and IDT might benefit through greater cross-disciplinary efforts.

In the following review, the focus is on instructional design in teaching in primary and secondary schools, and on teacher education as the context in which teachers are trained in instructional planning and implementation both initially and through graduate and professional development programs. The chapter highlights instructional design scholarship within an explicit instructional context—one that represents the largest formal educational endeavor in the world. While the studies in this chapter are international in scope, the review is limited to works published in English and therefore may not fully cover unique efforts in non-English speaking locales. In addition, numerous studies are published on technology in schools, but these are reported only when the research involves design of instruction more generally. Other chapters in this Handbook cover schools and technology integration in greater detail.

Research on Teacher Thinking and Planning

Just as instructional systems design grew from a period of increased emphasis on rational and scientifically based approaches in education to produce efficient and effective instruction, instructional planning in schools took a similar approach primarily based on objectives-first lesson planning as proposed by Robert W. Tyler in the 1940s and 1950s (Friesen, 2010; Molenda, 2009; Reiser, 2001; Wiburg, 1995). While early systematic ID frameworks and models were being explored by Robert Gagne and others in the 1960s, public schools widely adopted the related cognitively inspired mastery-based learning of the Madeline Hunter method (Hunter, 1967; Schrock & Byrd, 1987). Concerns with the Hunter method emerged when studies in the late 1970s found that teachers using it for lesson planning were no more effective or perhaps even less effective than those who did not use the Hunter method (Hunter, 1985; Slavin, 1989). Further, the findings were accompanied by widespread complaints from teachers about the time and effort this method required when dictated by school administrators, so the Hunter method faded from use. Despite decreased support by the educational establishment, the Hunter objectives-first model continued to be taught in some teacher education programs into the 1990s and recent texts on its use remain in print (Hunter & Hunter, 2004; Marzano, 2007).

Process–Product Research Foundations for Classroom Studies

Research on teaching into the 1970s was dominated by the "process–product" approach of attempting to identify characteristics such as training background and use of particular instructional techniques of expert teachers who produced high levels of student achievement (Borko & Shavelson, 1990). Based in a positivistic research tradition, the studies were focused on measurable variables, including observational data from objective outside observers counting particular instructional actions, along with demographic statistics such as gender, education, age, years of teaching, and other traits directly related to the teacher. Environmental and student characteristics were uncommon considerations in these studies which focused on teacher behavior and background and often examined teaching in laboratory or simulated settings. Underlying such studies are assumptions about the central role of the teacher in classrooms and a transmission model of instruction in which the teacher is the primary purveyor of learning. Understanding what teachers do in classrooms was therefore viewed as the prime causal determinant of the potential for students to accomplish content learning and the context for how planning is designed and implemented. As Cohen, Raudenbush, and Ball (2003) note, this type of causative study focused solely on teachers continues at present pushed by policy-makers seeking ready solutions to the complex problems of school reform, and is further confounded by an assumption that presence of resources is equivalent to classroom use.

Examples of research on teacher planning and design of instruction from the early process–product period include studies by Taylor (1970), who examined course plans from over 250 British secondary teachers, and Zahorik (1975), who studied teachers from a US urban area. Other studies employed experimental methods, setting various treatment conditions to see how planning was conducted (Zahorik, 1970). Common to these studies were findings that neither objectives nor assessment were foremost considerations in planning by school teachers despite the then prevalent rational, objectives-first models such as those of Tylor or Hunter (Molenda, 2009). While the foundations of such process–product studies are no longer as central in educational research design, some conclusions have been reconfirmed through more recent studies described further below. These include nonuse in practice of commonly accepted formal planning models and high variability among teachers in planning approaches.

The Interpretive and Cognitive Shift in Research

The 1970s were a period of concentrated political and scholarly questioning of the rational, technical and scientific paradigm of progress, with new views of education evolving that promoted emergence, deconstruction, and contextualism as themes of inquiry. This allowed fresh perspectives about the art of teaching as well as promoted the expansion of more naturalistic and interpretive methods in education research. The outcome of this fomentation and reexamination of educational practice was a more nuanced examination of teaching and learning along with expanded tools and methods for research (Blumenfeld, Marx, Patrick, Krajick, & Soloway, 1997; Borko, Liston, & Whitcomb, 2007; Lagemann, 2000; Willis, 2008; Zeichner, 1999). In particular, researchers shifted from observable characteristics to psychological frames attempting to evoke how teachers thought about teaching, planning and classroom strategies, and how this promoted or constrained their instructional practices (Borko & Shavelson, 1990). As Shavelson and Stern (1981) noted, a practical purpose of such studies was to understand teacher thinking as a way to empirically establish the nature of professional practice and find ways to increase the number of expert teachers. Areas of research focus included the impact of tacit models, beliefs, attitudes, and professional and practical knowledge in instructional decision-making.

While the handful of initial studies on teacher thinking in the 1970s continued to be influenced by the process–product paradigm using correlative or experimental designs (Peterson & Clark, 1978; Peterson, Marx, & Clark, 1978), later influential studies on the topic such as those by Yinger (1979, 1980) and McCutcheon (1980) took a qualitative approach, using case studies in classroom settings involving small numbers of teachers. These more intensive investigations included multiple methods such as studying teachers over time and applying stimulated recall and “think-aloud” or process-tracing sessions in reviewing instructional actions in addition to observation, interviews, and content analysis of written documents like classroom materials, planbooks, and teacher journals. Central to the findings on teacher thinking related to instructional planning and action were:

- Teachers did not follow rational or systematic planning models they may have learned in teacher education or through professional development.
- Much planning occurred mentally rather than on paper.
- Objectives are rarely a focus of planning while student needs and activities are a more common starting point.
- Curriculum materials are consulted for new ideas and strategies, but also serve as constraints based on resource availability and district mandates.
- Planning is a multistage process involving yearly, unit, weekly, and daily plans.
- Planning is more a general idea of what will happen when implemented in the classroom, with implementation shaped by a teacher’s understanding and anticipation of the response of students in the classroom at any given time (Borko, Roberts, & Shavelson, 2008; Borko & Shavelson, 1990).

From initial descriptive studies, researchers increasingly applied concepts from cognitive psychology to develop a model of teacher thinking based on teacher’s personal implicit theories or mental schema founded on professional beliefs, values, knowledge, and experiences through which teacher classroom action was shaped. Teaching involves a longer-term “preactive” or planning stage, and an “interactive” or enactment stage that involves applying preplans and schemas in the immediacy of classroom actions (Clark & Yinger, 1977; Yinger, 1979, 1980). In particular, Yinger proposed that teacher decision-making is premised on creating routines to deal with the complexity and uncertainty of classroom teaching. These routines serve to establish particular patterns of instruction and classroom management that allow a level of predictability. Yinger applied the term “automaticity” in referring to the way teachers are able to apply their implicit or tacit theories without much conscious thought, thus avoiding overload on a teacher’s cognitive processing. Further, Calderhead (1981a) contended that much teacher classroom practice is routinized or rule-based, applying heuristics in response to students so that teacher action is as much managerial as instructionally focused. A number of major reviews on teacher thinking summarize these studies in greater detail (Ben-Peretz, 2011; Blumenfeld et al., 1997; Borko & Shavelson, 1990; Calderhead, 1981b; Clark & Yinger, 1977; Fang, 1996; Raths & McAninch, 2003; Shavelson & Stern, 1981).

Recent Approaches

The studies on teacher thinking continue into the present, bringing newer tools along with research methods from outside education that have gained increased acceptance among educational scholars. For example, Gill and Hoffman (2009) applied discourse analysis of teacher meetings as a method to overcome some of the concerns about using primarily retrospective self-reporting in previous studies of teacher planning. Luehmann (2008) analyzed teacher blogs as a way to approach teacher thinking over time. In a related study, Power (2009) used autoethnography as a way to explore the relationship between higher education faculty at a Canadian university and an instructional designer to suggest the issues that hinder use of ID models in education.

> That instructional design has become equated, at least in the minds of some, with a form of insidious influence geared to mass produce educational outcomes must be recognized as a failure of the ID field and its proponents to establish its relevance and clearly reveal its usefulness to a critical and discerning population. (p. 3)

Design-based and developmental perspectives are also playing a role, reflecting trends in some segments of IDT to apply recent concepts from cognitive psychology and the neurosciences to learning and teaching scholarship (Blumenfeld et al., 1997). Rather than prescriptive theory as is foundational for ID, this iterative constructivist tradition comprises thinking in context, is learner-centered and inclusive of global and societal issues, and focuses on concrete experiences and personal views. However, Ben-Peretz (2011) notes that there is insufficient attention in recent studies to the links between teacher thinking to student outcomes and examining how knowledge is learned. Others have suggested the need for an increased understanding of the development of teacher knowledge and mental models. For example, Rimm-Kaufman, and Hamre (2010) proposed that a developmental psychological view of teacher professional trajectories would be a better basis for constructing professional development and changes in thinking over the career of a teacher. A related recommendation was to increase attention to teacher narratives in research studies to elucidate patterns in individual professional growth and teacher knowledge (Davis, Beyer, Forbes, & Stevens, 2011; Marcos & Tillema, 2006). A number of researchers have promoted greater teacher voice and self-study as approaches to enhance understanding of thinking and instructional dynamics (Cochran-Smith & Lytle, 1990; Loughran, 2007; Zeichner, 2007).

As scholars are reexamining research underlying teacher education in the light of such findings, researchers urge more careful and considered evidentiary reporting, a mix of methods that acknowledges the strength of experimental and interpretive approaches, and focus on the instructional interactions among teachers and students in which teachers are not the sole determinant of outcomes (Ball & Forzani, 2009; Borko et al., 2007; Cohen et al., 2003; Lin, Wang, Klecka, Odell, & Spalding, 2010). A provocative outcome from such reexamination is an acknowledgement of the strength of findings from and purposes of the earlier process–product research while also excoriating the limitations of these studies in terms of weak constructs and poorly conceptualized, unilinear causal chains. Rather than reject such studies, these scholars argue for more complementary efforts among quantitative and qualitative traditions to improve constructs, understanding of the situated nature of teaching and learning, and more powerful theory and results that can impact teacher education and school reform efforts.

Novice Versus Expert Planning

As studies elucidating the complexities of classroom teacher thinking about planning and instruction increased, new interest grew in examining the differences between novice and experienced teachers. This research is seen as a means of improving teacher education programs in higher education as well as professional development to support practitioners in the field (Ropo, 2004). Particularly influential in the framing of these studies is the work of Schön (1983) on the reflective and practice-based nature of professionalism, increasingly enhanced from an educational perspective by the writings of Shulman (1986, 1987) on teacher professional knowledge. In addition, these studies are rooted in psychology and research on learning differences between novices and experienced individuals emerging from examination of other professions (Boshuizen, Bromme, & Gruber, 2004; Bransford, Brown, & Cocking, 2000), as well as concepts emerging from constructivist epistemology including situated learning, cognitive apprenticeship, and communities of inquiry (Blumenfeld et al., 1997).

Several major emphases came out of novice–expert studies of preservice, beginning, and experienced teachers, many paralleling findings in studies of expertise in arenas outside of teaching (Grossman et al., 2009), including those of novice and experienced professional designers (see Tracey, this volume). First, students entering teacher education come with very strong beliefs and mental models about education from their many years in schools, and changing these through courses in higher education was shown to be difficult (Alger, 2009; Knobloch & Hoop, 2005; Richardson, 2003). Research taking a critical theory perspective indicated that such preconceptions could have negative impacts in teacher–student interactions in the classroom and impede student learning (Cook-Sather & Youens, 2007; Stillman, 2011). As ideas shifted from transmission models of learning to more situated perspectives, greater emphasis was placed on emergent classroom behaviors with teacher knowledge, beliefs, and attitudes being conditional, continually learned, and flexibly applied in response to classroom interactions and constraints (John, 1991, 2006; Jonassen, Cernusca, & Ionas, 2007)

In relation to classroom practice, preservice teachers typically are able to identify fewer instructional strategies (Brown, 2010; Graham, Burgoyne, & Borup, 2010; Sato, Akita, & Iwakawa, 1993) and develop more factual but less flexible lesson plans (So & Watkins, 2005). By contrast, experts are more sensitive to learner variations, classroom interactions and characteristics of task situations, identify problem parameters more rapidly, and spend more time on analysis while producing better solutions to problems (Elliott, Stemler, Sternberg, Grigorenko, & Hoffman, 2011; Ropo, 2004). In a multicountry study examining general pedagogical knowledge of preservice teachers at three points from initiation of the teacher education process to teaching internship, the researchers found distinct differences in focus among students from the countries studied: teaching methods and didactics in Germany; assessment in the USA; and cognition and content in South Korea and Taiwan (Blömeke et al., 2008). Across all countries, there were high effect sizes indicating the positive impacts of teacher education, particularly on lesson goals, decreases in feasibility concerns, increased use of technical terms, and more attention to affective and motivational instructional goals.

When hired into beginning teaching, new teachers struggle with establishing routines, focus more on classroom management, contextualize problems in terms of self, and have difficulty in the issues of hierarchical planning linked to overall curriculum, forcing planning into a daily cycle of activities with limited attention to longer-term learner goals and responses to individual learners (Alger, 2009; Liston, Whitcomb, & Borko, 2006; Sardo-Brown, 1993; Shoham, Penso, & Shiloah, 2003). When research on planning focuses on experienced teachers, findings indicate practicing teachers do not follow the models taught in their teacher education programs, even when these are reinforced in continuing professional development or enhanced in graduate-level teacher education programs (Cross, 2009; Knobloch & Hoop, 2005; Lloyd, 2007; Sardo-Brown, 1990). Yet surveys show that experienced teachers continue to promote the teaching of formal planning methods in teacher education even though they do not personally apply such models (Borko & Shavelson, 1990; Westerman, 1991).

What About Instructional Design for Teachers?

Given the important role of planning and design in teaching, IDT has continually seemed poised to make significant contributions to teacher education (Carr-Chelman, 2011; Flouris, 1988; Reiser & Dick, 1996; Shambaugh & Magliaro, 2006; Willis, Thompson, & Sadera, 1999). Despite the fact that most IDT programs are housed in schools, departments or colleges of education where teachers are prepared, the relationship between teacher education and the field of instructional design and technology has often been contentious as well as poorly defined. Critics have raised concerns including differing goals, strategies, resource requirements, and limited perspectives that are incompatible with school-level teaching and learning (John, 2006; Martin & Clemente, 1990; Oser & Baeriswyl, 2001). Burkman (1987) noted the chasm in the USA over 30 years ago, reporting on surveys of education leaders and analysis of content in educational psychology textbooks, concluding instructional design skills were covered spottily and inconsistently in teacher education programs. Multiple authors pointed to the growth of emphasis on the reflective practitioner over technical skills and educator rejection of rational ends-means planning (Earle, 1998; Martin & Clemente, 1990; Schneider, 2010; Schrock & Byrd, 1987; Snelbecker, 1987), making any inroads into teacher education challenging. In parts of Europe, the empirical foundation of didactics grew as a reform tradition and ID was generally ignored as an instructional theory (Oser & Baeriswyl, 2001; Seel & Dijkstra, 1997).

Empirical studies have examined impacts of instructional design on teacher planning and instruction since the 1980s, moving beyond earlier traditions focused on audiovisual and instructional materials in schools, and in conjunction with the adoption by the Association of Educational and Communications Technology (AECT) of a definition of the field emphasizing design. These studies have taken two primary routes: what happens when teachers learn instructional design in terms of their planning processes, and closely related but different, how does instructional design relate to the application and use of instructional technologies by teachers (see next section).

A handful of studies on teachers' uses of systematic planning appeared in the 1980s but studies of more classic ID understanding and application by teachers grew in the 1990s. B. Martin (1990) elaborated on results from earlier teacher planning studies using an instructional design lens, examining the differences between long-range and daily planning, written versus mental planning, and the application of planned strategies in contrast to implementation in daily classroom activities. She found that when looking at teachers' long-term plans, objectives played a more central role than indicated in earlier studies, often influenced by district-provided curriculum guides. Although the study included five teachers trained in instructional design and five without formal training, there was little difference in the plans they submitted as part of the research, with four of the five non-ID trained teachers having "at least a rudimentary knowledge of ISD even if they did not know it by that name." One of the non-ISD trained teacher participants stated, "[ISD] seems like common practice to me" (p. 69). In conclusion, Martin writes,

> It is important to remember that teaching is not instructional design, but rather a complex host of other behaviors, skills, and attitudes. Given this caveat, the use of instructional design may be an exceptionally useful tool for teachers to incorporate into their repertoire of teaching behaviors. A quote from one [ID trained] teacher is especially germane as she cautions us to take into account what teaching is and to keep instructional design flexible in this setting. 'I would hate to see lessons so rigidly planned that any spontaneity is discouraged.' (p. 72)

Moallem and Earle (Earle, 1996; Moallem, 1998; Moallem & Applefield, 1997; Moallem & Earle, 1998) provided the most detailed studies of teacher planning practices in relation to ID principles, including an intensive 3-year study of a beginning elementary teacher and a similar ethnographic study of an expert teacher. These researchers argued that the highly contextualized, reflective and social way of thinking about instruction of classroom teachers studies provided a stark contrast with the rational, technical and prescriptive process of ID, leading to the need for different instructional design models before there would be meaningful impact in schools. Young, Reiser, and Dick (1998) examined the planning processes of nine expert teachers, comparing their practices to that found in the Reiser and Dick textbook for teachers (Reiser & Dick, 1996). Despite finding little evidence of systematic planning practice, the authors proposed that ID training provides a solid foundation for novices to develop a personal planning style and coherent process of design. The ID-related teacher studies were complementary to findings of the teacher-thinking research summarized above, but also showed that approaching studies from an instructional design perspective provided a useful frame within which to examine decision-making, instructional strategies, and complex classroom realities.

Earle (1998) reviewed the debate on the potential of ID for schools, noting that research suggested some ID principles are used by teachers. At the same time, he suggested the empirical evidence from teacher thinking studies showed that existing models were inappropriate for the way teachers work, with a need "to bridge the gap between the theory of instructional design and the practice of teaching, developing practical models and principles to reach our common goal of enhancing teaching and learning" (p. 43). Among the findings Earle highlighted resulting from studies related to instructional design:

- Teachers implicitly apply ID principles but do not employ a classic ID model.
- ID can be taught successfully to preservice teachers. One course is insufficient, but does enhance perceptions about what is important in teacher planning.
- Teacher mental models differ from classic ID models, and there is a need for a common technical language of instruction as well as validation of the scientific basis of instruction.

In the USA, the past 10 years have seen different emphases in the relation of IDT to teacher education, in part because of increased grant funding in the areas of technology, mathematics and science, as well as state and federal mandates for standards and content testing in K-12 schools. In general, the findings of the earlier studies remain unchallenged. Research has continued on mental models as used by professional and beginner instructional designers (see Tracey, this volume), while a number of studies of teachers have examined teacher thinking in relation to technology (Ertmer & Ottenbreit-Leftwich, 2010; Graham et al., 2010; Mitchem, Wells, & Wells, 2003; Palak & Walls, 2009; Sang, Valcke, Braak, & Tondeur, 2010).

More recent studies that examined outcomes of teaching teachers formal ID models and frameworks have primarily occurred outside the USA, where ID instruction has been applied as part of a reform effort to improve teaching practice (Altun & Büyükduman, 2007; Alzand, 2010; Könings, Brand-Gruwel, & van Merriënboer, 2010; Krull, Oras, & Pikksaar, 2010; Ozdilek & Robeck, 2009). Interviews with eight elementary teachers in exploring the use of ID processes in planning indicated that teachers are constrained by central administration mandates on objectives, curriculum materials, and testing, minimizing analysis and design phases in teacher planning (Karaca, Yildirim, & Kiraz, 2008). Student-centered concerns and activities are central to lesson planning. Teachers develop detailed lesson plans as required by administrators but those interviewed admitted actual implementation is more improvisational. Researchers in Taipei surveyed 223 elementary teachers on their use of elements of the ADDIE model in instruction, with 69 having previous ID training (Ho, Kuo, Tsai, & Kuo, 2006). The respondents indicated they do not have time to use formal models, but the researchers found that all had an tacit understanding of the model elements.

Rose and Tingley (2008) found similar results from interviews with six Canadian mathematics and science teachers, suggesting that the participants intuitively understand ID concepts and perceive themselves as instructional designers when the term is explained. The teachers started with general goals in their planning often derived by consulting curriculum guides and teacher manuals. Central to their planning is caring about students, so that planning is not systematic but a "constant process of innovation and adaptation based on a keen attentiveness to their students' needs" (n.p.). The researchers argued that classic ID models are inherently dismissive of affective dimensions important to classroom teachers.

> A significant factor in the fundamental disconnect between systematic instructional design models and teachers' practices is the fact that instructional design models offer no apparent means by which teachers can express and act upon their belief that care is at least as important a part of the educational experience as the development of competence. (n.p.)

Design and Technology in the Classroom

The interrelationship in IDT of design and technology encourages curriculum that interconnects the two in teacher education course work and professional development efforts. Research from this perspective is oriented to the approach of the teacher as a user of technologies and modifier or creator of curriculum materials within the larger planning context.

Thirty years ago, F. E. Clark and Angert (1981) proposed that teacher educators should demonstrate and model the selection and use of audiovisual resources through systematic instructional design processes as a way to improve the quality and effectiveness of materials used in instruction. The concept of linking ID models and technology continues, as shown by textbook content commonly used in required teacher education technology courses (Lever-Duffy & McDonald, 2011; Morrison & Lowther, 2010; Newby, Stepich, Lehman, Russell, & Ottenbreit-Todd, 2011; Roblyer & Doering, 2010; Rogers, 2002; Smaldino, Lowther, & Russell, 2011). This combined approach of teaching instructional design in the context of technology is recommended by some advocates as one way to incorporate ID into the crammed teacher education curriculum (Hannafin, 1999; Savenye, Davidson, & Smith, 1991; Snelbecker, 1987; Summerville & Reid-Griffin, 2008). By the end of the 1990s, many studies involving instructional design and K-12 teaching in the USA had shifted to a technology integration focus.

Recent studies have indicated the key role curriculum materials play in new teacher planning and learning (Grossman & Thompson, 2008). Teacher design practices are seen as a way of customizing curriculum for localized student needs (Lloyd, 2007), developing pools of teacher-created, reusable resources that can be shared, and increasing the awareness of the instructional appropriateness and effectiveness of technology tools by formally applying ID principles to evaluation efforts (Wiburg, 1995). However, critics note that the teacher-as-materials-designer model promoted in some teacher education programs may be an idealistic position given constraints of time, costs, and pressures for standardized curriculum in school settings and the limited capabilities of novice teachers to create or adapt curricular materials. F. E. Clark and Angert (1981) pointed out that little research had been done to indicate the effectiveness of the ID-technologies based approach for future student achievement, a situation that continues into the present. Further, following research on teacher application of ID in materials selection and development in university course work, Kerr (1981) noted that insufficient attention had been given in such approaches to understanding teacher perspectives.

> If our goal is to affect positively the quality of instruction, we cannot afford to demand an approach to design that is not based on reality. The time has come to pay attention to the D in ID, and to discover how educators design. (p. 376)

Many recent analyses of systematic instructional design applied to teacher-created technology projects in the USA are case studies of preservice courses or graduate-level courses for in-service teachers. Many of these articles are preliminary narrative without a formal, detailed evaluation component reported. More a form of practitioner action research or best practices review, the conclusions are based on standard classroom artifacts such as student work, student end-of-course evaluations, and teacher-centered observation for assessment of outcomes rather than more formal research design and analysis. For example, Zhang (2000) notes the initial resistance to the formality of using the Dick and Carey ID model in designing Web-based units in a graduate-level technology course. These in-service teachers indicated that they were already experienced in curriculum and the ID model was too detailed and linear as they began the project, but the systematic design process resulted in better products because of the alignment of objectives, strategies, and assessments.

In another case study, Summerville and Reid-Griffin (2008) report on applying online modules to teach a modified ID model, the "Summerville Integrated Model," in a preservice technology course. The researchers reviewed model application based on examination of student work and questionnaires. In rejecting earlier ID models for their course, the authors noted that none had the level of flexibility, constructivist and learner-centered approach, and interrelatedness that their own circular model provided, including promoting higher-order thinking and reflective practice. The preservice teachers in the study used the revised model process in evaluating online learning resources and in developing a lesson plan that included instructional materials they created in the course. By applying the model, the researchers indicate that students gained confidence in both tool uses and lesson planning, were positive about the learning experience, and were better able to produce learner-appropriate lesson plans in later methods courses. However, Summerville and Reid-Griffin noted their teacher education colleagues' concerns with time required to implement instructional design in the technology course, potentially decreasing time on new technologies.

Churchill (2006) conducted a longer-term qualitative multi-case study of four teachers in Singapore as a way to understand the way teachers design technology-based learning and the "private theories" that guided their decision-making. The study of the experienced teachers occurred during and after a seminar that included materials development and introduction to instructional design frameworks as a way to promote more student centered learning. His study links the teacher-as-materials-designer approach with the teacher-thinking research described above. Data collection involved examination of prototyped instructional materials at multiple stages during and after the seminar using external reviewers, a cognitive analysis technique of card sorts, teacher journals during their teaching after the seminar, and follow-up interviews 6 months later. As in earlier studies, the findings show that the professional development led to limited impacts in thinking and practice. All four teachers shifted at least slightly towards more student-centered approaches, but only one moved from a direct instruction approach to a student-centered practice, while a second intensified what was already a student-centered approach. When themes of technology, teacher or students were the major explanatory factor for design decisions stated by a participant, that teacher's approach was direct teaching while the more student-centered teachers justified their decisions based on student learning. Churchill notes in conclusion that a teacher's focus on learning is not enough for change because of constraints that arise from the teacher's preexisting personal theories on students, impacts of an assessment-testing culture, and institutional influences which push in opposing directions. He urges greater consideration for practitioners' entrenched private theories in teacher professional development, noting that "if teachers could identify the theories that mediate their design, they are more likely to make better decisions regarding the means of implementing any desired changes" (p. 575).

A number of formal studies have examined the impact on preservice teachers of online-support tools in scaffolding lesson planning to enhance use of the systematic problem-solving approaches applied by expert teachers. One of the more comprehensive examinations of the impacts of support tools on novice teacher learning of instructional planning are the multiple quasi-experimental studies undertaken by Baylor and Kitsantas (Baylor, 2002; Baylor & Kitsantas, 2001, 2003, 2005; Kitsantas & Baylor, 2001). The support tools their team developed were tweaked in various treatment configurations, including instructivist (Reiser and Dick based) versus constructivist (Jonassan and Mayer influenced) models, incorporation of prompts by animated agents, and use of an ill-structured versus more structured learning problem. Data collection involved student questionnaires on attitudes and tool design as well as student-created lesson plans and reflective writings. The instructivist and constructivist tools equally improved performance and motivation. However, the instructivist tool better supported self-monitoring while the constructivist tool promoted cognitive flexibility. In terms of the problem structure, the instructivist tool provided better support for the ill-structured problem and a parallel improvement for solving a structured problem with the constructivist tool, the opposite of what the researchers had predicted. These results suggest that each ID approach has merit as novices approach instructional design for classrooms despite the debates between instructivist and constructivist oriented scholars.

Some studies have examined experienced teacher integration of technology more generally in relation to planning models. In one of the few studies that links systematic planning and technology to student achievement, researchers examined the impacts of professional development, showing higher-quality lesson planning resulted in positive teacher and student outcomes (Martin et al., 2010). In a series of reports from Cyprus, Angeli and Valanides (Angeli, 2005; Angeli & Valanides, 2005, 2009) examined issues of applying ID models in teacher education in relation to enhancing technology use, studying preservice teachers' thinking as well as teacher educator practices. As in earlier studies, they noted the need for changes to the classic ID models before these could be more applicable to teaching.

> Most importantly, these results show that there is a need to develop new ISD methodologies to bridge the gap between the world of teachers' work and the world of instructional design. An expanded view of PCK [professional content knowledge] provides a strong conceptual basis for such an ISD methodology, because it describes teachers' knowledge as highly contextual and situated in classroom experiences, as well as an integrative body of different forms of knowledge that interact with one another, such as content, pedagogy, and learners. These characteristics of PCK are in contrast with the generic and context- and content-free ISD models. (Angeli & Valanides, 2005, p. 295)

Conclusions: Prospects for Teacher Education

Given the important role of design in teaching, IDT has continually seemed poised to make significant contributions to teacher education with each new decade finding advocates proposing it is just around the corner. Over time, they have cited the field's understanding of audiovisual technologies, role in development of nationally adopted curriculum materials, successes in spreading ID in military and corporate settings, familiarity with computer technologies, expertise in distance learning, or expansion into the learning sciences and design fields (Carr-Chelman, 2011; Clark & Angert, 1981; Dick, 1986; Flouris, 1988; Hannafin, 1999; Norton et al., 2009; Savenye et al., 1991; Willis et al., 1999). Most of the concerns raised 20 years ago about prospects for ID in schools and teacher education (Burkman, 1987; Earle & Sheffield, 1995; Schrock & Byrd, 1987; Snelbecker, 1987) remain current. Few voices actively propose that systematic instructional design models will have major impacts on schools beyond the use of curricular materials created using ID principles or integration of emerging technologies led by those with instructional design expertise. Further, as this review has illustrated, formal research on ID and teachers is primarily occurring only within the immediate context of higher education courses. In the past decade, no studies of ID were found during this review involving practitioners in classroom settings in the USA except for those related to technology, with very limited studies on ID and school teaching outside the USA.

The findings reviewed here have much to offer IDT. While scholars in IDT have raised issues about the lack of studies of design uses in context (Bichelmeyer, Boling, & Gibbons, 2006) and have urged shifting emphasis to newer models and theory of design (Jonassen, 2008; Jonassen et al., 2007; Osguthorpe & Osguthorpe, 2007), the research on teachers and classrooms is a rich resource which remains relatively unexplored as a source of empirical evidence to enhance theory building and design frameworks. The initial research on teacher knowledge, planning and decision-making in classroom contexts had positive influences on IDT research. These research approaches led to expansion of methodologies in ID development and design studies, increasing recognition of context that negated simple process–product causality. An active track of studies on design thinking, development processes, and role of training on professional instructional designer practice (see Tracey, this volume) parallels the teacher research reviewed. The related methods, questions, and findings suggest that there are potentials for cooperation and sharing that may be productive for both areas of research.

The studies establish that the skeleton of ADDIE and related models are a logical foundation for instructional design decision-making in schools, but application is more complex and nonlinear, subject to multiple constraints, contextually framed, and continually reshaped through practitioner experience. Such findings provide potential grounding for theoretical advances in IDT and review of ID models. Further, there are recognized differences in effective teaching of design depending on whether the learners are novices to instruction such as preservice teachers versus more experienced practitioners common among graduate students. Given the differing levels of practical experiences, development of skills, tacit models of teaching, and underlying beliefs and attitudes, teacher education curriculum may need to vary to accommodate these evidence-based differences in initial knowledge and openness to new concepts. New directions in studying strategies to address novice versus experienced practitioners, while not yet applied to teachers, may have potential for opening new research perspectives (Fadde, 2009; van Gog, Ericsson, Rikers, & Paas, 2005).

At a broader level, the prospects generally for instructional design's impacts on teacher education appear to be declining based on the decrease in studies reviewed here. To some degree, the areas of IDT growth in studying preservice and classroom teachers are from those traditions of research that have shifted to design-based research and the learning sciences or those involving teacher knowledge related to technology from a TPCK and adoption perspective (see Handbook chapters). Despite proposals over 30 years ago for more research on the impacts of ID on schools and teachers (Kerr, 1981), such studies not only did not materialize but now do not appear central in the disciplinary agenda.

Negative predictions on the fate of instructional design in schools are not a certainty despite the evidence of downturn in the reviewed studies, but it is evident that changes would be needed to counter this trend. Teacher education is under major external pressures to reform and show that its curriculum and methods have an impact not only on the teachers emerging from their programs, but ultimately on the students that they teach (Wang, Odell, Klecka, Spalding, & Lin, 2010). The same intellectual trends that promoted interpretive and situated perspectives in each disciplines' research resulted in a strong skepticism among many teacher educators towards a science of teaching which could provide a common framework for training future teachers (Burkman, 1987; Grossman & McDonald, 2008). Under increased pressure for evidence-based results, a number of internal voices are arguing that a new science must emerge to satisfy policy-makers and prove that teacher education makes a positive difference (Ball & Forzani, 2009; Cohen et al., 2003; Lin et al., 2010). Teacher education leaders are promoting an inside reexamination of teacher education scholarship as a push-back to uninformed external proposals for how evidence is evaluated and how it leads to change. Part of this is a call for a new look at research as a way to provide more solid evidence as the basis of teacher education practice, and renewing a call for a more science based and less craft or domain-specific learning approaches to curriculum in education programs (Ball, Sleep, Boerst, & Bass, 2009; Singer-Gabella, 2012; Sternberg, 2008). Identified needs in research studies include adoption of a common terminology of instruction, recognition of the contributions of differing research traditions, better understanding of the impact of instructional resources and technology, and increased research on the relationship between teaching practice and learning outcomes.

> Educational phenomena are usefully studied using tools and perspectives from other disciplines, and the interdisciplinary culture needed to support inquiry into education depends on intellectual diversity among the faculty. Too rare, however, are scholars steeped in the instructional perspective or whose specialization is instruction. (Ball & Forzani, 2007, p. 539)

IDT's historical development of constructs and interdisciplinarity have much to offer the calls for shaping future research trajectories in teacher education, particularly in the need for a common terminology and the impact of resources and technology. The teacher-as-designer research reviewed in this chapter provides a potential foundation for future cooperation and growth between these fields, in tune with recent calls to remember what has been learned before (Lin et al., 2010).

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Fostering Relevant Research on Educational Communications and Technology

74

Martin Oliver

Abstract

Describing research as 'relevant' implies that there is an aim that it should serve; asking further how such work can be fostered raises questions about the encouragement and control of research practices. This chapter explores the idea of relevance in the context of research on educational communications and technology, and considers the mechanisms through which groups such as researchers and policy makers foster work that serves their interests. Firstly, historical patterns of cycles of promise then disappointment for technologies are noted. Then, the idea of relevance is considered in relation to the audiences with interests in work in this field. Next, mechanisms for fostering particular kinds of research are discussed, using concepts from Communities of Practice to frame the discussion. The chapter concludes by identifying ways of fostering relevant research that are distinctive to work in this field, such as the use of templates for knowledge representation and processes such as participative design, and problems that will persist in achieving this, such as the need to contextualize research claims in relation to specific teaching contexts.

Keywords

Communities of practice • Evidence-based practice • Policy sociology • Alignment

Introduction

> In the film 'Groundhog Day', the protagonist is forced to experience the events of a single day over and over again. He is free to act in any way he chooses, but whatever he does the day always finishes in the same way. […] People who have been involved over any length of time with educational technology will recognise this experience, which seems characterised by a cyclical failure to learn from the past. We are frequently excited by the promise of a revolution in education, through the implementation of technology. We have the technology today, and tomorrow we confidently expect to see the widespread effects of its implementation. Yet, curiously, tomorrow never comes. We can point to several previous cycles of high expectation about an emerging technology, followed by proportionate disappointment, with radio, film, television, teaching machines and artificial intelligence. (Mayes, 1995: n.p.)

This widely quoted excerpt from Mayes neatly summarizes many of the challenges that face research on educational communications and technology. There is hype; there is exploration; there is disappointment; and then a new topic arises that diverts attention. The date of Mayes' lament shows that this is nothing new; the continued relevance of the excerpt shows that the problem remains with us.

This chapter works through some of these challenges, identifying possible solutions but also considering how much of this is an inevitable feature of research in the field. This discussion serves to identify both opportunities to foster relevant research, but also the challenges which are likely to persist.

In order to do this, the next section starts by focusing on the idea of "relevance," considering it in relation to different contexts, audiences and traditions of research.

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What Is Relevant Research?

"Relevance" implies a sense of purpose—something cannot be relevant in general, only to particular situations or ends. This is just as true of research as for anything else, so, in order to reflect this, this section explores two questions: relevance to what, and to whom?

Contextual Relevance

Research on Educational Communications and Technology might be expected to inform practice or decisions in a wide range of settings, but differences between settings mean that work undertaken in one context may not be relevant elsewhere. In order to understand how this affects research, it becomes important to ask, how can contexts vary?

The first problem with this question is that "pinning down what we mean by context is not an easy task" (Luckin, 2010: 3). Luckin's discussion of the "spatial turn" in research identifies physical, digital, social, and historical elements that constitute our understanding of context. Each has a role to play in establishing whether a particular practice, such as an educational use of technology, will be considered successful, appropriate, and so on.

As a further complication, this already complex picture of context has been viewed from at least two perspectives. The first of these views context as something that "surrounds" activity; the second views context as something created through the weaving together of artifacts and practices. Even without going further into the ecological account of learning with technology that Luckin develops, this demonstrates just how different contexts can be. In addition to the practical questions that it raises—how similar, for example, is the historical and material context of this teacher to that of the research?—it also highlights that the introduction of any new technology, or even a new use of an existing technology, can be understood as changing the context of practice itself.

To illustrate some of the many problems this poses for research, it is worth considering the problems faced by the "One Laptop per Child" initiative. This work traces its roots back to Papert's seminal work on constructivism, but it has been shown that the principles derived from studies in western settings could not easily be applied in developing countries for organizational, technical and social reasons. The project has been criticized for adopting a simplistic, "one size fits all" model of change (Leaning, 2010) that assumes technology alone can cause beneficial change (Tabb, 2008). Rather than applying research to transform education in other contexts, the risk for such work is that the simplistic transfer of principles can come across as "an arrogant sense of superiority and a 'benign colonialist' attitude" (Leaning, 2010: 244).

The only way to avoid such issues is to assume that no research outcomes are universally relevant, but instead will need to be recontextualized each time they are applied. For example, the principles behind the "One Laptop per Child" initiative remain relevant in other contexts, but arise in different ways. Studies undertaken in South Africa show that older learners (studying at University) do indeed benefit from having individual devices to support learning—however, these may well be mobile phones rather than laptops, and it may involve considerable personal effort and hardship to fund their use, meaning that interventions might be better aimed at adults who can use income to sustain their use rather than children who depend on others to provide the infrastructure they need (Czerniewicz, Williams, & Brown, 2009). Thus, whilst some of the principles derived from earlier work can indeed be applied, they require reworking rather than simple application; the change in context makes their "relevance" complicated, so that it needs to be reestablished rather than assumed.

Contextual differences do not only apply at this macro level; even within relatively small areas, contexts vary considerably. The differences between home and school use of technology demonstrates this. Learners need to use different technologies, or use familiar technologies in new ways, depending on what they are trying to achieve and the settings in which they are acting (Livingstone & Bober, 2004). This is not a simplistic contrast in which one set of practices—say, the more extensive use of technologies in informal settings—is universally "better"; rather, it is simply that some uses of technology may be inappropriate in school but acceptable at home (Lankshear & Knobel, 2006). One example of this is in relation to information searching: being able to find videos on YouTube does not mean that a learner will be able to find and judge academic information sources appropriately, even if they can operate the search interface with equal technical skill (CIBER, 2008).

Many of these issues are considered explicitly within the field of mobile learning. Attempts to theorize what is important about mobility have moved away from a focus on the portability of devices, and towards the idea of learning across contexts (see, e.g., Sharples, 2005). This is particularly obvious in examples such as educational field studies, where data collected in one context might be analyzed and interpreted in another; or augmented reality simulations, in which information is used to supplement and hence transform experiences of what might otherwise be very familiar spaces (Roschelle & Pea, 2002). In this tradition of work, the difference between contexts becomes a resource for learning, rather than a problem: it remains important to study and understand it, but relevance arises from the contrasts and specialization that learners will encounter, rather than homogeneity.

Relevance to Audiences

Implicit in the idea of "relevance" is a purpose, and this in turn implies an actor. There are several possible groups of actors who might reasonably be thought of as audiences for research on educational communications and technology, and members of each may have their own purposes and interests.

Perhaps the most obvious audience is other researchers, for whom research is "relevant" if it helps them to advance their own work. In this sense, work might be relevant because it contributes evidence relevant to a research problem; methods through which it might be studied; theories, concepts or models through which it might be understood; or because it highlights a gap or problem that needs to be addressed in the first place. In terms of technologies, the importance of novelty—the ability to make a contribution to knowledge—can be seen as fuelling the cycles of work that Mayes (1995) identified. In this respect, new developments, prototypes and cutting-edge applications are more likely to be of interest than studies of well-established technologies, which is why proof of concept studies are more common than (for example) cohort studies of the roll-out of technologies that have been commercially adopted (Alsop & Tompsett, 2007). Different kinds of research are simply cited—a measure typically taken as an indicator of research impact—in different ways. Studies show that review articles, for example, are almost always more highly cited than any other kind of publication—but that does not mean that other kinds of research lack value or should not be undertaken (Cameron, 2005).

Irrespective of the topic, however, studies show that the format in which research is presented matters. Recent work on digital scholarship advocates a commitment to open sharing of research publications (e.g., Weller, 2011); studies show that across various disciplines, open access articles are more widely cited (Antelman, 2004).

While researchers might be one obvious audience, policy makers are usually given a higher profile in discussions of the relevance of research. Within traditions such as evidence-based policy, the link between research and policy is clearly formulated: research evidence is aggregated in a systematic way, judged in terms of the quality of evidence, and the outcomes (typically quantitative) are integrated (Nutley & Webb, 2000). Within this systematic, rational model, evidence is gathered "just in case"—it may relate to an issue of the moment, but reviews draw on all evidence already available; this specific aggregation may well have been unimagined by the researchers who undertook the work. However, such reviews are only possible when a series of studies has been undertaken with the same (or closely related) technologies. The ability to speak with confidence about the general value of a technology thus needs different kinds of research to the ones of most relevance to researchers.

Furthermore, while this model has widespread appeal, it has been criticized as failing to reflect how policy is developed and enacted, and how evidence is (or is not) used to inform that process. Patton (1997), for example, undertook studies of the ways in which evidence from commissioned evaluations was used to inform policy decisions and found that, for the majority of cases, it simply did not—the reports that were produced were not even read. Instead of the "just in case" model of evidence production and consumption, Patton advocates a "just in time" process of evaluation that generates evidence (which may or may not be quantitative, depending on what will best inform a specific audience) in relation to current concerns, so as to inform specific decisions that need to be made.

This attention to the practice of policy work has been developed more extensively in the area of policy sociology (Ball, 1997). This perspective recasts policy as a social process, rather than just as a collection of paper documents; policy is seen in terms of a "circuit of production," in which people develop, write, promote and implement policies. Each of these stages can involve different groups of people, each with their own competing interests. Provision of evidence at any point in this process can alter the balance of power, providing one group with an advantage in arguing for its preferred position (Patton, 1997), and changing the effects of the policy process. In such an account, "relevance" would be understood in terms of the potential for one group to use research evidence to gain advantage for their favored position over some alternative; it is therefore inherently political.

This echoes work on the kinds of study that have successfully influenced educational technology policy. Roblyer (2005) identifies four kinds of study that could move work forward, and which by implication might inform policy work: that which establishes relative advantage for particular technology-based strategies; research that improves implementation strategies; work that monitors important societal goals; and that which reports on uses outside of educational settings to develop work in educational contexts.

The other group for whom the question of research relevance arises is the broad category of "practitioners," normally understood to cover teachers. There are problems with simply "applying" research to teaching practice, just as there were complexities discussed earlier with the idea of applying research undertaken in one context within another.

This can be illustrated by work on technology and teacher training. Mishra and Koehler, focusing on teacher education programs, developed Shulman's framework for talking about professional knowledge to consider what teachers needed to know about technology. Shulman's original framework made the point that, in addition to knowing about their subject and about teaching, teachers needed to know about the specificities of how to teach their subject (a point analogous to the concerns about contextualization, above). Mishra and Koehler's development points out that, as well as knowing about technology, teachers also need to know about the technologies of teaching (e.g., interactive whiteboards, managed learning environments,) and the technologies of their discipline (e.g., concordances for languages, molecular modeling software for Chemists, patient monitoring equipment in clinical medicine). They also need to know about the specifics of using technology to teach their discipline—in Mishra and Koehler's terms (2006), "Technical Pedagogic Content Knowledge" or TPCK.

This explains why applied case studies are so relevant to practitioners: they directly address the problems of implementation in specific contexts that they face when teaching with technologies. It also offers an explanation of why these case studies are not widely read by teachers in other subject areas. Moreover, such studies are different again from the kinds of work that are most relevant to researchers or policy makers.

Of course, not all research needs to be so specific in order to be relevant to teachers: it is perfectly legitimate to view research as being relevant to knowledge about technologies for teaching, or just technology more generally. Russell's meta-review of studies of technological interventions (1999), for example, makes a perfectly legitimate contribution to knowledge about teaching with technology (rather than teaching with technology in a specific disciplinary context) by showing how rarely significant and meaningful differences are found in studies. Nonetheless, the idea of TPCK helps to highlight gaps in the research, and more specifically, in the research presented to teachers as part of their training. It allows relevant research to be undertaken by highlighting where there may be gaps, but also explains that studies may not be of obvious relevance simply because teaches are thinking about the specificities of their subject, rather than thinking about teaching in general. Studies have shown that interventions that address gaps in this way help practitioners to develop a better integrated understanding of the relationship between technology and teaching practice (Koehler, Mishra, & Yahya, 2007).

Another major group of "practitioners" who may form an audience for research is designers. Several well-established traditions of research inform design practices—for example, much of the field of human-computer interaction does exactly this. However, not all of this is relevant to questions of learning; Nielsen's Web usability guidelines (1999) for example are widely cited, even within work on learning and technology, but concern commercial transactions rather than instruction. By contrast, Mayer's work on the integration of verbal and visual information (e.g., 1997) and Sweller's work on cognitive load (e.g., 1994) have directly informed design principles for multimedia, information sequencing and representation in instructional materials. Similarly, instructional design work building on Gagné's events of instruction (1985) has produced extensive and highly developed guidelines that are of direct relevance to problems of learning and instruction. What these and other similar sets of principles share is a common orientation to recognized and recurrent problems encountered by designers producing instructional materials. Such research is relevant, because it can be directly applied to guide the design of instructional programs (Merrill, 2002).

Finally, while learners are commonly featured in research, they appear more often as the subject of studies than as an audience. While there has been much work undertaken to understand learners' practices and preferences, little of this is directly relevant to them; more often it is drawn upon to inform design. More common is that learners are appropriated—they are spoken for, often in ways that lend weight to particular positions. For example, the claim that there is a generational divide—whether between digital natives and immigrants, or new millenials, or net generation—serves to bolster the arguments of reformers who want teachers to make more use of technology, even if "rather than being empirically and theoretically informed, the debate can be likened to an academic form of a 'moral panic'" (Bennett, Maton, & Kervin, 2008: 775).

Of greater relevance to learners, arguably, are attempts to use the frameworks that researchers have developed to inform their own understanding of learners in order to support learners' own meta-cognition. Some of this work is of dubious value: for example, work on learning styles is widespread, and has led to the development of self-evaluation instruments that are intended to make students more aware of their own learning styles—ignoring the evidence that these "styles" are situated responses to learning tasks, heavily influenced by assessment regimes, and that there is little evidence that they are stable or persistent over time (Coffield, Moseley, Hall, & Ecclestone, 2004). However, there is evidence of the value of developments such as Open Learner Modeling, an approach that uses student models to raise students' awareness of their progress, practices and so on, so that they can make better informed choices about future actions (Kay, 1997). This approach has been shown to support reflection and metacognition, and further value may arise where these models can be shared with peers and tutors too (Bull & Nghiem, 2002).

To summarize, there are multiple audiences for research on educational communications and technology, and each tends to have its own distinctive interests. The result of this is that what will count as relevant research will depend on the interests of the audience that is considering it. This leaves researchers with a difficult dilemma: in response to this situation, their work must either be political (serving the interests of one group rather than another) or naïve.

Fostering Research

As the discussed of relevance shows, research does not take place in a social vacuum. Various interests stand to be supported, challenged or sidelined by research. Obviously, it is in the interests of each group to ensure that others are supported and encouraged to undertake the kind of work they need.

In this section, some of the processes through which this takes place are reviewed. This discussion draws on ideas from Wenger's work on communities of practice: this analyzes social practices to identify how groups stabilize what they do, manage new developments or new participants, and relate to other groups.

Specifically, this discussion uses the ideas of alignment and of constellations of practice. "Constellations of practice" are "configurations […] too far removed from the scope of engagement of participants, too broad, too diverse, or too diffuse to be usefully treated as a single community of practice" (Wenger, 1998: 126–7); instead, a constellation describes groups such as an institution or a social movement in which there may be many communities of practice, with divisions between them, but across which practices remain connected. "Alignment" explains how groups change their practices in order to confirm to the expectations of others (*ibid*: 179); it explains how some groups exercise power and why others respond, and how resources (such as funding) or other reifications (ideas, approaches, approval) can be used to encourage some practices within a constellation and discourage others.

First, however, some of the communities that constitute the constellation of practice for research on educational communications and technology are identified.

Traditions of Research on Educational Communications and Technology

Educational communications and technology is a diverse field that has seen different traditions of work rise and fall over the decades. Saettler (1990) provides a thorough account of the emergence and development of traditions of work in this field, specifically in the USA, and explores how they were shaped by different theories (such as behaviorism and cognitivism), technological interests (such as educational television and radio), research interests (media studies, artificial intelligence, instructional design, etc.) and funding and administrative infrastructures. Hawkridge (2002) provides a perspective that contrasts the evolution of the field in the USA with developments elsewhere. He highlights points of divergence that he argues reflect differences in "attitudes towards science, including beliefs in objective reality and natural laws. Nor can these origins be separated from industrial and military uses of systems analysis to solve problems." His account describes work in Europe, and particularly in the UK, as drawing drawn more extensively on social and critical theory, even if the roots of the field were drawn from work in the USA. Friesen (2009) similarly distinguishes between a positivist, instrumental tradition of work, influenced by the concerns of the US military, and alternatives that he describes as practical (concerned with interpretation or meaning) and emancipatory (concerned with critiques of power and control).

Friesen argues further that the latter traditions have been relatively neglected within the field internationally, which instead has been oriented almost exclusively towards solving instrumental problems. He cites Koper's claim that "E-learning research is *technology oriented* instead of *theory oriented*" (Koper, 2008: 356), for example, as exemplifying a body of work that focuses solely on asking how to develop better instruments, whilst neglecting to ask why those instruments are being asked for or used. In terms of the discussion of relevance above, such instrumental work supports the objectives of researchers and some policy makers, but neglects the practical concerns of audiences such as teachers. It also fails to ask the political question of whether the objectives of particular groups are the right ones to support in the first place. He illustrates this with studies of areas such as peoples' experiences of Internet use or of using technology to support conceptual development in mathematics.

It is worth highlighting, however, that there are traditions of work that do address Friesen's practical interests. As already noted, applied action research has relevance to teachers, precisely because it addresses their practical concerns. The emerging body of work described as design-based research (Barab & Squire, 2002) could also be argued to fit this agenda. This work takes as its starting point the idea that context affects learning and cognition; it therefore seeks to bring together applied studies of implementation with the work of theory building. It might be argued that this work is also emancipatory, in that it brings participants into the analysis and production of design so that it recognizes their interests and expertise, rather than the research being "done to" them (*ibid*: 4); however, while it may modify the conventional relationship between designers and users during the project, this does not really address broader concerns about equity and participation, which critical theory focuses on. Studies adopting this approach have demonstrated its ability to improve designs so that they support student engagement and learning outcomes more effectively (e.g., Dede, Nelson, Jass Ketelhut, Clarke, & Bowman, 2004).

Fostering Relevant Research by Practitioners

As the preceding discussion has shown, practitioners such as teachers may be well placed to undertake applied, contextually relevant research—and indeed, some do; however, they are not typically well supported in doing so, nor are their contributions particularly valued (Oliver & Conole, 2003). Nonetheless such case studies have practical value; can be used to inform other research (for example, through a synthesis or review study); and can act as a first step towards fuller participation in the research field (In Wenger's terms, they can act as legitimate peripheral participation).

Nonetheless, the relevance of such studies is first and foremost to the practitioners who undertake the work, and those in very similar contexts. Several attempts have been made to try and intervene in such studies to increase their relevance to others, too—notably, practitioners in different contexts, but also to researchers. Studies of such interventions have shown the importance of recognizing and rewarding practitioners' research; however, the most important determinant of fostering a credible research output was whether the practitioner was able to work with more experienced staff who can advise on the empirical work and its interpretation, and support the process of preparing it for dissemination (Smith & Oliver, 2000).

Where such support is not available, structured processes have been shown to help when describing and sharing evidence. Work in the field of learning design, for example, focuses on the production of reifications of pedagogic practice; it is closely related to instructional design, but begins from a "ground up" documentation of current practice that are then formalized and refined, rather than a "top down" specification of practice as determined by a particular theory. As such, it is an area in which practitioner studies are of obvious value. To encourage attention to important pedagogic features and generate consistent representations of pedagogic practice, pedagogic planning tools have been developed, and their value to practitioners evaluated (San Diego et al., 2008). These "use current good practice to create and check the relationships between the different aspects of the user's input (e.g. balancing learners' resource and teaching time; linking topics, outcomes, methods, and assessments; supporting decisions on sequencing and scope of topics; testing designs based on pedagogical frameworks; providing exemplars and links to existing web-based resources)" (*ibid*: 21). Generating consistent and formalized representations of practice in this way, it is suggested, allows the development of are intended to support "a user-oriented analytical approach to learning design" (*ibid*: 24).

This provides a useful example of the way in which artifacts help to foster research, and in particular, research that is relevant to other groups. One problem predicted by a Community of Practice perspective is that meaning is determined locally: peers within the community judge the appropriateness of an interpretation or action. This results in variability in the way that any resource might be made sense of or worked with. Developing standardized representations of practice helps to mitigate this problem: with interactions between communities in a constellation of practice, different possible interpretations are discouraged, so that—in this case—practice can be represented and understood in more consistent ways. Meanings are aligned through the use of artifacts that cross the boundaries between separate communities, and research into local practice is made more relevant to the community that developed the representational scheme (and potentially, to other communities who also use it).

An illustration of this is provided by studies of the community that has grown up around use of Learning Activity Management System (LAMS). LAMS generates sharable representations of practice, the intention being that these can be used to make practice more motivating, effective or efficient by sharing and refining approaches to learning and teaching. It has been argued that LAMS should be used to support approaches such as action research, since it can help teaches to formalize, reflect upon and share their pedagogy by using the learning sequences LAMS produces "as a form capturing the pedagogy appropriate to [a] type of objective" (Laurillard, 2008: 150). However, while studies have shown that practitioners find the idea of sharing their practice appealing in principle, it has not been easy to achieve in practice; for example, one evaluation of LAMS use by teachers concluded that "while they recognised the importance of sharing their practice with others, technical and cultural barriers need to be overcome" (Masterman & Lee, 2005: 3).

Even if such barriers could be overcome, the use of standardized representations is no guarantee that communities will develop consistent, nor even compatible, understandings of particular forms of practice. As Falconer's study demonstrated (2007), sometimes it is impossible to create a single representation that allows meaningful discussions about learning and technology across different professional communities, and work needs to be done by people to support and repair interpretations. Just as representations can act as "boundary objects" that allow separate communities to coordinate their work (Wenger, 1998: 106), people act as "brokers," moving between communities and engaging in "processes of translation, coordination, and alignment between perspectives. It requires enough legitimacy to infuence the development of a practice, mobilize attention, and address conflicting interests [… and] the ability to link practices by facilitating transactions between them" (*ibid*: 108).

One example of such effort is provided by work in the area of pedagogic pattern languages (Mor, Winters, Cerulli, & Björk, 2006). This work involves the generation and application of "design patterns," abstractions that represent previous successful responses to problems. In spite of the potential for such representations to support practitioners as they design instructional experiences, they found it hard to make sense of patterns that they encountered, and all but impossible to generate patterns based on their own practice. However—as was found with the earlier study of factors supporting practitioner-researchers (Smith & Oliver, 2000)—when researchers worked with teachers in problem-oriented workshops, teachers were able to generate and share meaningful design patterns by deriving them from case studies of practice, because they were able to relate the unfamiliar processes and representations to the kinds of narrative case descriptions that teachers *were* able to produce (Winters & Mor, 2008). The resulting patterns could then be shared with other communities of teachers, but were also of interests to researchers studying practices of teaching with technology.

Closely linked to these processes are concerns about language. Studies have explored what kinds of representations are most helpful teachers in develop their educational practice. A consistent message from this work was the central importance of any intervention having an immediate and recognizable relevance to practitioners' contexts of practice, which must furthermore "take account of the language, values, culture and priorities of their particular community" (Sharpe & Oliver, 2007: 123).

This implies that the specialized, expressive forms of representation used by design experts are likely to be inaccessible to the practitioners they might wish to support or influence. Such terminology may well be seen as "jargon" (Falconer, 2007); indeed, Falconer's study shows that if practitioners are unable to engage with the forms of representation that are used, the descriptions of practice that are generated will probably be viewed as irrelevant and meaningless, no matter how principled the pedagogic design that they represent. The specialized forms of representation may well be necessary for the design and development community—but work will be needed to adapt these forms to new audiences and ensure that they are comprehensible.

Fostering Relevant Research by Researchers

Many of the issues that arise when supporting teachers and other practitioners also arise for researchers: practices need to be aligned, and common understanding developed. The mechanisms through which these processes operate tend to be different for communities of researchers however than for working with practitioners.

The artifacts that researchers use to align each other's practices typically include theories, models and concepts, expressed through publications. Citation can be seen as a way of demonstrating an appropriate alignment with others in order to claim legitimacy within a field (Millen, 1997). Patterns of citation are therefore useful markers of discrete traditions of work, delineating and differentiating communities of researchers. Czerniewicz's study (2010) of literature characterized as "educational technology" shows how diverse and fragmented this field is. Her analysis revealed no hegemonic traditions (although instructional design is widely drawn upon and has been advocated by some authors as a potential unifying perspective). Instead there is a broad array of positions, linked to many different disciplines.

Fostering relevant research, from this perspective, involves generating and sharing theories, methods, instruments or other resources that other researchers wish to use to advance their own work. The consequence of this is that "relevance" becomes performative (Lyotard, 1979), with the value of work determined by the way in which others take it up. Work can therefore be made more relevant by signposting its contributions as clearly as possible—a conventional requirement for academic writing—but also by demonstrating its pedigree through adoption of the language and processes that other researchers recognize as being authoritative. This has led to criticisms of publishing and peer reviewing processes as being conservative and restrictive (see, e.g., Weller, 2011). The conventional account, by contrast, would be that peer review serves to challenge and test ideas, introduce new literature to authors and also to try and eradicate the most divergent reinterpretations of texts and practices: in other words, its function is to educate and raise quality.

However, just as with representations for practitioners, there is no guarantee that producing a theory or artifact means that communities will engage with it, or align their work to an author's ideas. Studies of the way that people engage with theories and models (e.g., De Freitas, Oliver, Mee, & Mayes, 2008) show that they judge them in terms of their relevance and similarity to already-used representations; such recontextualization is rarely documented, however, so that the lessons learnt are not used to revise or develop the theories. Many opportunities to "talk back" to theory are simply not taken (Bennett & Oliver, 2011), missing the chance to improve the relevance of theories and models.

What counts as relevant research also varies in relation to the questions currently being posed by researchers. Different questions become important at different moments in the cycles of technology that Mayes (1995) described in the excerpt that opens this chapter. He noted at the time—and others since have observed (e.g., Alsop & Tompsett, 2007; Czerniewicz, 2010)—that when new technologies are developed, simple questions about the efficacy and role of technology need to be answered. This tends to generate a slew of "proof of concept" case studies that demonstrate the feasibility of its use in educational settings. However, the risk is that, by orienting to the new technology, such studies fail to connect to existing bodies of work tackling well-established problems and issues. In other words, such studies are relevant to short-term concerns at the expense of addressing longer-term concerns and issues; indeed the relevance to longer-term issues may not be at all obvious.

For example, recent work on personalization and adaptive e-learning requires the development of systems that can anticipate a user's needs and actions in a credible way—yet such work often proceeds without reference to decades' worth of prior research in areas such as student modeling (Mödritscher, García, & Gütl, 2004). As a consequence, it can be hard to see the relevance of such new work for these established issues, and this can contribute to the fragmentation of literature in the field. Without conceptual links to prior work or systematic procedures for moving beyond individual studies, there is a risk that work of this kind will be irrelevant to researchers and practitioners alike (Alsop & Tompsett, 2007)—if not immediately, then as soon as a newer technology becomes the problem of the moment instead.

Awareness of these cycles, and of the longer-term issues that they can hide, is important as a check to the short-term pressures of policy and research funding (Conole, Smith, & White, 2007). Researchers are far from being the only audience for research work; however, while policy makers, teachers, designers, and managers may all have an interest in research on educational communications and technology, not all are equally well placed to sponsor, support or otherwise foster relevant research. Few teachers, for example, have anything to offer researchers that would lead them to realign their research to serve the teacher's interests. Policy makers, however, are able to influence research, in no small part because they can control the flow of resources that researchers need to operate (Conole et al., 2007). Processes of tendering and contracting help to ensure that research remains relevant to the interests of funding bodies, who in turn may represent the interests of government, trustees of charitable bodies, the military, and so on. As already noted, Friesen's critique (2009) of work in the field shows how military concerns about closed systems shaped the research agendas they funded. Saettler (1990) also provides a history of the relationship between educational technology research, funding and policy bodies, looking for example at the effects of the National Science Foundation's investment in projects to demonstrate the effectiveness of computer-assisted learning. A similar analysis for the UK is provided by Conole et al. (2007), who conclude that "research has a tendency to follow policy directives and technological developments, rather than informing them" (*ibid*: 53). Clearly, policy makers have been more successful at aligning researcher's work to their interests than the other way around.

Conclusions

The notion of relevant research implies a sense of audience and interests, and frames research in a political context. It raises questions about which audience's interests will be served by the work, and how this will alter their relationships with others. Research on educational communications and technology, however, tends to focus on problem solving, and has been criticized for its instrumentalism; critical questions about the politics of research are rarely addressed in literature in this field.

Many of the techniques used to foster relevant research are familiar and mundane: processes such as funding, training and peer review are familiar across disciplines, and remain powerful influences in this field. However, there are also techniques that are relatively distinctive to this research. These include the use of tools, formalisms and representations to elicit, standardize and share practitioners' knowledge and practices, and participative processes that bring designers into contact with users.

Nonetheless, challenges remain. The cycles of hype, hope, and disappointment that Mayes (1995) described are set to persist, so long as researchers orient to technologies of the moment, rather than to more enduring concerns or theories. Concerns about contextualization mean that studies undertaken in one setting (the classroom, a laboratory) may be hard to make use of in another (the home, say). Research continues to be led by funding, rather than leading the policies that determine how funds are allocated.

It seems unlikely that any single development will solve all of these problems simultaneously. However, several practical implications do follow from this. First, there is the need to build connections between fragmented communities of researchers working in this broad field—an issue that is likely to recur each time a new technology becomes the focus for work. Since this cannot be avoided, what is needed are mechanisms that will encourage connections between the new research areas and established, longer-term concerns. Peer review, conferences, and publications are established mechanisms that should help in this respect; however, these have not stopped the problem to date. Ways of improving processes such as peer review should be considered, as they have been in other fields (e.g., Schroter et al., 2004). As Weller argues (2011), there is also value in pursuing new opportunities for interdisciplinary work, which would help ensure the relevance of research in education and communication technology to other areas of concern. Review articles should be encouraged so that separate bodies of research activity can be related, particularly where this can bring together work separated by divergent terminology rather than conceptual differences.

Secondly, further work is needed to help practitioners such as teachers to share principled accounts of their practice and knowledge, with each other and with researchers. Attempts to encourage this have met with mixed success; there is evidence that both tools (such as representational formats) and interventions (such as support, training, or workshops) can help support such activity. It would be prudent to view such activity as an expert task, and to adopt a scaffolded approach towards supporting it—something which may initially involve working in partnership with more able peers, whose time may need to be paid for through special initiatives or research project funding.

Thirdly, there is a need for awareness of the social processes through which research is produced and used, analogous to recent work exploring policy as a process (rather than understanding it purely in terms of produced texts; Ball, 2008). The emerging body of work in the field of digital scholarship represents one viewpoint on the processes of production; much of the field of library and information sciences might be viewed as another. However, work on digital scholarship often focuses on exceptional cases (e.g., Weller, 2011), while studies in library and information sciences are primarily restricted to sections of the process concerned with published texts. An agenda of work that brought together the scope of the digital scholarship research with an evidence base developed from the kinds used in library and information sciences may help document and develop these relatively unstudied processes.

The processes of research use, and particularly of the ways in which research outputs are taken up in practice, require different kinds of study, however. Here, ethnographic approaches have value in understanding how people make sense of new technologies, and what they mean to them (Friesen, 2009). Similarly, design-based research becomes important as a way of ensuring the mutually informed adaptation of technology and practice (Barab & Squire, 2002). Projects that aspire to change practice, or to improve learning outcomes in classrooms rather than purely under controlled conditions, would benefit from incorporating empirically grounded work that links studies of practice to processes of technology adaptation and adoption. Similarly, policy makers and funders may wish to consider encouraging different kinds of studies, perhaps along the lines suggested by Alsop and Tompsett (2007), who advocate moving from studies that demonstrate an effect, to studies of efficacy of use in controlled situations, and from there to studies of use in typical practice settings, followed by case studies intended to reveal and understand unintended side-effects. This kind of structured lab-to-classroom progression promises a better chance of establishing the relevance of interventions than is currently possible.

Developments such as these will enable researchers to make their work more useful and more relevant, to their peers as well as to others.

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Epilogue

J. Michael Spector, M. David Merrill, Jan Elen, and M.J. Bishop

In the foreword to this *Handbook* by Prof. Youqun Ren, the notion of a revolution in schooling predicted by Alfred Bork in 1987 is discussed. In spite of the remarkable progress in technology in the intervening years, the promised revolution has not occurred and does not yet appear imminent. There were overly optimistic advocates of educational technology, failure to follow through on the policy level with promising innovations, and other reasons for failing to radically transform learning and instruction. Prof. Ren cites four realizations that need to be considered in addressing the challenge of transforming learning and instruction with technology: (1) technological improvement does not directly translate into improved learning; (2) the same technology may perform differently in different contexts; (3) the continuing development of technologies exacerbates the shortage of teachers and instructional designers who can make effective use of those technologies; and (4) technological, pedagogical, and content knowledge on the part of teachers and designers is more important than ever.

Many chapters in this *Handbook* address these four points and the associated challenges, as suggested in the Foreword. Researchers are urged to conduct research in the area of educational communications and technology that will make real and lasting differences in educational practice around the globe. One way of framing how to go forward is to build on connections between theory and practice—specifically on bridging learning theories and technology-enhanced learning environments, as suggested in Prof. Joost Lowyck's first chapter in this *Handbook*.

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Prof. Lowyck began Chap. 1 with the same interest in improving learning and instruction that Prof. Ren discussed; Lowyck also regards the emphasis on systematically and systemically improving learning as fundamental to the educational technology enterprise. Lowyck critically examined the history of efforts to bridge learning theory and technology-enhanced learning environments and developed five observations that we wish to take up in the remainder of this epilogue: (1) changes in society and educational practice influence the selection and use of learning theories and supportive technologies; (2) learning theories and associated technologies exist within a vague and not so well articulated conceptual framework; (3) learning theories and educational technologies are connected to how people process information and acquire expertise; (4) control in learning situations has shifted from system/teacher control to learner and shared/distributed control; and (5) learning theories and findings have been transformed into a fuzzy array of principles and applications that seldom contribute to the science of education and a close connection between theory and practice. We briefly continue the discussion that Prof. Lowyck began in Chap. 1 in the following sections.

Change and a Conceptual Framework (Spector)

While all five of Lowyck's observations are interrelated, the first two are linked quite closely. Significant changes have occurred in society and educational practice in recent years and these will surely continue, although the major shifts to in both society and practice appear to be linked with increasing emphasis on issues centering around empowerment—empowerment of disadvantaged segments of society and empowerment of individual learners. The latter has led to a somewhat vague conceptual framework guiding the development of instructional systems and learning environments. Perhaps the most clearly articulated conceptual framework for learning and instruction, and one that has theoretical foundations and empirical support, and that cuts across

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instructional design and the learning sciences is cognitive apprenticeship (Collins, Brown, & Newman, 1989). One could argue that most of the successful learning environments developed since then have been a variation of cognitive apprenticeship. Many other conceptual frameworks published since cognitive apprenticeship appeared acknowledge direct links to that early conceptual framework (see, for example, Milrad, Spector, & Davidsen, 2003; Seel, 2003).

The extent to which cognitive apprenticeship has been embraced by the instructional design and learning sciences communities is a topic worth investigating. If that framework is as widely adopted in one form or another, then it might become an explicit bridge across the troubled waters that separate various instructional and learning theorists and practitioners. However, the tendency toward developing apparently new theories, frameworks, and models needs to be addressed. The not-invented-here syndrome that Lowyck identified may account for much of the apparent and arbitrary separation of researchers and practitioners working to improve learning and instruction.

Presumably a shared goal is to develop a body of cumulative knowledge and refined theories, frameworks, and models to inform the planning, implementation, activation, evaluation, and management of learning and instructional systems. We want to do this so as to improve learning and instruction. However, the research to support this goal and overarching aim needs to be conducted in a variety of contexts, some of which involve actual classrooms, some of which involve design and development teams, some of which involve targeted studies of micro-interventions and so on. Carrying out one kind of study within such a wide array of possibilities should be acknowledged by others as contributing to a common set of research objectives aimed at better understanding learning so as to improve learning and instruction. All too often, there is a tendency to believe that the one niche one happens to be currently pursuing is more important than any of the other niches in which one might conduct a study and make a contribution.

Finally, whatever conceptual frameworks evolve in the future, it is likely that there will be some vagueness and openness. Learning is not a monolithic process or discrete activity that can be captured by a few variables that generalize across all possible scenarios and situations. Learning is complex. Learning is something that occurs naturally but also something that can occur with effort or even against one's own intentions. Some people used to say that a good teacher can *cause* learning to happen. The current mantra appears to be that a good teacher is one who can *allow* learning to happen. While each of these views has links to a theoretical framework (the former being linked to behaviorism and the latter being linked to socio-constructivism), neither seems fully satisfying. While learning is inherently complex, teaching is, as a result, even more complex, given the variety of learners and learning tasks involved. It seems, then, that there is much yet to be done to elaborate meaningful and compelling frameworks to guide the development of learning environments and instructional systems.

Information Processing and Knowledge Acquisition (Bishop)

Among the observations Prof. Lowyck made regarding what occurs at the intersection of learning theory and educational technology, he posited that learning theories and technology are connected by our foundational understandings of information processing and knowledge acquisition. Lowyck argued that, as our underlying epistemologies have shifted from objectivism to constructivism, so too have our views on how learners acquire, organize, and synthesize information as well as our perspectives on what tools and strategies will best optimize those processes. To demonstrate these connections, this section of Lowyck's chapter traced the evolution of thinking in the field about knowledge acquisition and the concomitant instructional technology developments from behaviorism through early cognitive theory and into constructivism and socio-constructivist theory. The merit of any instructional technology, Lowyck concluded at the end of this section, is defined by that tool's link with our understandings of underlying cognitive processes.

Clearly our perspectives on the nature of cognitive processes have had a profound effect on the design, development, integration, and implementation of technology for learning over the years (for a complete review, see Richey, Klein, & Tracey, 2011). In fact, many of the chapters in this *Handbook* reflect this connection between learning theory and instructional technology by opening with an introductory section that identifies some educational need with the intent of demonstrating how the proposed technology (whether mechanical/electronic or the application of scientific principles and theoretical knowledge) will support learners' cognitive processing in one way or another. However, while it appears this has at least been nominally true, in practical application the strength of the connection between instructional technologies and current understandings about knowledge acquisition within the sociocultural constructivist perspective may be more tenuous than we would like to think.

As Lowyck noted, technologies embedded in a sociocultural constructivist perspective must provide the interactive, adaptive tools learners need in order to have their own voice in the *instructional conversation*. But the instant an instructional designer makes his first decision within this learning context about the problem for study, the examples and/or artifacts to be used, the look and feel of the interface, the delivery platform, the nature of feedback to be offered, or even the way in which the learner physically interacts with the technology, he imposes something of his own understanding, culture, and general sense of the way things are into the learning environment—and, to some degree, circumvents the learner's own knowledge construction processes. As Wilson (2005) contended, "the capturing, packaging, and presentation of expertise is more than a technical matter—it says something about how we see knowledge, whether in embodied or transcendent terms" (p. 13).

Obviously a communication source (in this case the instructional designer) must encode messages in *some* way in order for them to be sent over a channel to the receiver (the learner); this is an inevitability of human communication that cannot be avoided. However, as Subramony (2004) argued we are too often "ignorant of the hidden assumptions and strong cultural values that accompany our work, and are consequently failing to take on the social responsibility of making this self-evident to our audience and clients" (p. 21, citing a personal communication with Schwen, 2003). Technologies built around our understandings of knowledge acquisition within a socio-constructivist framework require that we become more aware of these "moral dimensions" of instructional interactions and begin findings ways to evaluate our designs more systematically around these issues (Thomas, Mitchell, & Joseph, 2002). Osguthorpe, Osguthorpe, Jacob, and Davies (2003) concluded that, until we become more critical of the way we conduct and view our designs in relation to those who will use our products, we will continue to inadequately address the instructional needs of certain segments of the intended audience for our work.

At the same time there has also been growing recognition that—in addition to cognitive processes—emotions play a critical role in human learning as well (Pekrun, 2011; see all the chapters by Kim and Pekrun herein). It is increasingly clear that emotion or *affect* impacts knowledge acquisition in terms of the overall climate of the learning environment itself (how welcomed and safe the learner feels within the learning context), the learner's predispositions about the content under study (how interested and confident the learner feels going into the learning task), and the dynamic affective states the learner undergoes throughout the experience (failure/success, boredom/engagement, frustration, and the like). Graesser and D'Mello (2011) observed, "in fact, the inextricable link between affect and cognition is sufficiently compelling that some claim the scientific distinction between emotion and cognition to be artificial, arbitrary, and of limited value" (p. 12; see also Bickhard, 2003). Still others have suggested that this shift in our thinking about knowledge acquisition requires an even more fundamental shift in the very outcomes we are hoping to achieve as well. Goodyear (2011) argued

> In scoping the field of learning, technology, and affect, it would be a great mistake to focus on taken-for-granted but obsolescent educational goals and processes. Optimizing instruction for nineteenth-century outcomes is not the direction in which we should be heading (p. 244).

In light of these next steps in the evolution of our thinking about knowledge acquisition and the ways in which learning theory and instructional technologies are connected by this understanding, Wilson (2005) has suggested we take a broader view of instructional design research that extends our "pillars of practice" beyond individual cognition/behavior and social/cultural learning to include the "often neglected aspects of design, particularly the moral and value layers of meaning, and the aesthetic side of our work" (p. 15). While some of the chapters in this *Handbook* edition help to further frame this discussion, we are only just beginning to scratch the surface of the direct implications that values and affect should have on our thinking about the design, use, and evaluation of instructional technologies within a socio-constructivist paradigm. Let's hope that, between now and the 5th edition of the *Handbook*, there will be much more to discuss in these areas of inquiry.

Control Within Learning Environments (Merrill)

In Chap. 1 Lowyck summarizes the developments on control within learning environments with the following important conclusion: "The advent of cognitive and (socio-) constructivist approaches shifted the focus from program control to learner and shared control." He then qualifies this development with the following statements: "Learner support in technology rich environments is crucial for learning. … The expectation that open-ended learning environments in and of themselves would result in learning is questionable." These qualifications suggest that some form of direct instruction and guidance is necessary if learning from learner-centered in open learning environments is to be effective.

Several chapters in this *Handbook* address the issue of control in more learner-centered learning environments, as the following examples indicate. Brand-Gruwel, Kester, Kickken, and Kirschner reinforce Lowyck's observation that learners who are self-directed with knowledge about the structure of the domain may benefit, whereas those who lack these characteristics have difficulty learning from open-learning environments. Their chapter discusses approaches for helping learners acquire the necessary self-direction to profit from more open learning environments. Herrington, Reeves, and Oliver emphasize that learning is better in the context of real-world problems. Goodyear, Jones, and Thompson review many approaches for promoting learner collaboration and critique. Seel emphasizes the need for learning environments to promote the learner's development of appropriate mental models.

In spite of the research efforts reported in this *Handbook*, much instruction in training and education still relies on some form of tutorial instructional design in which an instructional system provides a considerable amount of direct instruction and significant guidance in solving problems. For more than three decades and again in 2010 the most widely used textbook for instructional design, which describes the design of primarily direct instruction, is *The Systematic Design of Instruction* by Dick, Carey, and Carey (2009) (see Johnson, Xue, Mackal, & Reiser, 2012). When an organization is faced with the need to enable their trainees to acquire specific skills, it is far more likely to rely on direct instruction than on any of the forms of learner-centered approaches described in the chapters of this *Handbook*.

Van Merriënboer and Kirschner's *Ten Steps to Complex Learning* (2012) and Merrill's *First Principles of Instruction* (2012) suggest a middle ground approach that integrates the best of problem-based learning, learner collaboration, and tutorial instruction. van Merriënboer and Kirschner (2012) suggest a systematic, four-component approach to instructional design that also attempts to integrate a problem-centered approach with more direct instruction. They suggest four training blueprints: (a) [whole] learning tasks, (b) supporting information, (c) procedural information, and (d) part-task practice. Learning is in the context of an easy-to-difficult sequence of authentic, real-world, whole tasks. Supportive information helps learners acquire the problem-solving skills for performing the tasks and relate this information to what they already know. Procedural information helps learners perform the task and is gradually faded as learners gain experience with the task. Part-task practice enables learners to automate routine aspects of task performance. The authors also describe how self-directed learning activities can be incorporated into their four-component approach.

Merrill's *First Principles of Instruction* (2012) suggests that effective instruction consists of four instructional phases: (a) activation, (b) demonstration, (c) application, and (d) integration. This model further suggests that effective instruction is problem-centered; that is, learners best acquire problem-solving skills in the context of a progression of real-world problems. *First Principles* suggests a problem-centered approach that first demonstrates the solution for an instance of a problem to be solved or a task to be completed. This approach then provides demonstration and guided application for the component skills required for the solution of the problem or the completion of the task in the context of a progression of increasingly complex instances of the problem or task. It concludes with learners engaged in solving additional instances of the problem or completing additional instances of the task.

Merrill and Gilbert (2008) suggest that peer interaction is best in the context of solving real-world problems or completing real-world tasks. They suggest that peer sharing of related experience is most appropriate for activation of previously acquired mental models that are appropriate for acquiring the desired problem-solving skills; peer discussion is appropriate during demonstration of problem solving; peer collaboration is appropriate during application of component skills to the solution of a problem; and, peer critique is appropriate for integration of the problem-solving skills into the repertoire of the learner. The *First Principles* approach integrates these forms of peer interaction into the problem progression instructional sequence by: (a) providing a peer sharing activation experience prior to demonstrating a solution of the problem; (b) providing opportunity for peer discussion during the demonstration of one or more instances of the problem; (c) engaging learners in problem-solving collaboration during the application of component skills to the solution of problems in the sequence; and (d) involving learners in peer critique of the problem-solving efforts of their fellow learners. *First Principles* promotes model building by helping learners activate an existing mental model or providing a structural framework that can be used to develop an appropriate mental model; *First Principles* provides guided demonstration and practice in the context of a progression of real-world problems; and, *First Principles* integrates peer collaboration and critique into the instructional sequence.

Merrill (2012) and van Merriënboer and Kirschner (2012) represent two attempts to combine problem-centered, learner-centered, and guided direct instruction into an integrated approach. It is hoped that before the next *Handbook of Research* is published that there will be more work on integrating the various approaches described in this edition into instructional design models that capitalize on the strengths of the different approaches described herein.

A Fuzzy Array of Principles and Applications (Elen)

Lowyck in Chap. 1 uses the following metaphor to describe the evolution of the theoretical nature of our field: "the former theories resemble rivers flowing in a riverbed while the latter show a delta structure where the river spreads out in a fan shape into many channels." While not everybody may totally agree with the metaphor nor the interpretation Lowyck provides of it, the metaphor clearly illustrates that in our current reflections multiple perspectives, complexity, and diversity are fully acknowledged. Different chapters in this *Handbook* clearly illustrate this: there is no methodological preference, the (contextual functionality and value) of qualitative and quantitative methods is recognized; the importance of more domain-specific considerations with respect to instructional strategies is fully recognized, and with new technologies, tools, or toys "new" lines of research are opened. While valuable in its own right this whole movement also results in a very dispersed field open to all types of evolutions and perspectives, characterized by diversity and—luckily—mutual respect. The backside of this evolution might be that we end up with a large set of small nuclei all working very hard on their tiny little problem, with their very particular technology, from their very idiosyncratic perspective. The danger does not seem to reside in the recognition of complexity and diversity; rather, it seems to reside in the absence of critical discussion between these nuclei, the absence of challenging questions about why new meanings are given to solid terms, what the relevance is of investigating a well-known principle simply because a "new" technology is on the market. The danger may reside in too much disengaged respect and not enough engaged criticism. Organizations like AECT (Association for Educational Communications and Technology), initiatives like this *Handbook*, and the Springer series entitled "Explorations in the Learning Sciences, Instructional Systems and Performance Technologies" (edited by J. M. Spector and S. P. Lajoie) may help to counter these dangers.

While Lowyck may sound a bit pessimistic, different contributions in the Handbook also reveal that attempts are being made to overcome the problems and to work towards a new basic understanding, theoretically sound and empirically at least verifiable. Work of Merrill on the first principles (2001, 2012), of Jonassen on different types of problem solving (2011), of Hannafin and colleagues on open learning environments (Hannafin, Land, & Oliver, 1999), and of van Merriënboer and Kirschner on a complex learning design model are simple examples. In all these cases efforts are being made to identify interrelated, theoretically sound principles for which empirical evidence can also be provided. It is to be acknowledged that all these kinds of efforts remain at a more general level and hence to some extent abstract. But getting to a theory that is at the same time applicable in a wide variety of settings, considers a complex amalgam of variables, while also being very detailed and concrete is impossible. That is simply not what a theory is about. Any general instructional theory will need to be translated to a specific context, and will be usable and testable only after operationalization.

The development of solid instructional theories is a challenge for the years to come. It will require reconciliation of perspectives, basic agreements on what the goal of an instructional theory should be, on how different instructional goals can be described, on what learner characteristics are relevant, on how differentiation in context gets understood. All of this requires that we understand very well that a learning theory is not an instructional theory, nor is an instructional theory a learning theory, as repeatedly argued by Mayer (2010), Reigeluth (1983), and others.

We expect that at least two emerging approaches will challenge both current learning theories and current instructional theories and hence also their interrelationships. The first challenge will come from evolutions in neuro-psychogological and neuro-pedagogical research. Our understanding of the functioning of the brain will question our current conceptualizations and help us to derive learning principles that are even more closely linked to the way we think and learn. The second evolution relates to increasing possibilities to document what learners actually learn while learning and studying. The need to rely on what learners think they have done, how much mental effort learners report to have engaged in is gradually diminishing. We will be better able to acknowledge that learning and talking about learning are two behaviors that each require to be explained in their own right. Let's hope that these new evolutions challenge us enough to open up our nuclei and start discussing about really important and relevant instructional principles.

Concluding Remarks

This *Handbook* has taken 3 years to develop. It may take a dedicated educational technology researcher another 3 years to work through all of the knowledge represented and referred to in these pages. About the time that task is completed, the next edition of this *Handbook* may be available. Just as the task of conducting research and development to improve learning and instruction is never-ending, the task of understanding that body of knowledge and then applying it to improve learning and performance is never-ending. It is our hope that this *Handbook* makes a meaningful contribution to such efforts.

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Her background in practice encompasses studio art, visual and interface design for instructional media, and management of interactive products for Apple Computer. She has taught instructional design and development at Indiana University for 18 years, served as Editor-in Chief for *TechTrends* and is currently the editor of *International Journal of Designs for Learning*.

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Research in Child Development (SRCD, 2009) Early Career Award, and the Richard Snow Award (APA, 2008), her research has been and is currently funded by the US Department of Education, Institute for Education Sciences and the National Institute for Child Health and Human Development. Most recently she is investigating the classroom learning environment for children with learning disabilities and instruction to improve reading for understanding. She also conducts research focusing on the language and literacy development of profoundly deaf children including those who use cochlear implants.

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Fletcher, J. D., Tobias, S., & Wisher, R. L. (2007). Learning anytime, anywhere: Advanced distributed learning and the changing face of education. *Educational Researcher, 36(2)*, 96–102.

Fletcher, J. D., & Morrison, J. E. (2008). Representing cognition in games and simulations. In E. L. Baker, J. Dickieson, W. Wulfeck, & H. O'Neil (Eds.), *Assessment of problem solving using simulations* (pp. 107–137). Mahwah, NJ: Lawrence Erlbaum.

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Linda Gilbert has been presenting and training on qualitative data analysis software since 1998. Dr. Gilbert received her Ph.D. in Instructional Technology from the University of Georgia in 1999, where she studied the use of qualitative data analysis programs by researchers who had experience working manually and with qualitative data analysis software for her dissertation work (*Reflections of qualitative researchers on the use of qualitative data analysis software: An activity theory perspective*). She was an invited keynote speaker at the Third Conference on Strategies in Qualitative Research: Methodological issues and practices in using QSR NVivo and NUD*IST, held at the University of London, Institute of Education in 2002. Her research interests involve the ways in which people use computers for higher-level creative and intellectual tasks, activity theory, and qualitative research methodology and practice.

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Susan R. Goldman, (Ph.D., University of Pittsburgh) is Distinguished Professor of Liberal Arts and Sciences, Psychology, and Education and Codirector of the Learning Sciences Research Institute at the University of Illinois at Chicago. She conducts research on subject matter learning, instruction, assessment, and roles for technology, especially in literacy and mathematics. A particular focus of her current research is on understanding the literacy demands in different disciplinary contexts and the implications of these demands for supporting learning. She is pursuing this work in the context of a recently funded major initiative of the Institute for Education Sciences, U. S. Department of Education, *Reading for Understanding Across Grades 6 through 12: Evidence-Based Argumentation for Disciplinary Learning*. As Principal Investigator for this grant, she is coordinating a research and development collaboration among five institutions (University of Illinois at Chicago, Northern Illinois University, Northwestern University, WestEd, and Inquirium LLC) and several school districts. They are researching the processes, instructional practices, and materials needed to support evidence-based argumentation from multiple sources in literature, history, and science across grades 6–12. In other work, Goldman is focusing on the language demands of ninth grade algebra. In the assessment area, she is developing Web-based tools for measuring digital literacy skills, including selection, analysis, and synthesis of multiple information sources in the context of inquiry tasks. She is also examining the cognitive, psychometric, and instructional validity of embedded assessments in two standards-based mathematics curriculum. She collaborates with educational practitioners to bridge research and practice, and has recently completed a project that focused on building capacity for high quality teaching and student learning in literacy in K-8 schools. She has developed and researched several technology-based environments for learning and assessment, including the mathematics problem-solving series *The Adventures of Jasper Woodbury,* and *The Little Planet Literacy Series.* Goldman is widely published in discourse, psychology, and education journals. Her contributions have been recognized by election to the National Academy of Education, being named a Fellow of the American Educational Research Association and of the Society for Text and Discourse, and selection as the Inaugural Outstanding Alumnus of the Learning Research and Development Center. Goldman serves the field through a number of editorial appointments, including serving as Executive Editor for *Cognition & Instruction* and Associate Editor for *Journal of Educational Psychology.* She is on the editorial board of *Reading Research Quarterly, Journal of the Learning Sciences,* and *Educational Psychologist.* Goldman is a board member and President of the International Society of the Learning Sciences (2011–2012), served as President of the Society for Text and Discourse (2000–2007), and Vice-President for Division C of the American Educational Research Association (2000–2002).

Peter Goodyear is Professor of Education and codirector of the CoCo research center at the University of Sydney. He is a Senior Fellow of the Australian Learning and Teaching Council and an Australian Research Council Laureate Fellow. His research interests include: methods and tools for the design of complex learning environments; computer-supported collaborative learning (networked learning); the nature of professional knowledge and professional learning; teachers' professional knowledge. He has been using online methods for collaborative professional learning and innovation for over 20 years—in the UK and Europe as well as Australia. He has extensive experience of managing large-scale evaluation projects. His latest books (2010) are *Students' experiences of e-learning in higher education: the ecology of sustainable innovation* (Routledge, with Rob Ellis) and *Technology-enhanced learning: design patterns and pattern languages* (Sense Publishers, with Simeon Retalis). He edits the journal *Instructional Science* and is a member of the executive of the Australian Association for Research in Education.

Erik de Graaff (Ph.D.). Professor in Engineering Education and PBL at Aalborg University, Associate Professor in Engineering Education at TU Delft

Erik de Graaff is trained as psychologist and holds a Ph.D. in social sciences. He has been working with Problem-Based learning (PBL) in Maastricht from 1979 till 1980. In 1994 he was appointed as associate professor in the field of educational innovation at the Faculty of Technology Policy and Management of Delft University of Technology. Dr. de Graaff has been a visiting professor at the University of Newcastle, Australia in 1995 and a guest professor at Aalborg University in Denmark. In 2007 he was appointed as extraordinary professor at Aalborg University. The collaboration with Aalborg University resulted in an appointment as full professor at the department of Development and Planning in 2011. Dr. de Graaff contributed to the promotion of knowledge and understanding of higher engineering education with numerous publications and through participation in professional organizations like SEFI, IFEES and ALE. He has published over 200 articles and papers and he has presented more than 50 keynotes and invited lectures. Since January 2008 he is Editor-in-Chief of the European Journal of Engineering Education.

Dr. Grabowski is Professor of Education in the Instructional Systems Program, College of Education at Penn State University. She is a former president of the International Board of Standards for Training, Performance, and Instruction (ibstpi) and current ibstpi fellow. She has also held an academic appointment at the University of Maryland School of Medicine and Syracuse University. In between academic appointments, she worked at the University of Maryland University College where she designed, developed and evaluated a premier distance education program for nuclear reactor operators, and designed multimedia materials for industry, the military, and medical environments. She has been nationally and internationally recognized for the innovative programs she designed and developed over the years. She has also received two outstanding book awards from the Association for Educational Communications and Technology, has published widely, and has been an invited keynote speaker on four continents. Her research over the years has focused on pedagogical uses of emerging technologies, with a special emphasis on online teaching and learning for K-12, college, and adult learners.

Sabine Graf has a Ph.D. from Vienna University of Technology, Austria, and is presently an Assistant Professor at Athabasca University, School of Computing and Information Systems, in Canada. Her research expertise and interests include adaptive and personalized learning systems, student modeling, ubiquitous and mobile learning, artificial intelligence, and collaborative learning technologies. She has published more than 80 peer-reviewed journal papers, book chapters, and conference papers in these areas, of which three conference papers were awarded with a best paper award. Dr. Graf is Executive Board Member of the IEEE Technical Committee on Learning Technologies, Editor of the Learning Technology Newsletter, a publication of the IEEE Computer Society's Technical Committee on Learning Technology (TCLT), and Associate Editor of the International Journal of Interaction Design and Architectures. She is an active member of the research community, serving as editorial board member of three international journals, workshop chair and organizer of eight international workshops, doctoral consortium chair at three international conferences, and guest editor of three special issues. Dr. Graf has been invited to given keynote/invited talks at universities/companies/conferences in Austria, Canada, Colombia, New Zealand, Taiwan, and UK.

Charles R. Graham is an associate professor in the Department of Instructional Psychology and Technology at Brigham Young University, with interest in technology-mediated teaching and learning. Charles studies the design and evaluation of online and blended learning environments and the use of technology to enhance teaching and learning. He has authored articles in many journals, including *Quarterly Review of Distance Education*, *Educause Quarterly*, *Small Group Research*, *Educational Technology*, *TechTrends*, *Educational Technology Research & Development*, *Active Learning in Higher Education*, *Journal of Computing in Teacher Education, Computers in the Schools* and the *International Journal of Instructional Technology and Distance Learning*. Charles has also published work related to online and blended learning environments in edited books including *Online Collaborative Learning: Theory and Practice*; *Blended Learning: Research Perspectives*; *The Encyclopedia of Distance Learning*; and the *AECT Handbook of Research on Educational Communications and Technology.* Charles also coedited the *Handbook of Blended Learning: Global Perspectives, Local Designs,* which contains 39 chapters with examples of blended learning in higher education, corporate, and military contexts from around the world.

Dr. Green, a former K-12 teacher, is a Professor in the Department of Elementary and Bilingual Education at California State University, Fullerton where he specializes in educational technology. His degree is in Instructional Systems Technology from Indiana University. He has written and presented in the areas of integrating educational technology in teaching at learning in K-12 and higher education, instructional design, and online distance education. He is the coauthor of *The Essentials of Instructional Design: Connecting Fundamental Principles with Process and Practice (2nd Edition).* He is a contributing editor for *The Social Studies*.

Brian Greer studied mathematics at Cambridge University (B.A., 1966) and then education and psychology at Queen's University, Belfast (M.Sc. in Developmental and Educational Psychology, 1969, Ph.D. in Psychology, 1973). He worked in the School of Psychology at Queen's University till 2000, advancing to the position of Reader. From 2000 to 2005 he was a Full Professor in the School of Mathematical Sciences at San Diego State University, before moving to Portland, Oregon, where he continues to work as an independent scholar, often closely in collaboration with his wife, Swapna Mukhopadhyay. As part of a fruitful long-term collaboration with Lieven Verschaffel and others, he was a Senior Visiting Fellow at University of Leuven in 2005 and 2007.

His work evolved from a general interest in the psychology of mathematical cognition to a more practice-oriented interest in mathematics education, to an interest in the social, cultural, and political aspects of mathematics education. These phases are exemplified, respectively, in three of his books: *Analysis of Structural Learning* (with M. A, Jeeves, 1983, Academic Press), *Making Sense of Word Problems* (with L. Verschaffel and E. De Corte, 2000, Swetz & Zeitlinger), and *Opening the Cage? Critique and Politics of Mathematics Education* (edited with O. Skovsmose, in press, Sense Publishers). During the first phase (1973–1983), his main interests were in structural learning and in the relationships between cognitive and developmental psychology and mathematics education. During the second phase (1983–1996), he worked on multiplicative structures, mathematical modeling, probability and statistics, and word problems. Since 1996, his work has focused on critical mathematics education, with a continuing interest in the relationships between psychology and mathematics education.

Silvana di Gregorio received her Ph.D. in social policy from the London School of Economics in 1986. She has worked in several applied research settings in the UK. As Director of Graduate Research Training at Cranfield School of Management during the 1990s, she developed her interest in methodological issues relating to CAQDAS. In 1996 she set up SdG Associates focusing on consulting and teaching on a range of packages that support qualitative analysis. She is coauthor with Judith Davidson of *Qualitative Research Design for Software Users* (2008) which addresses both methodological and practical issues related to working with CAQDAS packages. She is currently exploring the use of Web 2.0 tools to support the analysis of qualitative data.

Jennifer Hamilton, Ph.D. is a Senior Study Director at Westat. She has more than 17 years of experience in program evaluation and applied research, and has directed numerous multisite evaluations and research projects involving at-risk children and youth. She currently serves on the Board of Directors of the Eastern Evaluation Research Society. With her educational background in applied statistics, Dr. Hamilton's current research interests focus on evaluation methodology, with a focus on experimental and quasi-experimental designs. She has written and presented on a number of topics including power estimation, missing data imputation, fidelity of implementation, logic models, and randomized designs.

Michael Hannafin earned his Ph.D. in Educational Technology from Arizona State University, and has since held academic positions at the University of Colorado, The Pennsylvania State University, and Florida State University. Currently, he is the Charles H. Wheatley-Georgia Research Alliance Eminent Scholar in Technology-Enhanced Learning and Professor in the Department of Educational Psychology and Instructional Technology at the University of Georgia (UGA) where he directs the Learning and Performance Support Laboratory—an R&D organization that studies the potential for and impact of emerging technologies for teaching and learning. His current research focuses on the study of technology-enhanced teaching and learning environments—especially those that are open and student-centered in nature.

Phillip Harris is executive director of the Association for Educational Communications and Technology. He previously was Director of the Center for Professional Development at Phi Delta Kappa International, the association for professional educators, and was a member of the faculty of Indiana University for 22 years, serving in both the Department of Psychology and the School of Education.

Dr. Jan Herrington is Professor of Education at Murdoch University in Perth. The last 25 years of her professional life have been devoted to the promotion and support of the effective use of educational technologies in learning in schools and universities. Jan's recent research focuses on mobile learning, authentic learning, and the use of authentic tasks as a central focus for e-learning courses. She has published many journal articles, conference papers and chapters, and several books including a coedited book entitled *Authentic Learning in Higher Education* (with Anthony Herrington) and a coauthored book in 2010 (with Thomas C Reeves and Ron Oliver) *A Guide to Authentic e-Learning*, winner of the Association for Educational Communication and Technology (AECT) Outstanding Book of the Year Award. She was a Fulbright Scholar in 2002 at the University of Georgia, USA, and has won awards for her research including the AECT Young Researcher Award.

Janette Hill earned her Ph.D. in Instructional Systems Design from Florida State University, and has since held academic positions at the University of Northern Colorado and Georgia State University. Currently, she is a faculty member in the Department of Lifelong Education, Administration, and Policy at the University of Georgia (UGA) where she also serves as Department Head. Her current research focuses on the study of emerging/Web-based technologies, community building in virtual environments, resource-based learning, and information/knowledge management systems.

Dr. Ellen S. Hoffman is a Professor and Chair of the Department of Educational Technology in the College of Education at the University of Hawai'i-Mānoa, the state's only research-intensive university located in Honolulu. She teaches graduate and undergraduate courses on campus and online. Courses include research and evaluation methods, foundations of instructional design, advanced doctoral seminars, and emerging technologies for teachers. Her research has focused on research methods in educational technology, technology policy, distance education, digital libraries in schools, information literacy, usability of networked information systems, and systemic change at the K-12 and higher education levels. She has served as an administrator in academic computing, as a consultant for the Michigan Department of Education, and worked as a technology coordinator and computer teacher at a private elementary school. She is an Internet pioneer who worked on the NSFNET project from 1987 to 1995 and served as the Director of User Services, Learning Technologies, Eastern Michigan University, from 1995 to 1998. Her background is in anthropological archaeology and journalism. She earned her undergraduate and master's degrees from the University of Michigan and a doctorate in Educational Leadership from Eastern Michigan University. Her publications include articles in *TechTrends*, *Educational Technology and Media Yearbook*, *School Library Media Research,* and *Computers in the Schools.*

Dr. Hsu is Assistant Professor of Educational Technology at Boise State University. He earned his Ph.D. in Instructional Systems with a doctoral minor in Educational Psychology from the Pennsylvania State University. He also holds two degrees of EdM in TESOL and Education and Technology from SUNY at Buffalo. His research interests include learning and instruction innovation through emerging technologies, cognitive and metacognitive processes of integrating multiple representations in STEM fields, and collaborative learning. He has been selected as one of the mLearning Scholars of Boise State University in both 2011 and 2012 for integrating and studying mobile learning and Web 2.0 technologies in his class. He also teaches graduate courses on research method, graphic design for learning, mobile app design, and emerging trends in Educational Technology.

Dr. Ifenthaler's research interests focus on the learning-dependent progression of mental models, complex problem solving, decision making, situational awareness, game-based learning, and emotions. He developed automated and computer-based methodologies for the assessment and analysis of graphical and natural language representations (SMD Technology, HIMATT, AKOVIA). Additionally, he developed components of course management software and an educational simulation games (DIVOSA, SEsim). He is also interested in the development of educational software and learning management systems (LMS) as well as technology integration into the classroom. Dr. Ifenthaler has published multiple books and book chapters as well as numerous articles in leading journals of the field. Dr. Ifenthaler is the current Fulbright Scholar-In-Residence at the Jeannine Rainbolt College of Education, University of Oklahoma.

Kristi Jackson began using qualitative data analysis software in 1993, became an expert and trainer of one of the leading software packages in 1996, and started her own company using the software and coaching other researchers on the methodological implications of software use in 2002. She spends a third of her time collecting data for evaluation research projects (primarily in education), a third of her time using NVivo to analyze data, and a third of her time consulting with other researchers. From NVivo versions 2 through 8, the sample data that accompanied the software was based on her analysis. Many of her conference presentations and published papers discuss the implications of the growing importance of qualitative data analysis software, and she is recognized as one of the international leaders in this area. Her article on "Blending technology and methodology: A shift toward creative instruction of qualitative methods with NVivo" (*Qualitative Research Journal*, 2003) was one of the first, detailed examinations of how to incorporate software into graduate-level qualitative methods courses. She was a principal organizer of the Technology in Qualitative Methods day at the International Congress on Qualitative Inquiry (May, 2008), and she is frequently invited as a speaker in the area of Qualitative Data Analysis software and qualitative methods. Her current research interests include conceptualizations of "transparency" in the qualitative research process by researchers who use Qualitative Data Analysis software, as well as those who do not.

Lai Jiang is a researcher and coordinator in the Institute of Tropical Medicine, Antwerp. She received her Ph.D. at the University of Leuven. Her research deals with the effects of support in learning environments. A particular point of interest relates to learners' use of scaffolds/tools in computer-based environments. She has an expertise in the analysis of data to look deeply into the students' cognitive operations of different tools/scaffolds. Her research is devoted to gain an in-depth understanding on the comprehensive interactions between learner-related variables and characteristics of learning environments

Dr. David Jonassen is Curators' Professor at the University of Missouri where he teaches in the areas of Learning Technologies and Educational Psychology. Since earning his doctorate in educational media and experimental educational psychology from Temple University, Dr. Jonassen has taught at the University of Missouri, Pennsylvania State University, University of Colorado, the University of Twente in the Netherlands, the University of North Carolina at Greensboro, and Syracuse University. He has published 35 books and hundreds of articles, papers, and reports on text design, task analysis, instructional design, computer-based learning, hypermedia, constructivism, cognitive tools, and problem solving. His current research focuses on the cognitive processes engaged by problem solving and models and methods for supporting those processes during learning, culminating in the book, *Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments*.

Chris Jones is a Reader in the Institute of Educational Technology at the Open University. He authors course materials for the master's programme in Online and Distance Education and coordinates the Technology Enhanced Learning strand of the Doctorate in Education (Ed.D.). His research focuses on the utilization of the metaphor of networks to the understanding of learning in tertiary education. Chris has a longstanding interest in collaborative and cooperative methods for teaching and learning and in the use of the ideas of Communities and Networks of Practice.

Chris was the principal investigator for a UK Research Council funded project "The Net Generation encountering e-learning at university" until March 2010. Chris has published over 70 refereed journal articles, book chapters, and conference papers connected to his research. He is the joint editor of two books in the area of advanced learning technology—*Networked Learning: Perspectives and Issues* published by Springer in 2002 and a second edited collection with Lone Dirckinck-Holmfeld and Berner Lindström (2009) *Analysing Networked Learning Practices in Higher Education and Continuing Professional Development*. Sense Publishers, BV. Chris is on the Steering Committee of the international Networked Learning Conference series and the editorial boards of the *International Journal of Computer-Supported Collaborative Learning*, *Research in Learning Technology* and the *Journal of Flexible and Distance Learning*.

Ton de Jong received his master's in cognitive psychology at the University of Amsterdam and received a Ph.D. in Technological Sciences from the Eindhoven University of Technology on the topic "problem solving and knowledge representation in physics for novice students." Currently he is full professor of Educational Psychology at the University of Twente Faculty of Behavioral Sciences where he is department head for Instructional Technology. He specializes in inquiry learning (mainly in science learning) by technology. He was project manager of the EC projects SERVIVE, KITS, AND CO-LAB in which simulation and gaming was the central didactical approach, and currently is coordinator of the EC SCY project that focuses on learning by design, again in science. He also coordinated several national projects including the ZAP project. In the ZAP project interactive simulations for psychology were developed that are sold worldwide. For ZAP and SimQuest he has won a number of international prizes. Ton de Jong published over 100 journal articles and book chapters and is on the editorial board of six ISI journals. He is associate editor of *Instructional Science* and of the *Journal of Engineering Education*. In 2006 he published a paper in *Science* on inquiry learning with computer simulations.

Nuri Kara is a Ph.D. candidate in the department of Computer Education and Instructional Technology at Middle East Technical University. He also works as a research assistant there. His primary interests are educational robotics, smart toy-based learning, technology-enhanced learning, faculty development, and game-based learning.

Her research interests revolve around the changes brought by digital technologies in society and in the educational system, and their impact on how human beings learn individually and socially. In education, she uses collaborative action research methods as a means to understand and explain how users experience technologies. In noneducational settings, she studies the impact of digital technologies on the social integration of minorities and marginalized populations. In the past few years she has been involved with several charitable organizations to help adults living with intellectual disabilities develop new capabilities through solving ill structured problems and developing a better sense of self-advocacy. She has published articles on technology in education, including how teachers use technologies in their activities, how technologies can be used to learn and how they can be used to design learning individually and in communities of practice.

Turkan Karakus is a Ph.D. and lecturer at the Department of Computer Education and Instructional Technology in Ataturk University. Her main research interest is the training of instructional designers. She is also interested in game-based learning, human computer interaction, online education, and Internet safety for children.

Dr. Trent Kaufman is Cofounder and President of Education Direction, an education reform company that provides data-driven decision-making consulting, training, and coaching to over 500 districts and schools around the country. Trent earned his doctorate from the Harvard Graduate School of Education in Education Policy, Leadership, and Instructional Practice. His research includes district and school use of the Balanced Scorecard and other performance management systems to drive instructional improvement. Trent earned his master's degree in Education Leadership from the University of California at Berkeley, where he also earned his administrative license. Trent is a former middle and high school teacher, department chair, technology coordinator, athletic coach, dean of students, assistant principal, and principal and is now a national faculty member for High School Futures. He has served as a teaching fellow for the Data Wise weeklong summer institute, as well as teaching the year-long Harvard Data Wise course; in addition he has delivered over a dozen invited Data Wise presentations at conferences and events nationwide. Trent is an author of *Collaborative School Improvement: Eight Practices for District-School Partnerships to Transform Teaching and Learning* (2012, Harvard Education Press) and is a contributing author of *Data Wise in Action* (2007, Harvard Education Press).

Kristen Kereluik is a doctoral candidate in educational psychology and educational technology in the College of Education at Michigan State University. Her research focuses on cognitive, contextual, and motivational variation in the use of multimedia tools for teaching and learning.

Liesbeth Kester is Associate Professor for Effective Learning Strategies in the Centre for Learning Sciences and Technologies (CELSTEC) at the Open University of the Netherlands. She is associate editor of the Journal of Computer Assisted Learning, a member of the editorial board of Educational Technology Research and Development and a member of the editorial board of the Dutch Academic Book Guide. Her expertise includes multimedia learning, hypermedia learning, personalized learning, cognitive aspects of learning, including for example, prior knowledge and learning, testing and retention or worked examples and learning, and designing and developing flexible learning environments.

Wendy Kicken is Assistant Professor at the Open University in the Netherlands. Her research and consultancy activities focus mainly on helping students to self-direct their learning by means of a development portfolio and an appropriate guidance model.

ChanMin Kim is Assistant Professor of Educational Psychology and Instructional Technology at the University of Georgia. Her Ph.D. is in Instructional Systems from Florida State University. Dr. Kim's primary interests are in the intersection of cognitive and noncognitive aspects of teaching and learning, especially as they interact with technologies. Her research agenda involves improving learning in domains typically regarded as challenging or difficult. She focuses on facilitating learners' emotion control, motivation, and self-regulation throughout the implementation of a virtual change agent in online learning environments.

Yoon Jeon Kim is a doctoral candidate in the Instructional Systems program at Florida State University. After she received her bachelor's degrees in Educational Technology and Business Administration from the Ewha Womans University in South Korea, she decided to come to FSU to become an educational researcher. She wants to help children, especially children in poverty, to have opportunities to receive better education and live healthy and productive lives. She firmly believes that new educational technologies can open up more learning opportunities in and outside of school. She currently works with her advisor, Dr. Valerie Shute, on various projects developing innovative ways of assessing complex cognitive and noncognitive skills in dynamic learning environments. Particularly, for her dissertation study, she plans to develop an assessment to measure and support creativity. She loves to explore and learn new digital media technologies that can support sociocultural embodied learning. In her educational technology class she teaches for preservice teachers, she tries to model to her students what a technology-savvy teacher acts like by integrating various technologies throughout the semester-long course.

Dr. Kinshuk is NSERC/iCORE/Xerox/Markin Industrial Research Chair for Adaptivity and Personalization in Informatics, Associate Dean of Faculty of Science and Technology, and Full Professor in the School of Computing and Information Systems at Athabasca University, Canada. His work has been dedicated to advancing research on the innovative paradigms, architectures, and implementations of learning systems for individualized and adaptive learning in increasingly global environments. Areas of his research interests include learning technologies, mobile and location aware learning systems, ubiquitous technologies, cognitive profiling, and interactive technologies. With more than 300 research publications in refereed journals, international refereed conferences, and book chapters, he is frequently invited as keynote or principal speaker in international conferences (22 in past 5 years) and visiting professor around the world (16 in the past 5 years in Finland, Germany, Italy, Japan, Taiwan, and Ukraine). He also has a successful record of procuring external funding over 11 million Canadian dollars as principal and coprincipal investigator. He is Founding Chair of IEEE Technical Committee on Learning Technologies, and Founding Editor of the Educational Technology & Society Journal (SSCI indexed with Impact Factor of 1.067 according to Thomson Scientific 2009 Journal Citations Report).

Paul A. Kirschner is professor of Educational Psychology, Program Chair of the Learning and Cognition program and Coordinator of Research at the Centre for Learning Sciences and Technologies (CELSTEC) at the Open University of the Netherlands. He was President of International Society for the Learning Sciences in 2010, is Chief Editor of the Journal of Computer Assisted learning and Associate Editor of Computers in Human Behavior, and coauthor of Ten Steps to Complex Learning. His areas of expertise include computer-supported collaborative learning, designing electronic, and other innovative learning environments, media-use in education, and innovation and the use of information technology educational systems.

James D. Klein is the Walter Dick Distinguished Professor of Instructional Systems Design at Florida State University and Professor Emeritus at Arizona State University. He has authored over 60 refereed journal articles, 3 books, 11 chapters, and numerous conference papers, winning several awards for his scholarship. He has served in a number of leadership positions including Development Editor of Educational Technology Research & Development and as a fellow of the International Board of Standards for Training, Performance and Instruction. He was identified as the third most productive author in Educational Technology, Research & Development from 1989 to 2008. Dr. Klein's research, teaching and consulting activities are in the areas of instructional design, strategies for active learning, and performance improvement. He can be reached at jklein@fsu.edu.

Dr. Joris Klerkx is a post-doctoral research expert at the Computer Science department of the Katholieke Universiteit Leuven in the research group Human-Computer Interaction (HCI). His research interests include user experience design (i.e. information visualization, facetted search, multi-touch, mobile devices), metadata, and flexible access to a global learning infrastructure based on open standards in general. Joris coordinated the research on educational content discovery in the EU eContentPlus project of ASPECT and has been furthermore involved in other EU eContentPlus projects of ICOPER, MACE and MELT. Currently, he's technical coordinator of the ARIADNE foundation and active in the CEN workshop on Learning Technologies.

Gerald A. Knezek, Ph.D.: Professor of Learning Technologies. Dr. Knezek has two decades of experience in teacher training in information technology, and three decades of experience in research design and analysis. He has worked in multivariate data analysis as well as modeling and simulations for much of his career. Dr. Knezek previously served as a member of a research group that examined U.S. Dept. of Education *Preparing Tomorrow's Teachers* (PT3) projects to share data and extract common research findings. He has served as evaluator for several U.S. National Science Foundation projects. He was President of the Society for Information Technology & Teacher Education (SITE) from 2008 to 2011. He was a Fulbright Scholar to Japan in 1993–1994 and held Fulbright Senior Specialist appointments to Ecuador in 2006–2007 and the Netherlands in 2011–2012.

Matthew J. Koehler is an Associate Professor of Educational Technology and Educational Psychology at Michigan State University. His research and teaching focus on understanding the affordances and constraints of new technologies; the design of technology-rich, innovative learning environments; and the professional development of teachers. He has collaborated with Punya Mishra to develop theoretical, pedagogical, and methodological perspectives that characterize teachers who effectively integrate technology, pedagogy, and content knowledge (TPACK). His work has been published in several prominent national and international research journals. Dr. Koehler teaches undergraduate, master's, and doctoral in the College of Education on educational psychology, educational technology, teacher education, and research design.

Anette Kolmos (Ph.D.). Professor in Engineering Education and PBL and Chair holder of the UNESCO Chair in Problem-Based Learning in Engineering Education at Aalborg University.

During the last 20 years Anette Kolmos has conducted research in the following areas: Change to PBL curriculum, development of transferable skills and faculty development. She is actively involved in developing the profile of Engineering Education Research in Europe as well as internationally.

She has been involved in SEFI activities for more than 20 years and she is Past President of SEFI (2009–2011). She is cofounder of IIDEA, a joint initiative of SEFI and IFEES establishing leadership training institute focused on establishing a global network of engineering faculty development programs to disseminate learning about the transformation of engineering education worldwide. Professor Dr. Kolmos is associate editor for European Journal of Engineering Education, SEFI and has served as associate editor for Journal of Engineering Education. She has published more than 170 articles in various journals and she has given more than 50 keynote addresses and invited lectures.

Dr. Kopcha joined the LDT at UGA faculty in January 2010. He received a Ph.D. in Educational Psychology from Arizona State University in 2005. Dr. Kopcha is an educational technologist specializing in the implementation of technology in today's classrooms. Prior to working at the University of Georgia, he spent 5 years as a teacher of mathematics in Connecticut and 3 years at San Diego State University in the Department of Educational Technology. He has written several articles on topics such as learner control over elements of instruction and self-presentation bias in self-report data. His current research focuses on the use of technology to support the elements of cognitive apprenticeship between student and master teachers. He is presently developing a technology-driven supervision process that supports the student teaching field experience and examining the impact of that process on the knowledge and performance of student teachers. This research is funded in part by the University Grant Program at SDSU.

Dr. Koszalka earned a Master of Science degree in Instructional Technology and a Doctorate in Instructional Systems Design with a minor emphasis in Cultural Anthropology. She is currently a professor in Syracuse University's Instructional Design, Development and Evaluation program. Her research focus is studying the integration of learning, instruction, and technologies in instructional and learning environments.

She has spent considerable time exploring technologies in university-level instruction, specifically for education, medical, and engineering domains. She maintains active collaborations with K-12 educational technology integration efforts both in the US and abroad. She often serves in both evaluation and research roles for instructional projects and consults on instructional design, educational technology integration, and human performance efforts in many contexts.

Dr. Robert Kozma is an independent consultant operating out of San Francisco, California, and an Emeritus Director and Principal Scientist at the Center for Technology in Learning at SRI International in Menlo Park, California. For 20 years prior to his position at SRI, he was a professor and research scientist at the University of Michigan. His research expertise includes technology policy in support of education reform and economic and social development, technology assessment and evaluation in education reform, media theory, the impact of technology on cognition, and the application of technology to improve teaching and learning. He has consulted with the Ministries of Education in Egypt, Thailand, Jordan, India, Singapore, Norway, and Chile and with Intel Corporation, Cisco, Microsoft, the World Bank, OECD, UNESCO, and the Ford Foundation on the use of technology to improve educational systems. He provided pro-bono consulting for the Millennium Villages Project on the role that ICT can play in supporting poverty reduction and development in Africa. In all, he has directed or codirected more than 25 research and development projects, authored or coauthored more than 75 academic articles, chapters, encyclopedia entries, and books, and given more than 100 presentations and invited addresses at national and international conferences. He began his career as a primary mathematics teacher in the inner city of Detroit, Michigan.

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Gary R. Morrison received his doctorate in Instructional Systems Technology from Indiana University and is a professor and graduate program director in the instructional design and technology program at Old Dominion University. His research focuses on cognitive load theory, instructional strategies, K-12 technology integration, and distance education. He is author of two books: Morrison, Ross, and Kemp's *Designing Effective Instruction* (5th Edition) and Morrison and Lowther's *Integrating Computer Technology into the Classroom* (3rd Edition). He has written over 25 book chapters and over 40 articles on instructional design and educational technology. Gary is the editor of the *Journal of Computing in Higher Education* and is on the editorial boards of *Computers in Human Behavior, Quarterly Review of Distance Education,* and Libraries Unlimited's *Instructional Technology Serie*s. He has worked as instructional designer for three Fortune 500 companies and the University of Mid-America. Two of the distance education courses he designed were accepted for broadcast on PBS and NPR. Gary is a past president of Association for Educational Communication and Technology's (AECT) Research and Theory Division and Design, Development Division, and Distance Learning Division. His research focuses on cognitive load theory, instructional strategies, K-12 technology integration, and distance education. Gary is a past president of Association for Educational Communication and Technology's (AECT) Research and Theory Division and Design and Development Division, and is the current president of the Distance Learning Division.

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Awards and recognition he has received for his innovative teaching and research with learning technologies include an Australian Award for University Teaching (1997), an Australian Learning and Teaching Council Fellowship (2006), a Fellowship from the Association for the Advancement for Computer in Education (2007) and a Fellowship from of the Australasian Society for Computers in Learning in Tertiary Education (2009).

Fred Paas works as a full professor of educational psychology at Erasmus University Rotterdam in the Netherlands, as professorial fellow at the University of Wollongong in Australia, and as adjunct professor at the university of New-South Wales, Sydney, Australia. His main research interest is in instructional control of cognitive load in lifelong learning of complex tasks. His six most influential publications have been cited over 4,000 times, including "Cognitive Load Theory and Instructional Design" (Educational Psychologist, 2003), "Cognitive Load Measurement as a Means to Advance Cognitive Load Theory" (Educational Psychologist, 2003), "Cognitive Architecture and Instructional Design" (Educational Psychology Review, 1998), "Variability of Worked Examples and Transfer of Geometrical Problem-Solving Skill" (Journal of Educational Psychology, 1994), "The Efficiency of Instructional Conditions" (Human Factors, 1993), "Training Strategies for Attaining Transfer of Problem-Solving Skill in Statistics" (Journal of Educational Psychology, 1992).

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Dr. Picciano's major research interests are school leadership, education policy, Internet-based teaching and learning, and multimedia instructional models. He has authored numerous articles and nine books including *Data-Driven Decision Making for Effective School Leadership* (2006, Pearson), *Educational Leadership and Planning for Technology*, 5th Edition (2010, Pearson), Blended Learning: Research Perspectives (2007, The Sloan Consortium), *Distance Learning: Making Connections across Virtual Space and Time* (2001, Pearson), and *Educational Research Primer* (2004, Continuum). He has also conducted three major national studies (2007, 2009, 2010) with Jeff Seaman on the extent and nature of online and blended learning in American K-12 school districts. In 2010, Dr. Picciano received the Sloan Consortium's Award for Outstanding Achievement in Online Education by an Individual.

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Jochen Rick's research interests lie at the intersection of learning, collaboration, and new media. He creates innovative and effective educational technologies and researches their value in authentic contexts. With a M.S. in Electrical Engineering and Ph.D. in Computer Science, he feels comfortable developing for new technologies. As a learning scientist, he recognizes the potential these technologies have to support constructivist learning. In particular, he values exploratory, design-based, and inquiry-based collaborative learning. His current focus is on supporting colocated collaborative learning with interactive surfaces. He is the founder of *surfacelearning.org*, an interactive interdisciplinary resource for research on interactive surfaces and learning.

In 2010, he joined the Department of Educational Technology, Saarland University as a research fellow/instructor, contributing a computer science perspective to an interdisciplinary department. Before that, he spent 3 years as a postdoc at the Open University working with Yvonne Rogers on supporting colocated collaboration with shareable interfaces. In 2007, he received a Ph.D. in Computer Science (area of Learning Sciences and Technology) from the Georgia Institute of Technology; his dissertation research, supervised by Mark Guzdial, investigated the role that personal home pages play in academia. His work on CoWeb (Collaborative Websites) was the first research on using wikis to support learning in university classes.

Steven M. Ross received his doctorate in educational psychology from Pennsylvania State University. He is currently a senior research scientist and professor at the Center for Research and Reform in Education at Johns Hopkins University. Dr. Ross is the author of 6 textbooks and over 125 journal articles in the areas of educational technology, at-risk learners, educational reform, extended learning time programs, and research and evaluation. He is a noted lecturer on school programs and educational evaluation, Editor Emeritus of the research section of the *Educational Technology Research and Development* journal, and a member of the editorial board for four other professional journals. In 1993, he was the first faculty recipient of The University of Memphis Eminent Faculty Award for teaching, research and service, and recently held the Lillian and Morrie Moss Chair of Excellence in Urban Education and a Faudree Professorship at The University of Memphis. He has testified on school restructuring research before the U.S. House of Representatives Subcommittee on Early Childhood, Youth, and Families, has been a consultant to the National Science Foundation on project evaluation design, and is a technical advisor and researcher on current federal and state initiatives regarding the evaluation of out-of-school learning, technology usage, evaluation of principals, and supplemental educational services. Current projects include the evaluation of a school-wide social-emotional learning program ("Together 4 All") in N. Ireland, a city-wide turnaround initiative in Syracuse, NY, and after-school mentoring and experiential learning programs for children and adolescents in multiple states.

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Dr. Savenye has published over 70 articles, chapters, and monographs related to instructional design and evaluation of technology-based learning systems. She is the Associate Editor of the new Journal of Applied Instructional Development, serves on several editorial boards, serves as a manuscript reviewer for several additional journals, and has served as guest editor for several special issues of educational technology journals. She has held several elected conference leadership positions. She has also made over 140 presentations at international, national and regional conferences and workshops. She has been awarded numerous federal and foundation grants in these areas. She has designed and produced numerous digital media products and programs.

Her research and teaching focus on instructional design, assessment, and evaluation for online, eLearning, and technology-based learning systems in schools, museums, universities, and corporations.

Dr. Savoy is currently a Math Field Service Specialist with Pearson/School Achievement Services. Prior to joining Pearson/America's Choice, he led many school improvement efforts as the Director of Policy and Research at DCVOICE, a nonprofit community advocacy organization. He began is educational career as a high school math and physics teacher and school improvement chair. Dr. Savoy is coauthor of several publications on the subject of user-design.

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Dr. Seel has published 18 books, among them the textbook "Psychology of Learning" (2nd ed.), as well as more than 150 refereed journal articles and book chapters in the area of education and cognitive psychology. He is associate-editor of several journals, such as *Frontiers of Cognitive Science* and *Technology, Instruction, Cognition and Learning*. He is also the editor-in-chief of the Encyclopedia of the Sciences of Learning.

Dr. Shen is currently Assistant Professor in the Department of Mathematics and Science Education at the University of Georgia. His scholarly work focuses on developing a comprehensive instructional theory based on transformative modeling, designing and implementing innovative technology-enhanced science modules at the middle and high school levels, fostering interdisciplinary science learning at the college level, and constructing diagnostic assessments in science at all levels.

Tae Seob Shin is currently an Assistant Professor in the Department of Education at Hanyang University, Seoul, South Korea (HYU). He received his Ph.D. in Educational Psychology and Educational Technology from Michigan State University (MSU). He holds an M.A. in Educational Psychology and a B.A. in Education from Seoul National University (SNU). Dr. Shin's research interests include motivating students to learn, developing pre- and in-service teachers' technological pedagogical content knowledge, and understanding motivational aspects of online learning environments. His research has been presented at various international conferences including American Educational Researcher Association (AERA), American Psychological Association (APA), and Society for Information Technology and Teacher Education (SITE). He has coauthored two book chapters and published several articles in peer-reviewed journals. A recipient of the 2009 APA Dissertation Research Award (Dissertation Title: Effects of Providing Rationales for Learning a Lesson on Students' Motivation and Learning in Online Learning Environments), Dr. Shin also received the Korean Honor Scholarship from the Korean Consulate General in Chicago. He was also the recipient of Robert Craig Fellowship in Psychological Studies in Education at MSU, where he completed his Ph.D. under the guidance of W. Patrick Dickson. Other honors and awards include the 2009 SITE International Conference Outstanding Paper Award, MSU AT&T Faculty-Staff Awards in Instructional Technology, and Cum Laude Honors at SNU.

Valerie Shute is a Professor at Florida State University. Before coming to FSU in 2007, she was a principal research scientist at Educational Testing Service (2001–2007) where she was involved with basic and applied research projects related to assessment, cognitive diagnosis, and learning from advanced instructional systems and where she generally honed her psychometric skills. Prior to ETS, Val worked in industry for 2 years, and before that, she was enthusiastically employed at the Air Force Research Lab in San Antonio, Texas (1986–1999). She earned a Ph.D. in cognitive/educational psychology from the University of California, Santa Barbara (1984), and held a 2-year postdoctoral fellowship at the Learning Research and Development Center. Her general research interests hover around the design, development, and evaluation of advanced systems to support learning—particularly related to twenty-first century competencies. Towards this end, she's been involved in (a) exploratory and confirmatory tests of aptitude-treatment interactions using the controlled environments offered by intelligent tutoring systems, (b) student modeling research using evidence-centered design, and (c) developing automated knowledge elicitation and organization tools. An example of current research involves using immersive games with stealth assessment to support learning—of cognitive and noncognitive knowledge and skills. Another example of current research involves externalizing mental models and assessing understanding of complex phenomena. Towards that end, she and her colleagues are developing a suite of model-based tools that are used to assess understanding and provide the basis for informative and reflective feedback during instruction.

Kennon Smith is an assistant professor in the Indiana University Interior Design Studies group. Her research interests include design pedagogy and comparative design. She teaches courses on design principles and sustainable design, as well as conducting design studios.

J. Michael Spector is Professor and Chair of the Department of Learning Technologies at the University of North Texas. Previously, he was Professor Educational Psychology and Instructional Technology and Graduate Program Coordinator for Learning, Design, and Technology at the University of Geogia (2009–2012), and prior to that he was the Associate Director of the Learning Systems Institute and Professor of Instructional Systemsat Florida State University (2004–2008). He was Chair of Instructional Design, Development and Evaluation at Syracuse University (2000–2004) and Director of the Educational Information Science and Technology Research Program at the University of Bergen (1996–1999). He is a distinguished graduate of the United States Air Force Academy and earned a Ph.D. in Philosophy from The University of Texas at Austin (1978). His recent research is in the areas of intelligent support for instructional design, system dynamics-based learning environments, assessing learning in complex domains, distance learning, and technology integration in education. Dr. Spector served on the International Board of Standards for Training, Performance and Instruction (*ibstpi*) as Executive Vice President; he is on the Executive Committee of the IEEE Technical Committee for Learning Technology and is Past President of the Association for Educational and Communications Technology (AECT). He is the editor of the Development Section of *Educational Technology Research & Development* and serves on numerous other editorial boards. He coedited the third edition of the *Handbook of Research on Educational Communications and Technology*, is again lead editor on the fourth edition. He has more than 100 journal articles, book chapters and books to his credit.

Donald Stepich, Ph.D. Steve is an Associate Professor and Department Chair in the Instructional and Performance Technology (IPT) Department at Boise State University. His research interests include the use of instruction to develop professional expertise. A frequent author and conference presenter, he is a member of ISPI and ASTD, and a contributing editor to Performance Improvement Quarterly. Don completed his doctorate in education at Purdue University.

Kate Thompson is a research associate at CoCo research center. Her PhD examined the intersection of learning sciences theory (multiple representations, CSCL) with simulation model use, and sparked an interest in user-specific scaffolds and strategies for the interrogation of simulation models. Kate's background in environmental science has led her to a systems perspective, and work on environmental education programs has involved mobile learning as well as virtual worlds. Currently, Kate's research is focussing on measuring and representing processes in CSCL as well as designing for these environments.

Sigmund Tobias is Eminent Research Professor, University at Albany, SUNY. Previously he was: Distinguished Research Scientist, Institute of Urban and Minority Education, Teachers College, Columbia; Distinguished Scholar, Fordham University; Research Professor, City College, CUNY. He was (1987–1988) President of the Division of Educational Psychology, American Psychological Association. His research interests include educational technology, adapting to unexpected events, assessment of metacognition, and adapting instruction to student characteristics.

Among his recent publications are the following:

Fletcher, J. D., & Tobias, S. (2011). Turning the corner in educational technology: Reflections on a half-century of research. *Educational Technology, 51*(5), 14–20.

Tobias, S., & Duffy, T. D. (2009). *Constructivist instruction: Success or failure?*. New York, NY: Routledge, Taylor and Francis.

Tobias, S. (2009). An eclectic appraisal of the success or failure of constructivist instruction: In S. Tobias, & T. D. Duffy (Eds.), *Constructivist instruction: Success or failure?* (pp. 335–350). New York, NY: Routledge, Taylor and Francis.

Tobias, S. (2010). Generative learning, paradigm shifts, and constructivism. A tribute to Wittrock. *Educational Psychologist, 45*, 51–54.

Tobias, S. (2010). The expert reversal effect and aptitude treatment interaction research. *Insructional Science, 38*, 309–312.

Tobias, S. (2010). Aptitudes and instructional methods. In N. J. Salkind (Ed.), *Encyclopedia of research design* (Vol. I, pp. 38–40). New York, NY: Sage.

Tobias, S., & Everson, H. T. (2009). The importance of knowing what you know: A knowledge monitoring framework for studying metacognition in education. In D. L. Hacker, J. Dunlosky, & A. Graesser (Eds.), *Handbook of metacognition in education* (pp. 107–127). New York, NY: Routledge, Taylor, and Francis.

Tobias, S., & Fletcher, J. D. (2009). Transforming learning with technology redux. *Educational Technology, 49(3)*, 54–58.

Tobias, S., & Fletcher, J. D. (2011). *Computer games and instruction.* Charlotte, NC: Information Age.

Tobias, S., & Fletcher, J. D. (2011). Computer games and instruction. The present, and future. In S. Tobias, & J. D. Fletcher (Eds.), *Computer games and instruction* (pp. 525–545). Charlotte, NC: Information Age.

Tobias, S., Fletcher, J. D., Dai, D. Y., & Wind, A. (2011). Review of research on computer games. In S. Tobias, & J. D Fletcher (Eds.), *Computer games and instruction* (pp. 127–222). Charlotte, NC: Information Age.

Monica W. Tracey is an Associate Professor of Instructional Technology in the College of Education at Wayne State University. Her teaching and research experience center on the theory and research of design and its applications. She is a recipient of the 2011 Association for Educational Communications and Technology Achievement Award and the 2008 Design and Development Award. Tracey has worked for over 25 years in design and on design projects. Her work includes designing internationally and across disciplines. Recently, she directed a large-scale cross-cultural customized instructional design and performance improvement project in Dubai, The United Arab Emirates.

Agustin Tristán-López, Ph.D. (Solid Mechanics) is the General Director of the Institute of Evaluation and Advanced Engineering, San Luis Potosi, Mexico and is affiliated with the International Test Commission. He focuses on educational assessment for professional certification and statistical models for evaluation of teaching and learning, psychometrics with the Rasch model and validity and design of tests for nursing and health-related projects.

Mieke Vandewaetere is a postdoctoral researcher at the Center for Instructional Psychology and Technology (KU Leuven) and at the Academic Center for General Practice (KU Leuven). Her research interests are learners' perceptions and how they influence self-controlled tool use; complex learning and medical education.

Dr. George Veletsianos is Assistant Professor of Learning Technologies at the University of Texas at Austin. His teaching and research interests focus on the study of emerging technologies and pedagogies in online and hybrid education settings, and their relationship to student and instructor experiences and practices. Foci areas include online education, pedagogical agents, adventure learning, and networked participatory scholarship.

Dr. Katrien Verbert is a postdoctoral researcher of the Research Foundation—Flanders (FWO) at the HCI research unit of the Katholieke Universiteit Leuven. Her research interests include content models, content reusability, context-aware recommendation and personalization, and applications thereof in technology-enhanced learning, science information systems, and music information retrieval. In that respect, she is currently involved with the RAMLET IEEE LTSC standardization project that is developing a reference model for resource aggregation. She is also involved with the EU FP7 project ROLE that is focusing on the issue of contextual recommendation as a basis to support the development of Responsive Open Learning Environments. A key element of the ROLE vision for PLEs is that they should be adaptive depending on the needs, preferences and skills of the learner. In this context, she is involved in research on user-centric and context-aware methodologies, technologies and systems for tracking learner interactions with content and tools. These interactions are used for data analysis and computing of personal, social and contextual information about users and applications that is used as a basis for recommendation. She coorganized the workshop on Context-Aware Recommendation for Learning, at the Second Alpine Rendez-Vous in 2009 and the First workshop on Recommender Systems for Technology Enhanced Learning (RecSysTEL) that is jointly organized by the Fourth ACM Conference on Recommender Systems (RecSys 2010) and the 5th European Conference on Technology Enhanced Learning (EC-TEL 2010).

Lieven Verschaffel (1957) obtained in 1984 the degree of Doctor in Educational Sciences at the Katholieke Universiteit Leuven, Belgium. From 1979 until 2000 he obtained several subsequent research positions at the Fund for Scientific Research-Flanders. Since 2000 he is a full professor in educational sciences of that same university.

His major research interests are: teaching and learning of (mathematical) problem-solving skills, metacognitive and affective aspects of (mathematics) learning, and mathematics education. He is the coordinator of a Concerted Research Action funded by the Research Council of the KU Leuven entitled "Number sense: analysis and improvement" and he is the coordinator of the Scientific Network on "Critical and Flexible Thinking" that stimulates and supports research collaboration between several Belgian and European teams on this topic. He is a member of the editorial board of several international journals such as *Mathematical Thinking and*

Learning, *Educational Studies in Mathematics*, *Educational Research Review*, *Learning and Instruction*, *Human Development*, and *Cambridge Journal of Education*. His publication list contains about 120 SSCI-ranked international journal articles, 200 other journal articles, 25 monographs and edited volumes, 120 book chapters, and 75 papers published in international congress proceedings. For his contribution to (mathematics) education, he has been honored several times. In 2009 he was elected in 2009 as Member of the Flemish Royal Academia for Sciences and Arts of Belgium, and, in 2010 as a Member of the Academia Europaea.

Steven W. Villachica, Ph.D. Steve is an Associate Professor of Instructional and Performance Technology (IPT) at Boise State University. His research interests focus on leveraging expertise in the workplace in ways that meet organizational missions and business goals. He is currently working on an NSF grant to increase engineering faculty adoption of evidence-based instructional practices [NSF #1037808: Engineering Education Research to Practice (E2R2P)]. A frequent author and conference presenter, he is a member of ISPI, ASTD, and AECT. A contributing editor to *ETR&D*, Steve completed his doctorate in educational technology at the University of Northern Colorado.

Wayan Vota is a senior director at Inveneo, a social enterprise deploying sustainable tools of ICT to rural and underserved communities. His 15 years of experience includes technology solution assessment and design, and the sustainable deployment of information and communication technologies in a variety of global settings. He has developed and deployed technology solutions for USAID, UNICEF, Cisco Systems, Hewlett-Packard, and PricewaterhouseCoopers Moscow and advised the government of Jordan on its ICT in education policy, strategy, and operational plan. Wayan Vota draws on Inveneo's extensive experience in delivered solutions to more than 2.1 million people in 917 communities across 27 countries around the world. Mr. Vota also advises the World Bank on best practices in the deployment and use of ICT devices for education.

Mr. Vota has addressed the Clinton Global Initiative, International Telecommunications Union, Korea Institute of Science and Technology, the World Summit on Information Society, and the Government of Queensland, Australia on sustainable deployment methodologies. He is a Technology Museum Laureate, Global Social Business Incubator Alumni, DevEx International.

Donovan R. Walling is an independent scholar, writer, and editor and a senior consultant for the Center for Civic Education. He previously was Director of Publications for Phi Delta Kappa International. His numerous publications feature works on arts education, civic education, and the teaching of writing, including *Writing for Understanding, Why Civic Education Matters,* and *Public Education, Democracy, and the Common Good.*

Dr. Feihong Wang is a postdoctoral research associate in the School of Education at Virginia Tech. Dr. Wang's work has focused on technology-supported teaching and learning, game-based learning, collaborative learning, and distance education. She earned her Ph.D. in Instructional Design and Technology at Virginia Tech in 2010.

Scott Warren works as an Associate Professor of Learning Technologies at the University of North Texas. His current research examines the use of emerging online technologies such as immersive digital learning environments and educational games and simulations in K-20 settings. Prior to working in higher education, he taught both social studies and English in public schools for nearly a decade. His early work included creating the *Anytown* world to support writing, reading, and problem solving. His current work is with *The 2015 Project* alternate reality course and he designed the online literacy game *Chalk House*.

Dr. West is currently an assistant professor of Instructional Psychology and Technology at Brigham Young University. He has taught technology integration courses for preservice teachers for 4 years. He also teaches courses on instructional technology, program evaluation, and research strategies. He researches the design and support of learning environments that foster collaborative creativity, collaborative online learning, and technology integration in K-16 environments, as well as the effective training of preservice teachers in technology integration.

Dr. David Wiley is an associate professor in the Department of Instructional Psychology and Technology at Brigham Young University and associate director responsible for the research unit of the Center for the Improvement of Teacher Education and Schooling (CITES) in the David O. McKay School of Education. David is founder and board member of the Open High School of Utah and chief openness officer of Flat World Knowledge. Dr. Wiley leads the Open Education Group at BYU and is currently Senior Fellow for Open Education at the National Center for Research in Advanced Information and Digital Technologies (Digital Promise). Formerly he was an associate professor of instructional technology and Director of the Center for Open and Sustainable Learning at Utah State University. Nonresident fellow at the Center for Internet and Society at Stanford Law School, visiting scholar at the Open University of the Netherlands, and recipient of a US National Science Foundation's CAREER grant are among his other honors and accomplishments. David is Founder of OpenContent.org and was recently named one of the 100 Most Creative People in Business. His career is dedicated to increasing access to educational opportunity for everyone around the world.

Alexander Wind is currently in the PhD program in Educational Psychology and Methodology at the University at Albany, SUNY. He is also an adjunct with the Institute for Defense Analyses. His research interests are in the construct of dealing with the unexpected (and the related construct of mental rigidity) and the focus of this chapter, the relationships between gameplay and learning outcomes.

Recent publications include:

Fletcher, J. D., & Wind, A. P. (in press). The evolving definition of cognitive readiness for military operations. In H. F. O'Neil, Jr., R. S. Perez, & E. L. Baker (Eds.), *Teaching and Measuring Cognitive Readiness.*

Fletcher, J. D., & Wind, A. P. (2011). *Preparing to be Prepared: Cognitive Readiness and Dealing with the Unexpected* (IDA Document D-4402). Alexandria, VA: Institute for Defense Analyses.

Tobias, S., Fletcher, J. D., Dai, D. Y., & Wind, A. P. (2011). Review of research on computer games. In S. Tobias, & J. D. Fletcher (Eds.), *Computer games and learning* (pp. 127–222). Charlotte, NC: Information Age Publishing, INC.

Dai, D. Y., & Wind, A. P. (2011). Computer games and opportunity to learn: Implications for teaching students from low socioeconomic backgrounds. In S. Tobias, & J. D. Fletcher (Eds.), *Computer games and learning* (pp. 447–502). Charlotte, NC: Information Age Publishing, INC.

His current projects include an ongoing study involving a computerized instrument of dealing with the unexpected and a study of mental rigidity, the Einstellung Effect. The latter will be the topic of his dissertation.

Wally Wulfeck is a Senior Research Psychologist at the Space and Naval Warfare Systems Center in San Diego, CA, where he serves as Coprincipal Investigator and Project Scientist on the Interactive Multisensor Analysis Training (IMAT) project. The IMAT effort is developing new approaches to teaching complex tasks involved in sensor employment for Anti-Submarine Warfare. Products include training systems, mission simulations, and Navy tactical decision aids. The IMAT vision is to integrate training, mission rehearsal, tactical execution, and post-mission analysis to develop and maintain mission-related critical skills. IMAT products are prototypes for future human performance support systems which span career-long skill development from apprentice to master performance, across missions, platforms, and communities, at individual, team, platform, and command levels.

Dr. Wulfeck served during 2004–2007 as Deputy Science and Technology Officer for the Capable Manpower Future Naval Capability program at the Office of Naval Research (ONR). In that position he managed the $100 million budget and led the effort to redefine the program for future years.

Dr. Wulfeck has a continuing record of training research, technology development, and transition to operational use. During the 1990s, he directed the Instructional Simulations Division and Training Research Computing Facility at the Navy Personnel Research and Development Center in San Diego, California. His division developed training systems for use throughout the Navy and DoD, including the Naval Education and Training Command; the Naval Submarine School; Trident Training Facilities; AEGIS Training Center; the Navy/Marine Corps Intelligence Training Center; the Propulsion Engineering School, Naval Training Center Great Lakes; and the Joint Staff.

He is the author of well over 100 journal articles, book chapters, technical reports, and conference presentations. Dr. Wulfeck has also served as Science Advisor to the Chief of Naval Personnel, and received the Navy Meritorious Civilian Service Award.

Dr. Wulfeck received his Ph.D. in learning from the University of Pennsylvania in 1975, following undergraduate and graduate degrees in Mathematics and Mathematics Education from the University of California, Santa Barbara. He is a member of the American Psychological Society, the American Educational Research Association, and the Cognitive Science Society.

Charles Xie is a senior scientist at the Concord Consortium, a nonprofit organization focused on educational technology. He is currently the principal investigator of several NSF-funded research projects on engineering education and augmented reality. He developed the *Molecular Workbench* software, which has reached nearly a million users worldwide and won a prestigious *Science* Prize for Online Resources in Education. His current research covers the educational applications of mobile computing, sensors, simulations, infrared imaging, and CAD/CAM.

Miguel Angel Ylizaliturri-Salcedo, B.Sc., (Computer Engineering) is an Assistant Professor at the University of San Luis Potosi and head of the Informatics Department of the Institute of Evaluation and Advanced Engineering, San Luis Potosi, Mexico. He is responsible for test scoring and the development of software for online testing and item banking. Along with Dr. Tristán-López, he is developing software for lexical analysis of texts in Spanish.

Patricia A. Young, Ph.D. is an Associate Professor in Literacy Education at the University of Maryland, Baltimore County. Dr. Young earned her Ph.D. in Education: Language, Literacy and Culture from the University of California Berkeley. For the last decade, Dr. Young's experiences and education have culminated into her present work. Dr. Young developed the Culture Based Model as an instructional design framework that supports designers in creating culture-based information and communication technologies. Her current research involves mapping the model to a variety of interdisciplinary uses. This research is outlined in her book *Instructional Design Frameworks and Intercultural Models* (2009) published by IGI Global. Dr. Young's research also examines the history of Instructional Design and Technologies made by and for African Americans and Race & Ethnicity in Urban Teacher Education. She has published referred articles in journals such as: Artificial Intelligence and Society; British Journal of Educational Technology; Journal of Educational, Technology & Society; Journal of Language, Identity and Education; and Race, Ethnicity & Education. In 2009, Dr. Young received the Outstanding Journal Article Award from the Association of Educational Communications & Technology—Design & Development Division for her article: *Integrating Culture in the Design of ICTs.*

Glossary[1]

21st century skills Those skills believed necessary to contribute to workforce production and maintenance of a high quality of life in the twenty-first century, including skills related to creativity, collaboration, communication, critical thinking, information literacy, media literacy, and technology literacy.

Academic emotions Affective experiences in relation to academic activities or the outcomes of the activities.

Action research Research conducted by practitioners that follow a cyclical process including posing a question, collecting data, reporting findings and, based on those findings, posing new research questions; may be used interchangeably with "teacher research" or "practitioner research."

Activity theory A theoretical framework which takes the collective activity involving agents, objects, goals, and resources as a composite unit of analysis.

Actor network theory An approach to investigate socio-technical network building process.

Adaptive system A computer-based system or learning environment that provides personalized learning materials, either instruction, content, or support and feedback.

ADDIE An acronym which stands for Analysis, Design, Development, Implementation, and Evaluation; the origins of the term are uncertain and it is common to other disciplines; it may be a mnemonic device for the stages of system engineering as they are applied to instructional design.

[1] This glossary represents a synthesis of the keyword definitions provided by contributors to the *Handbook*. Some of these definitions have been altered slightly for consistent form, and others have been combined to provide readers with a useful synthesis. One should bear in mind that these terms have been defined by the authors from the perspective of their particular chapters and for the purposes of this *Handbook*. For a more comprehensive definition of the field and its domains, readers are encouraged to consult: Januszewski, A., & Molenda, M. (Eds.). (2008). *Educational technology: A definition with commentary*. New York: Routledge.

Affective states Typically, affective states is used as a collective term for emotions, feelings, moods, and attitudinal states.

Affordances The tasks or activities made possible by specific features or functions of technologies.

AKOVIA Automated knowledge visualization and assessment—a Web-based tool to support learning and assessment.

Alignment A term developed in relation to communities of practice, denoting the process through which one community is influenced by another and then modifies their activities; it is also used to refer to the consistency and coherence between goals, objectives, activities, and assessments.

Alternative assessment Any assessment method that is an alternative to simple fact-based tests; examples include portfolios, problem conceptualizations, and concepts maps; alternative assessments are typically linked directly to a specific unit of instruction or curriculum module and may be customized for specific students.

Analogical reasoning A kind of nondeductive and naturalistic reasoning in which what is known about one exemplar is used to infer new information about another exemplar.

Applied research Research aimed at providing solutions to practical problems or producing findings useful in professional practice, unlike basic research which generally seeks to find fundamental causes for a variety of phenomena.

Artificial Intelligence (AI) A branch of computer/cognitive science that aims to simulate or embed human intelligence in information-processing devices.

Artificial Intelligence in Education (AIED) A highly interdisciplinary research field based on computer science, education, and psychology, applying AI techniques to the design of learning environments.

Assessment The measurement of performance, learning, skills, artifacts, portfolios, or products; evaluation of individual knowledge, skills, and attitudes; a process to determine the state of an individual's knowledge, skills, and attitudes.

J.M. Spector et al. (eds.), *Handbook of Research on Educational Communications and Technology*,
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Assessment methods Methods for assessing the quality or completeness of knowledge acquisition and performance.

Assessment standards Specifications that provide evidence for the quality of the three primary aspects of evaluation: validity, objectivity, and reliability.

Augmented reality Technologies that present on a digital device an interactive narrative, navigation means for learners, and/or academic information all of which are superimposed on (a representation of) a physical location or device.

Authentic assessment Assessment of learning through the evaluation of meaningful products and performances under natural rather than artificial (e.g., examination) conditions; the tasks are either replicas of or analogous to those actually encountered in practice.

Authentic learning environments Pedagogical conditions in educational contexts that provide opportunities for students to collaboratively undertake challenging and realistic tasks resulting in meaningful products and significant learning.

Automatic scoring Software-based techniques that produce instantaneous measures of the performances of a person on a test, an essay, an e-portfolio, or any other source of evidence based on academic or professional assessment standards.

Behaviorism The perspective that learning is the association of stimuli and responses through rewards and punishments with little or no emphasis on cognitive processes; the view that the most important factor influencing learning is reinforcement; behaviorism is often investigated using experimental research designs.

Benefits of educational technology The monetary or monetized value of the effects of educational technology interventions; more generally, the affordances made possible by educational technologies.

CAQDAS Computer-Assisted Qualitative Data Analysis as coined by Fielding and Lee in the 1990s; some writers refer to it as Computer-Assisted Qualitative Data Analysis Software; it is an alternative term to QDAS for software tools that support the analysis of qualitative data.

Case study Qualitative or mixed methods research providing in-depth inquiry of a bounded social system or complex situation (the case).

Case-based approach Uses a real or realistic story to situate a problem or a dilemma as a basis for learner inquiry, discussion, investigation, and solution development.

Case-based learning system Consists of four essential elements: instructional purposes, learning and teaching, assessment and evaluation, and learning outcomes for both short-term results and long-term impact.

Causal attribution Retrospective appraisal of the relation of observed effects and likely causes.

Causal expectancies Prospective appraisal of the relation of causes to anticipated effects.

Change agent A person or event primarily responsible for initiating and guiding an organization, system, group, or individuals to make changes that are sustainable, feasible, and effective for a given system.

Change management The process by which change is guided, influenced, and communicated within an organization or system.

Civics education Includes the knowledge, skills, and dispositions required for active and responsible participation in society.

Cognitive abilities Abilities to perform such functions as perceiving, reasoning, and judging which are generally associated with knowing and understanding.

Cognitive appraisal A subjective evaluation of situations, competences, activities, and outcomes.

Cognitive demands Mental processing requirements associated with a given learning task; cognitive load theory distinguishes intrinsic load inherent in a task, extraneous load associated with factors surrounding the task, and germane load pertinent to successful performance of the task.

Cognitive processes Processes such as attention, retrieval, and metacognition that control learning and retention.

Cognitive resource theory A cognitive–psychological research theory that emphasizes the limitations of working memory capacity.

Cognitive task analysis An analysis process using structured interviews and other strategies to identify the implicit and often nonconscious mental processes and decisions that experts use to achieve a goal and/or solve a complex problem.

Cognitive tool Cognitive tools are those learning resources intended to help learners construct new knowledge by such means as dynamic representations and context-sensitive interactions; cognitive tools are typically computer-based tools that can extend thinking processes such as problem solving and creativity and in doing so support the learning process.

Collaboration script An explicit description or an internal resource that helps individuals participate successfully in a group learning activity; typically it focuses on some combination of role definitions and guidance about the sequence of activities to be undertaken.

Collaborative learning A situation in which two or more people learn or attempt to learn something together using their combined knowledge and abilities to solve a problem or construct a response.

Colocated collaborative learning Pedagogy that emphasizes the criticality of social interaction synchronously coordinated among learners who are in the same physical location.

Communities of practice Used in an account of the social processes of learning that focuses on participation in stable communities over time.

Competency A related set of knowledge, skills, abilities, dispositions, and other personal attributes, relevant to a task or targeted learning outcome.

Computational modeling The process of studying the behavior of a system using computer simulations and mathematical models.

Computer-supported collaborative learning (CSCL) Refers to a situation in which computer technology plays a significant role in the way in which students work together to maximize their own and each other's learning.

Computer-based scaffolding Support delivered by a computer that allows learners to meaningfully participate in and gain skill at a task that they could not complete unaided; see also instructional scaffolding and scaffolding.

Conative domain Theorized part of the mind, in addition to cognitive and affective, that drives individual will, intent, and ethics.

Conceptual age learning Learning in a knowledge society that is flexible, accessible, immediate, interactive, and focused on collaboration.

Confirmatory evaluation A structured or systematic process to determine the extent to which the assumptions and problems that led to a project or program are still applicable.

Connected teaching Instruction using information and communications technology and informed by policy and research in educational technology.

Constructivist epistemology A naturalistic approach to the theory of knowledge that focuses on describing how people actually develop knowledge and beliefs; an essential aspect of a constructivist epistemology is the notion that individuals construct internal representations in response to various situations as a natural process of interpreting their experiences.

Constructivist principle of learning The notion that the learner is active in coproducing knowledge, rather than a passive recipient of that knowledge.

Context Information that characterizes an object, person, place, or other aspects of a situation; situational factors that influence understanding and meaning making.

Context-aware The capability to leverage mobile sensors and locative technologies to filter and present information to the user on a mobile devices relevant to a physical position.

Context modeling The process of building and frequently updating context information in a context model.

Conversational agent A type of pedagogical agent programmed to interact with learners in open-ended conversations.

Cooperative inquiry A mode of inquiry for action research involving the participant in self-study in groups commonly employing qualitative or mixed methods to understand meaning and outcomes focused on practice.

Cost–effectiveness analysis Analysis that assesses and compares the costs and effects or effectiveness of competing projects or alternative solutions.

Costs of educational technology The value of both direct and indirect resources required to plan and implement educational technology interventions.

Critical mathematics education Mathematics education emphasizing the challenges emerging from the critical nature of mathematics education (especially those concerning equity and social justice).

Cultural–historical theory A research paradigm assuming that development results from the interplay between the individual mind and society; the most important factor influencing learning is social interaction with the world and with others.

Culture All that is man-made, including adaptations to nature; the evolved human capacity to classify and represent experiences with symbols, and to act imaginatively and creatively; the distinct ways that people living in different parts of the world classify and represent their experiences, and act creatively.

Culture-specific Specialized or localized to a target audience.

Data acquisition The process of recording measures of physical or psychological conditions and converting the resulting measures into values that can be manipulated and analyzed.

Data analysis The process of inspecting, cleaning, transforming, and modeling trends or patterns in data in order to highlight useful information, draw conclusions, and support decision making.

Data visualization Graphical representation of data sets or analysis results for the purpose of illustrating relationships among variables and/or subjects in the data.

Data-based decision making Using results to inform pedagogical and programmatic decisions.

Data-driven decision making Similar to data-based decision making with emphasis on creating motivation for action.

Decision making Selecting between two or more alternatives using criteria that are useful to determine which alternative is the best for the conditions in a given situation; the cognitive processes involved in the selection of a course of action among several alternatives.

Design All the activities involved in generating intentional change (e.g., learning or performance) via artifacts and experiences; the activity of creating a plan that can be executed to produce an artifact or an event.

Design and development research The systematic study of design, development, and evaluation processes with the aim of establishing an empirical basis for the creation of instructional and noninstructional products and tools and new or enhanced models that govern their development.

Design and development tools Devices, often computer-based, that support the efficiency and yield of instructional designers and developers.

Design experiments Design research or a specific subset of design research wherein design features of a treatment (e.g., learning program, educational resource, teaching approach) are systematically varied to identify those features with comparatively powerful or weak effects.

Design knowledge Specialized forms of knowledge required to carry out design activities; design knowledge is distinct from scientific knowledge and includes both tacit and explicit declarative and procedural knowledge.

Design model An abstract description of how design can be carried out; a pattern for describing, prescribing, and realizing a way of viewing an act, object, artifact, or product.

Design pattern Captures and shares design experience in a structured text which states the essence of a solution, links it to the contexts in which the solution is applicable, and provides a rationale that connects solution, problem, and context.

Design research Research that is committed to developing theoretical insights and practical solutions simultaneously in real-world (as opposed to laboratory) contexts; it is most often conducted through long-term collaboration among researchers, practitioners, and other stakeholders.

Design science The scholarly research aimed at the explanation and prescription of the design process.

Design-based research See design research.

Desktop manufacturing A digital manufacturing system that is small enough to fit on a desktop and affordable enough for personal use, including personal digital fabrication systems and related technologies such as 3D printers and scanners.

Developmental psychology A subdiscipline of psychology that assumes cognitive processes change in a qualitative fashion as a function of development; an important factor influencing learning is the stage of cognitive development of the learner.

Digital fabrication Translation of a digital design into a physical object through manufacturing technologies such as computer-controlled die cutters and milling machines, 3D printers, and automated assembly systems.

Digital literacy The knowledge and abilities needed to search, locate, organize, analyze, evaluate, and synthesize information to communicate, manage, produce, and perform other tasks involving digital information and technologies.

Digital texts Publications that users can read online or on an e–book device. See also e-books.

Discourse analysis Research method focusing on the use of language through the close study of words, text, speech, or written documents, including understanding of themes, meaning, semiotics, or interaction patterns.

Economic development Increased output or productivity of an economy or policies or structures put in place to promote such development.

Education reform Policies and programs intended to make significant changes in an educational system resulting in significant improvements in learning and performance.

Educational data mining (EDM) A highly interdisciplinary research field based on psychology, education, computer science, and statistics, with a focus on analyzing data that come from the tracking of learner behavior in electronic learning environments; see also learner analytics.

Educational innovation Application of new educational models, methods, and/or resources affecting the traditional relationships between learning systems, teachers, and students.

Educational modeling The process of building learning scenarios using a modeling language, technique, or technology.

Educational psychology The study of theory and practice related to the psychology of teaching, learning, and behavior in educational and training settings.

Educational technology The study and practice of supporting learning and performance by creating, using, and managing appropriate technological processes and resources; any tool, equipment, or device that helps accomplish learning goals; educational technology includes both instructional and learning technologies; the disciplined application of scientific principles and theoretical knowledge to support and enhance human learning and performance; the study and use of technological resources and devices for teaching and learning; see also Januszewksi & Molenda (2008).

Educational technology policy Mandates for schools to utilize educational technologies in classrooms based on the belief that (1) technology can improve instruction and facilitate learning, and (2) students need to develop technology literacy and skills in order to become productive members of society in a competitive global economy.

Educational technology research The study of the impact and effects of using technology to facilitate and enhance learning and performance.

EEG Electroencephalography, which is a neuroimaging technique that involves the recording of voltage fluctuations resulting from ionic current flows within the neurons of the brain.

Efficiency Producing the most of a desired outcome at a given cost, or producing a given desired outcome at the lowest possible cost.

e–book A publication in a digital format that users can read with an electronic device such as an e-book reader, a tablet device, a computer, or a phone; e-book sometimes also refers to the devices on which people read digital publications.

e-learning Learning that happens through an electronic form or is supported with digital devices.

e-learning standards A set of specifications for the design of the components of a learning system.

Electronic books See e-books.

Emotion regulation Processes by which individuals make changes in themselves and their environments in order to influence their emotions.

Epistemology The branch of philosophy focused on examining the nature, methods, limitations, and validity of knowledge.

ERP Event-related potential, which is an electrophysiological response to a sensory, cognitive, or motor stimulus that is measured using electroencephalography.

Essential processing Essential processing is the learner's cognitive processing during learning that is needed to mentally represent the presented material; essential processing includes selecting relevant information and organizing it as presented.

Ethics across the curriculum Teaching and integration of ethics across all disciplines in a formal context.

Ethics as design Use of a design process to address moral or ethical constraints.

Ethnography In depth, holistic inquiry into a human social group typically delineated by a common culture using methods of interview, observation, and artifact analysis undertaken in a naturalistic setting to produce a rich or thick description as its end product.

Evaluation Assessing whether learning occurred and/or learning and other objectives have been achieved for a group of learners associated with a course or program; determination or judgement of the value, worth, or quality of a program, project, or set of activities.

Evidence-based policy A policy model in which research evidence is synthesized through systematic processes of aggregation, typically favoring the integration of randomized control trials.

Evidence-based practice Adopting evidence as the foundation for educator practice.

Evidence-centered design (ECD) A framework that provides design principles to build and implement educational assessments as coherent evidentiary arguments.

Experimental design A type of study which uses random selection and assignment of participants to a treatment or control group; this should result in groups that are statistically equivalent on both observable and unobservable characteristics thereby allowing causal inference and attribution.

Expertise Skill and knowledge gained over time by consistently solving problems of increasing complexity and achieving goals in an environment with stable regularities.

External validity Stimulus materials that are realistic in either content or design that relate to real-life applications.

Extraneous processing In cognitive load theory, the learner's cognitive processing during learning that does not support the instructional goal; a kind of undesirable cognitive load; see cognitive demands.

Feedback Information about actual performance in relation to the intended goal for the purpose of improving learning or performance.

Fidelity The extent to which implementation matches the intended program model.

Flexible learning environments A learning environment in which learners are able to follow and design their own learning trajectories given the formal learning goals.

fMRI Functional magnetic resonance imaging, which is a neuroimaging technique that uses the change in magnetization between oxygen-rich and oxygen-poor cerebral blood as its basic measure of brain activity.

fNIRS Functional near-infrared spectroscopy, an optical neuroimaging technique that images brain activity by detecting changes in cerebral blood flow using a near-infrared light sensor.

Formative assessment A constant adjustment process used by both teachers and students to improve teaching and learning using information gathered from formal and informal assessments.

Formative evaluation A structured or systematic process to continuously monitor the progress of a project or program to help ensure its success in achieving intended outcomes; sometimes referred to as process evaluation; the basis for a fidelity of implementation study; the iterative collection and feedback of process data to support program development and improvement.

Formative research Often a synonym for design research; may also refer to the formative testing and subsequent refinement of any treatment (e.g., learning programs, educational resources, or teaching approaches).

Front-end analysis A systematic approach to analyzing the specific knowledge, skills, motivation, prior experience, and tools required to perform a job or set of tasks in advance of designing training or performance improvement interventions.

Generational differences The theory that people born within an approximately 20-year time period share a common set of characteristics based upon the historical experiences, economic and social conditions, technological advances, and other societal changes they have in common.

Generative processing The learner's deep cognitive processing during learning aimed at making sense of the presented material; it includes mentally reorganizing information and integrating it with relevant prior knowledge activated from long-term memory.

Gestalt psychology An approach in psychology that assumes the human mind is operating in a holistic fashion with self-organizing tendencies; the most important factor influencing learning is reaching insight and understanding through restructuring.

Grounded theory A formal and rigorous process of collecting and analyzing qualitative data using an inductive approach to generate commonalities with methodological variations including social, interpretive, and critical grounded theory.

HIMATT Highly Integrated Model Assessment Technology and Tools; a set of related and interoperable Web-based tools to analyze concept maps and text that can be represented in the form of a concept map in order to determine progress of learning in complex, problem-solving domains.

Historical inquiry Constructing historical interpretations after exploring, questioning, scrutinizing, and analyzing multiple sources.

Human performance technology (HPT) The study and practice of improving productivity and performance in an organization by planning and implementing interventions that are results-oriented, comprehensive, systemic, the effectiveness of which can be measured.

ICT (information and communications technologies) competencies Abilities that involve basic and general-purpose applications of information and communication technologies in the home, office, or school.

ICT impact The documented influence of information and communication technologies on any of a range of potential outcomes, such as teaching practice or student learning.

ICT literacy assessment Diagnosis and evaluation of ICT competencies, from management, storing, navigation, and communication of information to creatively produce new information and the use of digital or electronic devices and telecommunications.

ICT policy Governmental policies and programs related to the implementation and use of information and communication technologies.

Ill-structured tasks Tasks with ill-defined learning goals, with multiple solutions or solution paths, and/or with partially defined initial, transition, or goal states.

Immersive technologies Technologies that create the impression that one is participating in a realistic experience via the use of sensory stimuli, narrative, and symbolism.

Individual and group differences Those preferences, traits, and learned behaviors that define and differentiate each learner, educator, and cohort from their peers in the ways they understand themselves, how they learn, interact, and respond to information and contextualize it.

Informal learning Learning activities that typically take place in out-of-school settings, including activities that comprise after-school programs or those in youth and community organizations, including museums, botanical gardens, and zoos; informal learning may also include self-instructional activities.

Informal science education Science learning experiences, programs, or activities take place outside the classroom in such settings as museums, science centers, and media outlets.

Information processing theory A research theory that assumes the human mind is an information-processing device with different components; the most important factor influencing learning is the active mental processing of information.

Information visualization The use of computer-supported, interactive, visual representations of abstract data or objects to amplify cognition and improve comprehension.

Innovative technologies New or emerging products or technologies that enable new methods of communication or interaction with resources that affects learning and instruction.

Inquiry learning An approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, formulating hypotheses, testing hypotheses, explaining findings, and generating alternative possibilities in the search for new or deeper understanding.

Instruction Any activity that supports learning and informs teaching; a conversational form that has the potential for leading to learning.

Instructional communications system A communications system made up of interrelated parts that depend on each other for input and output, working together toward the common goal of facilitating learning.

Instructional design (ID) A methodology for analyzing, designing, producing, evaluating, delivering, and testing a learning system; the systematic process and design science involved in creating instructional activities and learning environments that facilitate engagement in the learning process; the activity of creating a plan for an instructional conversation which can be executed through live and/or technology-based means to supply the potential for learning; a purposeful activity that results in strategies, activities, and resources which facilitate or enhance learning; see also Januszewksi & Molenda (2008).

Instructional design model An abstract description, usually at a high level of generality, of how instruction can be designed; a graphic or verbal representations of organized procedures for planning and implementing instructional materials, materials and programs.

Instructional designer A person who has or is acquiring the competencies to design instruction; see also http://www.ibstpi.org.

Instructional development The execution of a design to produce through live and/or technology-based means conversational occasions and/or other resources to promote learning.

Instructional engineering A methodology based on software and knowledge engineering principles, applied to instructional design.

Instructional message design The specification and manipulation of media for the purpose of supporting learning.

Instructional products Planned solutions that facilitate a change in learning (e.g., a digital educational game) or performance (e.g., an electronic performance support system).

Instructional scaffolding Support provided by a teacher/parent, peer, or a computer- or paper-based tool that allows students to meaningfully participate in and gain skill at tasks that they could not complete unassisted; see also computer-based scaffolding and scaffolding.

Instructional strategies Methods or approaches to support learning.

Instructional systems design (ISD) A structured process for the design, development, implementation, and evaluation of learning to improve performance and ensure the quality of instruction with primary roots in adult education; an abstract concept that refers to a variety of instructional design models often connected with or based on the concepts of systems engineering and systems engineering methods; see also instructional design, instructional development, and instructional engineering.

Instructional technology Educational technologies teachers and others employ to support learning; see also see also Januszewksi & Molenda (2008).

Intelligent tutoring system (ITS) A system designed to tutor learners and that can adapt based on learner variables such as performance and preferences.

Interactive spaces A generic category meant to capture environments that intend to connect disparate devices through networking protocols and may include sensor and recording technologies.

Interactive surfaces A generic category meant to capture a range of devices including smartphones, tablets, and tabletops.

Internal validity In a research context, that which is designed to eliminate sources of extraneous variance from the environment that could confound results.

Interpretive tradition Qualitative research with an emphasis on individual perception and interpretation of experience, often from the participant's point of view; includes narrative, auto-ethnographic, and phenomenological approaches.

Kinesthetic learning Learning that is grounded in movement, gesture, posture to enhance cognitive and affective components.

Knowledge diagnosis A systematic assessment of structures of declarative knowledge and procedural knowledge by means of specific measurements.

Knowledge-based design The structure of a learning system resulting from a knowledge engineering activity.

Learner agency The empowerment of the learner as an active entity capable of self-regulation.

Learner modeling The process in which cognitive, affective, and behavioral characteristics of individual learners are measured and incorporated in a model, with the aim to personalize learning for the individual; also called user modeling (UM) or student modeling.

Learning The outcome of acquiring knowledge or information; the process of constructing knowledge and skills; a relatively stable change in what a person knows or can do.

Learning ability The ability develop knowledge and acquire expertise and/or to direct and regulate one's own learning.

Learning analytics The measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs.

Learning design The application of design knowledge while developing a concrete unit of instruction, such as a course, a lesson, a curriculum, or a learning activity.

Learning environment An instructional system that offers a task environment with learning resources and that provides support to help students develop the knowledge and skills involved in that task.

Learning opportunity Instructional interventions or situations aimed at providing learners an opportunity to develop knowledge and skills.

Learning styles a general description of the attitudes, behaviors, and preferences that influence how an individual may best learn various things.

Learning technology Educational technologies learners use to accomplish specific learning objectives and tasks.

Learning theories Learning theories reflect the outcomes of research on learning that have developed over time with changing paradigms; they provide a conceptual framework and sets of key variables likely to influence learning.

Learning through collaboration A learning process in which two or more people communicate, share resources, and/or negotiate meanings to achieve their shared learning goals.

Lesson planning Processes for designing classroom instruction, commonly used by teachers in primary and secondary schools and applied within a curriculum framework.

Location-based method The capability to leverage GPS, compass, and gyroscope technologies to present environment-specific digital media to learners as they move through a physical area with a smartphone or similar mobile device.

Logic model A representation of the (a) assumptions and problems leading to a project or program, (b) the input factors and variables that affect the situation and that may or may not be affected by the planned intervention, (c) the immediate outputs of interim and enabling developments of the project or program, and (d) the short-term and longer-term outcomes of the project or program; a visual depiction of the theory of change associated with a project or program.

Mathematics education The practice of teaching and learning mathematics, along with the associated scholarly research.

Media arts An art form making use of electronic technologies such as computer graphics, animation, interactive art, robotics, and virtual environments.

Medical education The institutions and processes (formal and informal) involved in preparing medical students entering the medical profession as physicians and the processes of maintaining professional development opportunities for practicing physicians.

Medical school reform Large-scale efforts to update and enhance overall medical school curriculum.

Mental model A mental representation that people use to organize their experience about themselves, others, the environment, and the things with which they interact; its functional role is to provide predictive and explanatory power for understanding these phenomena.

Mental representation A theoretical construct to explain ongoing information processing in the human brain.

Message Ordered sets of perceptual elements or cues drawn from a particular pool and assembled in a deliberate way for the purpose of modifying psychomotor, cognitive, or affective behavior.

Metacognition The knowledge of and ability to monitor one's own cognitive processes while formulating and modifying plans, assessing progress, and reevaluating goals.

Millennials People born in or after 1982 (approximately) who are members of the first generation who were born after the advent of digital media and who have grown up with these media; also called digital natives.

Mobile learning Learning that leverages the portability and connectivity of a smartphone, tablet, or other device that can be held without strain in one hand and moved from one location to another.

Model A mental or physical construct of a referent; the referent of a model may be a natural or artificial object, process, or phenomenon.

Model-based reasoning Model-based reasoning is the process of analyzing the natural world and making inferences through using, building, evaluating, and refining models; an instructional strategy which involves students working with models; it often refers to the theory of mental models.

Motivation to learn Desire and willingness to initiate and continue learning-related activities.

Multicultural Relating to or including several cultures.

Multicultural learning The respect for and support of multiple cultures within an instructional setting or learning environment incorporating instructional materials presented in a manner that supports their existing cultural interpretations so as to maximize the effective learning potential and foster respect for diversity.

Multimedia learning Learning supported with multiple media (e.g., text, pictures, and video).

Multiuser virtual environment Digital systems allowing many online users to build digital spaces, manipulate avatars, and interact with other online users and the virtual environment.

Natural user interface A system in which the user manipulates a digital application using hands, gestures, or spoken language.

Needs assessment A structured or systematic process to determine the nature of a problematic situation as an initial step in elaborating alternative solution approaches.

Networked learning Learning in which information and communication technology is used to promote connections between and among learners, between learners and tutors, or between a learning community and various resources.

Neuroimaging The use of direct or indirect methods to image the structure and function of the brain.

Neuroscience The study of the nervous system that advances our understanding of human emotion, cognition, and behavior.

Non-scaffolding instructional support A category that includes other tools (e.g., job aids) that help students accomplish tasks.

One-to-one scaffolding Dynamic support provided by one teacher/parent to one student that allows the latter to meaningfully participate in and gain skill at a task that he/she could not complete unaided.

Open educational resources Educational materials either in the public domain or licensed under an open license such as Creative Commons.

Open learning environments Learning settings where the individual engages learning activities with minimal external direction (see self-directed learning).

Organizational change The dynamic shifts in the complex and multifaceted practices, beliefs, and structures within an organization from one state of being to a different state as a result of planned or unplanned agents of change.

Participatory action research A specific genre of action research that differs from classroom-based action research in that emphasis is on addressing critical social issues that extend beyond the classroom.

Pathfinder A system for deriving and representing the organization of knowledge structure.

Pedagogical agent Anthropomorphous virtual characters employed in online learning environments to serve various instructional goals.

Peer scaffolding A type of one-to-one support that is provided by a peer rather than a teacher/parent and guided by a scaffolding framework that allows students to meaningfully participate in and gain skill at a task that they could not complete unaided.

Performance appraisal The procuring, analyzing, and documenting of facts and information about an employee's net worth to the organization with the goal of measuring and constantly improving the employee's present performance and tapping the future potential.

Performance evaluation Prepared by an organization on a periodic basis to determine if employees are working up to, or beyond, the minimum standards of their job descriptions.

Performance task A performance task is a goal-directed assessment exercise consisting of an activity or assignment that is completed by the student and then judged by the teacher or other evaluator on the basis of specific performance criteria.

Performance-based training A special application that closes gaps between actual and desired human performance in organizations that arise owing to a lack of skill and knowledge.

Personalized instruction Instruction that has been modified or adapted in some way, either manually by the teacher or automatically using adaptive technologies, to meet the individual needs of a learner based on information obtained about that individual student.

Personalized learning The method by which learners are offered tailored instruction and support, personalized to the individual needs, goals, or behavior of learners.

Phenomenology A philosophical discipline aimed at understanding lived individual experiences or life worlds; a naturalistic approach to epistemology.

Philosophy of science The study of how scientific knowledge develops over time and across a variety of disciplines with emphasis on evidence, knowledge production, and the formation of theories to explain observed phenomena.

Policy sociology An account of the process of policy formation and implementation that focuses on actors and their actions, rather than exclusively on the policy texts that are produced.

Portfolio assessment Structured examinations of collected samples of student work.

Post-positivist science A model of scientific inquiry that emphasizes the notions of falsification and establishment of causal relationships to develop meaningful interpretations of phenomena.

Precedent With regard to design knowledge, a precedent is the experience (immediate or vicarious) one designer obtains of the work of another and/or any life experience that affords the basis for design moves/decisions.

Preservice teachers Candidates for primary or secondary teaching positions enrolled in an initial teacher education program en route to becoming classroom practitioners.

Prior knowledge Existing learner knowledge that influences which to-be-learned knowledge is selected and how it is organized and integrated.

Problem solving The process of articulating and solving problems in which a person has to change a starting situation into a desired end situation with through various operations and transformations; a mental process that involves discovering, analyzing, and solving tasks.

Problem types External factors defining problems create categories of problem types based on structuredness, complexity, and context.

Problem-based learning An instructional approach in which students construct knowledge and develop expertise as they solve problems representative of actual problems in a professional discipline.

Professional development The acquisition of the skills, knowledge, and expertise and other characteristics of a profession such as teaching; the training of teachers who are already teaching students in schools.

Professional ethics A set of standards and/or codes of conduct intended to guide the behavior and practice of the members of a given profession.

Program evaluation A structured or systematic process to determine how well a project or program is being implemented (fidelity of implementation) and to what extent the project or program is achieving its intended aims (impact); the systematic determination of a program's quality, utility, and/or effectiveness for use to make decisions and guide action.

QDA Qualitative Data Analysis; the range of processes and procedures whereby a researcher moves from the qualitative data that have been collected to some form of explanation, understanding, or interpretation.

QDAS Qualitative data analysis software; software tools that support the analysis of qualitative data.

Qualitative research Systematic and rigorous investigation of human behavior or phenomena commonly undertaken in naturalistic settings that emphasize words, meanings, beliefs, and symbols rather than numeric (statistical) patterning.

Qualitative research methods Methods of social research based principally on theoretical principles of interpretivism as expressed in approaches such as symbolic interactionism, hermeneutics, and ethnomethodology.

Quantitative tools Statistical analysis techniques designed to help discover trends and derive inferences regarding associations among variables in a data set.

Quasi-experimental design A design that results in intervention and comparison groups demonstrating baseline equivalence on observed characteristics through a process other than random assignment.

Realistic mathematics education A view that mathematics education should give students guided opportunities to reinvent or discover mathematics by doing mathematics.

Real-world problemsolving Goal-oriented activities to reduce unknowns and solve a problem that actually exists or easily could exist; the process includes representing situations, defining goals, generating possible strategies, executing selected strategies, and reflecting on the effects.

Representation A depiction of an object or system visually, mathematically, and/or with text.

Research Using a systematic process to test a hypothesis or study phenomena.

Research funding Monetary (and in-kind) support for research.

Research methods Procedures and analytic techniques used to empirically establish the validity of claims.

Research paradigm Set of practices (what is studied, kind of research questions posed, how and with what tools studies are conducted, how results are analyzed and interpreted, etc.) defining a scientific discipline or subdiscipline; example research paradigms include positivist, interpretivist, critical, and post-structural approaches.

Research quality Formal process for evaluating systematic research studies examining design, methods, analysis, and assumptions for validity and credibility.

Rubrics Scoring guide for assessing performance based on the articulated performances related to performance criteria.

Scaffolding Guidance to support students in identifying goals, self-checking, navigating, assessing progress, understanding, and refining goals and strategies.

Scaffolding The process by which a teacher, a more knowledgeable peer, or tools within the learning environment assists a student at appropriate times appropriate in solving problems or accomplishing tasks that would otherwise be out of reach; see also computer-based scaffolding and instructional scaffolding.

Science of learning The scientific study of how people learn.

Scientific inquiry The disciplined investigation of phenomena with emphasis on understanding natural and social phenomena, seeking evidence, and explaining unusual events.

Scientific reasoning The ability to apply the scientific inquiry skills of hypothesis generation, experimentation and/or observation, and evidence evaluation in reasoning or problem-solving situations.

Self-directed learning Ability to formulate one's own learning needs, determine goals, initiate learning tasks, and assume responsibility for decisions associated with one's own learning.

Self-regulated learning Ability to monitor and steer one's own learning processes; see self-directed learning.

Self-regulation An active process characterized by learners setting goals for their learning and attempting to monitor and regulate their knowledge and behavior.

Serious games Computer or video games intended to support specific learning outcomes.

Simulation Imitating the behavior of a real-world process or system by simplifying and depicting the operation of critical elements and interactions over time using symbolic representations intended to help someone learn about the process; a technological environment that simplifies or enhances reality while retaining the fundamental validity of what is to be experienced or learned.

Situated cognition An approach that stresses that the context in which something is to be learned affects what is learned; more specifically, an approach that proposes that learning takes place as people solve problems and accomplish tasks within the social and physical contexts where the learning is actually applied.

Situated learning Assumes that knowing is inseparable from doing, and all knowledge is situated in activities bound to physical, social, and cultural contexts; learning should be presented in authentic contexts where learners would actively understand and use their learning.

Situation awareness Is the perception of current environmental elements with regard to their dynamic changes and the comprehension of their meaning.

Smart toy Play materials including tangible objects alongside electronic components that facilitate two-way child/smart toy interaction to carry out a purposeful task.

Social constructivism Emphasizes social interaction and collaboration among learners as essential components in the process of learning and teaching; as members of a learning community, learners become involved in common activities that embody certain beliefs and behaviors these learners need to acquire.

Social constructivist theory A research theory that combines perspectives from developmental psychology and cultural-historical theory; the most important factor influencing learning is the construction of meaning and knowledge through the interaction with others.

Social responsibility Systematic planning or design emphasizing outcomes at the societal level.

Stealth assessment A nonintrusive, evidence-based approach to assessment that is woven directly into learning environments to gather ongoing performance data and yield valid inferences about competency states.

STEM The fields of Science, Technology, Engineering and Mathematics; a new variant called STEAM includes the arts.

Stimulus materials Materials, often instructional in nature, that are designed to present a message in a systematic manner of which the resulting effect can be observed and/or measured.

Student modeling A process whereby information about students is stored, including domain competence and individual domain-independent characteristics; the process of building and updating the student model.

Student-centered learning A pedagogical approach in which students have primary responsibility for determining learning goals and/or the means to reach these goals.

Studio pedagogy A pedagogical pattern found in multiple fields of design study that includes consistent elements including group work space, public critique, hands-on practice as the primary activity of students, and support for problem solving as a primary activity of instructors.

Summative assessment A structured or systematic process to determine the extent to which an individual has achieved or is achieving the intended aims of instruction.

Summative evaluation A structured or systematic process to determine the extent to which a project or program has achieved or is achieving its intended aims.

Support device usage The use of support devices by learners, expressed in quantitative and qualitative variables.

Support devices Devices aiming to support learners in executing a learning task.

Symbolic cognitive theory A cognitive-psychological research theory that assumes meaning is conveyed in cognitive schemas and rules; the most important factor influencing learning is what the learner already knows.

System change Alterations in the complex actions, resources, structures, and relationships of a social or physical system within the system as well as with surrounding systems and influences that may be nested, interconnected, or interdependent.

Systems thinking The process of understanding and reasoning how elements in a complex whole influence one another and lead to or result in system behaviors.

Systems approach A robust, multidisciplinary problem-solving process with emphasis on determining the problem to be solved and then characterizing it through an iterative process until known processes can be brought to bear in resolving it.

Systems philosophy A way of thinking about and dealing with complex systems and their components.

Teachable agent A type of pedagogical agent that learns and improves as a result of interactions with human learners.

Teacher education A formal process for training primary and secondary teachers for classroom positions, most commonly through initial coursework in higher education and including ongoing professional development for practitioners.

Teacher technological knowledge The knowledge teachers have for effectively integrating technology in their teaching.

Teaching Guiding, showing, training, and otherwise facilitating the construction of knowledge and skills.

Technological, pedagogical and content knowledge (TPACK) Refers to the multiple and interconnected layers of professional knowledge (technological knowledge, pedagogical knowledge, content knowledge) that teachers need to integrate technology into learning and instruction.

Technology The application of knowledge to solve practical problems and change or manipulate human surroundings; technology includes the use of materials, tools, techniques, and more; technology involves knowledge, machines, techniques, systems, and so on in order to solve a problem or perform a specific function.

Technology integration Creating, using, and managing innovative and appropriate technological processes and resources to enhance learning and performance; the effective implementation of educational technologies to accomplish intended learning outcomes; the practice and art of incorporating technology into educational contexts; the use of informational and educational technology in instructional settings to support learning.

Technology readiness Possession of knowledge and skills preparing one to become a productive technology-using member of modern society.

Technology transfer The process of transferring or sharing knowledge, technological resources, and devices, methods of manufacturing, and other information among universities, governments, or other institutions.

Technology-enabled assessment Assessment that utilizes technology to facilitate and improve a teacher's ability to measure student learning outcomes.

Textbooks Publications used to teach a subject, especially in the context of formal education.

Theory of change The evidence or research-based rationale that explains how and why a project or program (an intervention) will transform a problematic state of affairs into a desired state of affairs.

Toy Play objects or materials usually designed for children.

TPACK See technological, pedagogical, and content knowledge.

Training A systematic approach to learning and development to improve individual, team, and organizational effectiveness; instruction intended to improve performance or support learning of a specific level of knowledge and skill required to perform some aspect of a job or task.

Transfer of learning Generalization of learning to novel situations that go beyond tasks learned.

Transfer of responsibility The student's assumption of control of a task that was previously scaffolded.

Transformative policy Political or administrative procedures that allow for experimentation or testing of ideas; in this case, with reference to using technologies in teaching and learning.

Usability The ease with which the intended audience (called users) can achieve the intended goals or objectives for a product, service, or software, as assessed using observation, measurement, and heuristic review.

Virtual worlds Immersive simulated environments in which a participant uses an avatar (a digital representation of oneself) to interact with digital agents, artifacts, and contexts.

Visual arts Fine and applied visual art forms, including drawing, painting, photography, sculpture, and video and filmmaking.

Visual arts education Teaching and learning related to the visual arts.

Web 2.0 A term coined to cover Web applications that allow users to create and share information, and collaborate on the Web; second-generation Internet-based services that include tools that let people collaborate and share information online, such as social networking sites, wikis, communication tools, and folksonomies.

Web-based learning environments The result of the instructional design/engineering process when delivered on the Web.

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