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

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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 micro-theories 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 policymakers, 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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