Springer International Handbooks of Education

SPRINGER REFERENCE

Marc J. de Vries *Editor*

Handbook of Technology Education

Springer

Springer International Handbooks of Education

The *Springer International Handbooks of Education* series aims to provide easily accessible, practical, yet scholarly, sources of information about a broad range of topics and issues in education. Each volume follows the same pattern of examining in depth a field of educational theory, practice and applied scholarship, its scale and scope for its substantive contribution to our understanding of education, and, in so doing, indicating the direction of future developments.
The volumes in this series form a coherent whole due to an insistence on the synthesis of theory and good practice. The accessible style and the consistent illumination of theory by practice make the series very valuable to a broad spectrum of users. The volume editors represent the world's leading educationalists. Their task has been to identify the key areas in their field that are internationally generalizable and, in times of rapid change, of permanent interest to the scholar and practitioner.

More information about this series at http://www.springer.com/series/6189

Marc J. de Vries
Editor

Handbook of Technology Education

With 108 Figures and 40 Tables

Springer

Editor
Marc J. de Vries
Department of Science Education and Communication
Delft University of Technology
Delft, The Netherlands

ISBN 978-3-319-44686-8 ISBN 978-3-319-44687-5 (eBook)
ISBN 978-3-319-44688-2 (print and electronic bundle)
https://doi.org/10.1007/978-3-319-44687-5

Library of Congress Control Number: 2017950489

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This *Handbook of Technology Education* is the first on technology in the prestigious Springer series of educational handbooks. That means it is a milestone publication for the field of technology education, as Springer is a highly respected publisher and the handbook series for many years already had volumes on science and mathematics education. The fact that there is now a volume on technology acknowledges that technology education has matured to the level where a handbook like this can be produced. This does not mean that 2017 is the year in which technology education can claim this maturation for the first time. There was an earlier *Handbook on Technology Education Research and Development*, published by Sense Publishers in 2009. There are two good reasons to have a new handbook now. In the first place, 2009 is eight years ago and a lot has happened since then. The Sense handbook is not outdated in that the information it contains is no longer relevant, but it does not contain recent developments and debates. Secondly, for the visibility of the field of technology education, it is important to have a volume in the well-established and respected handbook series by Springer. For a long time already, Springer has been committed to technology education by publishing the *International Journal of Technology and Design Education* since 1990. The fact that Springer now has a technology education volume in the handbook series confirms this commitment.

That technology education can be said to have mature to a certain extent, but perhaps not always to the extent that other school subjects have evolved, can be read from this handbook also. Some topics are obviously missing and the reason for that is that it appeared not to be possible yet to find a critical mass of research to be surveyed in a handbook chapter, and mostly this meant that it was also not possible to find an author for that topic. Particularly, the final section is rather thin, more than it would have been for science or mathematics education. Some other examples are: the relation between technology education and mathematics education, biotechnology in technology education, and teachers' concepts of technology (education). Hopefully, a second international *Handbook of Technology Education* will fill those gaps when more studies on those topics have become available.

It was a pleasure for me to work with seven colleagues who served as part editors and whom I have learnt to appreciate so much in the years that I know them and have worked with them. My respect for them has increased even further during the process of editing this handbook together with them. Many thanks for the excellent work (in the order of their parts), John Dakers, John Williams, Moshe Barak, Wendy Fox, John Ritz, Kay Stables, and Steve Keirl. It was great working with you (again).

This was not my first experience in working with Springer. Once more, I am impressed by the high level of professionality with which the process of publishing with them is supported. Thank you, Bernadette Ohmer, Marianna Pascale, Mokshika Gaur, Sindhu Ramachandran, Audrey Wong, and all the other Springer people whose names I never got to know but who did their work in the background to realize this publication.

Many thanks of course to all authors. Several of you met a new side of me, as you have found out how persistent I can be when it comes to deadlines. Apologies for being very "pushy" at times. Thanks for delivering high-quality texts. Together we have made a very good publication.

January 2017 Marc J. de Vries
Delft

Contents

About the Editor

Marc J. de Vries
Department of Science Education and Communication
Delft University of Technology
Delft, The Netherlands

Dr. Marc J. de Vries is professor of Science Education and affiliate professor of Christian Philosophy of Technology at Delft University of Technology, the Netherlands. He is currently the editor-in-chief of *International Journal for Technology and Design Education*, published by Springer. He was the editor of an introductory book on philosophy of technology for technology educators, *Teaching About Technology*. He is the chairperson of the PATT Foundation that organizes the international PATT conferences, in cooperation with colleagues worldwide. He previously worked as a technology teacher educator, coauthored a Dutch textbook for secondary technology education, worked with Dutch educational television on a series for technology education, cofounded the Dutch Association for Technology Teachers, wrote a book on the history of Philips Research (*80 Years of Research at the Philips Natuurkundig Laboratorium (1914–1994)*), and serves as series editor for the International Technology Education Studies book series with Sense Publishers.

Contributors

Piet Ankiewicz Department of Science and Technology Education, University of Johannesburg, Auckland Park, South Africa

Cecilia Axell Department of Social and Welfare Studies, Linköping University, Norrköping, Sweden

Moshe Barak Department of Science and Technology Education, Ben-Gurion University of the Negev, Beer Sheva, Israel

David Barlex University of Exeter Associate, Exeter, UK

Durdane Bayram-Jacobs Science Communication, Science Education and Communication, Delft University of Technology, Delft, The Netherlands

Marnie Best School of Education, University of South Australia, Adelaide, SA, Australia

Paulo Blikstein Graduate School of Education and (by courtesy) Computer Science Department, Stanford University, Stanford, CA, USA

Berit Bungum Faculty of Social and Educational Sciences, Department of Teacher Education, NTNU-The Norwegian University of Science and Technology, Trondheim, Norway

Donal Canty University of Limerick, Limerick, Ireland

Vinson Carter Department of Curriculum and Instruction, University of Arkansas, Fayetteville, AR, USA

Dennis Cheek National Creativity Network, Jacksonville, FL, USA

Entrepreneurship and Innovation Track, IÉSEG School of Management, Paris, France

Vicki J. Compton Ministry for Primary Industries, Wellington, New Zealand

Christine M. Cunningham Museum of Science, Boston, MA, USA

John R. Dakers Delft University of Technology, TUDelft, The Netherlands

Michael K. Daugherty Department of Curriculum and Instruction, University of Arkansas, Fayetteville, AR, USA

Martha E. Davis Museum of Science, Boston, MA, USA

Michael A. de Miranda Claude H.Everett, Jr. Endowed Chair in Science and Engineering, Texas A&M University, College Station, Texas, USA

Marc J. de Vries Department of Science Education and Communication, Delft University of Technology, Delft, The Netherlands

Bjørn-Tore Esjeholm The University of Tromsø – The Arctic University of Norway, Alta, Norway

Martin Fislake Department of Technology Education, University of Koblenz, Koblenz, Rheinland-Pfalz, Germany

Wendy Fox-Turnbull School of Sciences and Physical Education, University of Canterbury, Christchurch, New Zealand

Bev France School of Curriculum and Pedagogy, Faculty of Education and Social Work, The University of Auckland, Auckland, New Zealand

Jacques Ginestié Aix-Marseille Université, EA 4671 ADEF, Marseille, France

Gabriele Graube Technical University of Braunschweig, Braunschweig, Germany

Mishack T. Gumbo Department of Science and Technology Education, University of South Africa, Pretoria, South Africa

Michael Hacker Hofstra University Center for STEM Research, Hempstead, NY, USA

Maaike Hajer HU University of Applied Sciences Utrecht, Utrecht, The Netherlands

Malmö University, Malmö, Sweden

Jonas Hallström Technology and Science Education Research (TESER), Department of Social and Welfare Studies, Linköping University, Norrköping, Sweden

Eva Hartell KTH Royal Institute of Technology, Stockholm, Sweden

Cliff Harwood Chanel College, Masterton, New Zealand

Grietjie Haupt Department of Science, Mathematics and Technology Education, University of Pretoria, Pretoria, South Africa

Ann Marie Hill Faculty of Education, Queen's University, Kingston, ON, Canada

Kaiju Kangas Faculty of Educational Sciences, University of Helsinki, Helsinki, Finland

Steve Keirl Goldsmiths, University of London, London, UK

Nina Kilbrink Department of Educational Studies, Karlstad University, Karlstad, Sweden

Richard Kimbell Goldsmiths, University of London, London, UK

Remke Marleen Klapwijk Delft University of Technology, Delft, The Netherlands

Cathy P. Lachapelle Museum of Science, Boston, MA, USA

Diarmaid Lane School of Education, University of Limerick, Limerick, Ireland

Kuen-Yi Lin National Taiwan Normal University, Taipei City, Taiwan

Thomas Loveland University of Maryland Eastern Shore, Baltimore, MD, USA

Denise MacGregor University of South Australia, Adelaide, SA, Australia

Ingelore Mammes Faculty of Education, University Duisburg-Essen, Essen, Germany

Gene Martin Texas State University, San Marcos, TX, USA

Chris Merrill Department of Technology, Illinois State University, Normal, IL, USA

Louise Milne Faculty of Education, University of Waikato, Hamilton, New Zealand

Sonja Niiranen Department of Teacher Education, University of Jyväskylä, Jyväskylä, Finland

Margarita Pavlova The Education University of Hong Kong, Hong Kong, Hong Kong

Owain Pedgley School of Engineering, University of Liverpool, Liverpool, UK

Stephen Petrina Faculty of Education, The University of British Columbia, Vancouver, BC, Canada

Joseph C. Pitt Department of Philosophy, Virginia Tech, VA, USA

Patricia Potter Pompallier Catholic College, Whangarei, New Zealand

Philip Anthony Reed STEM Education and Professional Studies, Old Dominion University, Norfolk, VA, USA

John Ritz Old Dominion University, Norfolk, VA, USA

Marion Rutland Department of Education, University of Roehampton, London, UK

Niall Seery Athlone Institute of Technology, Athlone, Ireland

Royal Institute of Technology, KTH, Stochlom, Sweden

Pirita Seitamaa-Hakkarainen Faculty of Educational Sciences, University of Helsinki, Helsinki, Finland

Bahar Sener School of Engineering, University of Liverpool, Liverpool, UK
Department of Industrial Design, Middle East Technical University, Ankara, Turkey

Wendy Slatter School of Curriculum and Pedagogy, Faculty of Education and Social Work, The University of Auckland, Auckland, New Zealand

David Spendlove University of Manchester, Manchester, UK

Yvonne M. Spicer National Center for Technological Literacy, Museum of Science, Boston, MA, USA

Kay Stables Goldsmiths, University of London, London, UK

Giovanni P. M. Stijnen NEMO Kennislink, Amsterdam, Netherlands

Johannes Strobel School of Information Science and Learning Technologies, University of Missouri, Columbia, MO, USA

Maria Svensson Department of Curricular, Pedagogical and Professional Studies, University of Gothenburg, Gothenburg, Sweden

Maarten C. A. van der Sanden Science Communication, Science Education and Communication, Delft University of Technology, Delft, Netherlands

Gerald van Dijk HU University of Applied Sciences Utrecht, Utrecht, The Netherlands

Belinda von Mengersen National School of Arts, Australian Catholic University, Sydney, NSW, Australia

P. John Williams School of Education, Curtin University, Perth, WA, Australia

Part I

Philosophy of Technology and Engineering

Philosophy of Technology and Engineering 1

John R. Dakers

Abstract

Since the second world war, technical education was, and I would argue still is, considered to be vocational in nature. Formerly, technical education was considered to be a training ground for boys who were considered to be less academic as informed by an intelligence test administered at age eleven. Girls were also tested and similarly, those who failed the test were streamed into the study of domestic science, a vocational training for their futures as housewives and mothers. This ideology followed the basis of the academic – vocational divide or the Cartesian brain versus the body debate. Alas, these debates continue in a variety of formats to this very day, albeit politically nuanced in the actual delivery of a more sophisticated school system. The delivery of Technical education today has undergone a metamorphosis into what we now recognise as Technology education. However, many would argue that technology education continues to lack a critical and philosophical perspective as stated by Goodman:

> Whether or not it draws on new scientific research, technology is a branch of moral philosophy, not of science. [. . .] Technology must have its proper place on the faculty as a learned profession important in modern society, along with medicine, law, the humanities, and natural philosophy, learning from them and having something to teach them. As a moral philosopher, a technician should be able to criticize the programs given him to implement. As a professional in a community of learned professionals, a technologist must have a different kind of training and develop a different character than we see at present among technicians and engineers" (Goodman, 2010: 40–41)

The following chapters in this section offer a variety of critical and philosophical perspectives on the technology education.

J.R. Dakers (✉)
Delft University of Technology, TUDelft, The Netherlands
e-mail: dakers@orange.fr

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_67

Keywords
Philosophy • Technological literacy • Pedagogy • Engineering • Technology • Nomodology • Social critique • Religion • Problem solving • Culture • Teaching

Contents

Introduction

First published in 1970, Paul Goodman offers a somewhat prescient perspective that serves to reveal, in succinct terms, that the content of technology education needs to transcend the mere provision of vocationally orientated skills, which tends to continue as the dominant orthodoxy today. In the evermore technologically textured world we now inhabit, the delivery of technology education at all levels, including the concept of STEM education (science, technology, engineering, and mathematics), must, for Goodman, include the development of critical and philosophical competencies, competencies that are not considered to be separate, distinct, and different from other curriculum subjects, but are, rather, considered as integral and complementary to them.

Considering technology from this standpoint is not a recent phenomena. It can be traced back to the ancient Greek philosophers such as Plato (*Laws*) and Aristotle (*Physics*). Plato, for example, argued that technology imitates nature: modern example being airplanes imitating bird flight. However, Aristotle, his former student, disagreed. Aristotle made an ontological distinction between nature and technology:

> the former have their principles of generation and motion inside, whereas the latter, insofar as they are artifacts, are generated only by outward causes, namely human aims and forms in the human soul. Natural products (animals and their parts, plants, and the four elements) move, grow, change, and reproduce themselves by inner final causes; they are driven by purposes of nature. Artifacts, on the other hand, cannot reproduce themselves. Without human care and intervention, they vanish after some time by losing their artificial forms and decomposing into (natural) materials. (Franssen et al. 2015)

These ancient examples of competing philosophical perspectives on technology, as well as the many contemporary debates offered today, such as those offered in this section, serve to continue to challenge the received wisdom of the day regarding the relationship between the development of human beings and their technologies. According to Henry Bergson's writing in 1911, the development of human intelligence and creativity is, and continues to be, a direct result of this interaction:

> If we could get rid ourselves of all pride, if, to define species, we kept strictly to what the historic and prehistoric periods show us to be the constant characteristics of man and of intelligence, we should say not *Homo sapiens*, but *Homo faber*. In short, intelligence,

> considered in what seems to be its original feature, is the faculty of manufacturing artificial objects, especially tools to make tools, and of indefinitely varying the manufacture. (Bergson 1998: 139)

While philosophical issues relating to technology have been debated for millennia, the concept of a distinctive philosophy of technology is now an established academic domain, albeit as a relative newcomer. Marc de Vries explores this in some detail in his chapter *General Introduction*. He explores the progress of the philosophy of technology in terms of its conceptualization. Drawing particularly from Carl Mitcham's *Thinking Through Technology* and the *Philosophy of Technology and Engineering Sciences* edited by Anthonie Meijers, de Vries explores the relationship between engineering and technology as well as the natural sciences. However, he does make some important distinctions between technology and science, especially in terms of modeling. This leads on to a discussion regarding the importance for an ethical dimension being a necessary part of the learning process about technology. This is especially true with regard to designing where value-laden judgments become a relevant focus. De Vries concludes by postulating on the future role of philosophy in relation to technology education.

In my own chapter entitled *Nomadology, a lens to Explore the Concept of Technological Literacy*, I attempt to fuse the concept of what the French philosophers Gilles Deleuze and Felix Guattari call nomadology, with the philosophy of Célestin Freinet, a French educationalist and philosopher who believed in a more student-centric form of pedagogy. In so doing, I attempt to open up a discussion on the concept of technological literacy as a necessary component in the teaching and learning that is related to technology. I argue that there is much more to technology education than the mastering of technological know-how and the techniques associated with the fabrication of artifacts. Considered thus, technology cannot be autonomous, it is, rather, part of a more complex network of relationships that include social, economic, political, cultural, and philosophical discourses that both affect human beings and is affected by human beings.

Joseph Pitt questions why we do not examine the relationships between the curriculum subjects that are taught in both schools and beyond. In his chapter, *Teaching Science and Technology*, he suggests that in order to understand technology, one needs to develop a deeper understanding as to how the related historical, cultural, religious, and social aspects are intertwined and how these relationships impact upon technological development and each other. Pitt also goes on to question the merits and funding of the concept of "big science and technology." He argues that this concept has difficulty in articulating with current theory. Clearly, this presents problems for the teaching of science and technology.

The chapter *From Crit to Social Critique* by Stephen Petrina considers the extent to which students' critique of their own design projects within the school setting transfers beyond the school and into the social. Petrina explores the philosophical question of whether school-based technology education critiques, which tend to be based upon self-reflection, enable students to develop a critical capacity that is transferrable to the social. This has a significant impact, Petrina argues, upon the pedagogy utilized in the delivery of technology education. Social critique involves a significant ethical dimension, which engenders conflicting perspectives relating to technological development in the social arena. Conflicting perspectives relating to environmental, feminist, indigenous, and spiritual issues for example. His chapter reveals the complexities associated with the transition from crit to social critique.

Dennis Cheek considers the long-standing interrelationship between technology and religion in his chapter *Religion and Technology*. He discusses a variety of evidence, some of which dates back to Paleolithic times, that demonstrates this sometimes fragile, but demonstrably, long-standing union. Cheek argues that this relationship has implications for technology education. Religion can hinder technological progress as well as assist in its development depending upon personal perspectives. Both religion and technology seek, or so they claim, to solve problems which meet the needs of and improve the human condition. Both have established an evolving theories and practice, and both form a complex network of relationships with culture, politics, and philosophy. While Cheek offers many well-established examples of this interrelationship, he goes on to question why it is that there exists a lack of materials and engagement about this dynamic between religion and technology within school settings.

Conclusion and Future Directions

While these chapters consider the philosophy of technology and engineering from different perspectives, some common themes can be seen to emerge. Technology, and ipso facto technology education, is a complex area to study. The interrelationships between discourses surrounding technology and the social, economic, political, cultural, religious, and philosophical serve, not only to reveal this complexity but also to highlight the ethical dimensions associated with the development of technology.

Given the technologically textured world we now inhabit and the one in which future generations will continue to inhabit, the subject area of technology education needs to develop a critical and philosophical perspective in those who study the subject. It is crucially important that as technology develops at an almost exponential rate, one that seriously impacts upon our very existence, we need to enable a more informed and critical citizenry in the future.

References

Bergson, H L. (1998). *Creative evolution* (trans: Mitchell, A.). New York: Dover.

Franssen, M., Lokhorst, G-J., van de Poel, I. (2015). Philosophy of technology. In Edward, N. Z. (Ed.), *The stanford encyclopedia of philosophy* (Fall 2015 ed.). http://plato.stanford.edu/archives/fall2015/entries/technology/. Accessed 7 Nov 2016.

Goodman, P. (2010). *New reformation: Notes of a neolithic conservative*. Oakland: PM Press.

Philosophy of Technology: Themes and Topics

2

Marc J. de Vries

Abstract

Main themes in current philosophy of technology are the nature of technical artifacts, the nature of technological knowledge, the nature of models in technology and engineering, and norms and values in technology. These are studied in the context of an "empirical turn" that took place in philosophy of technology. A next step in this discipline will probably be an axiological turn.

Keywords

Philosophy of technology • Knowledge • Modeling • Normativity

Contents

Introduction

Although the philosophy of technology was a relative latecomer in the philosophies of specific human scientific and cultural activities, it has become a well-established academic domain. It aims at systematic reflection on technology. The purpose of such reflections can be purely theoretical, but philosophers of technology also try to

M.J. de Vries (✉)
Department of Science Education and Communication, Delft University of Technology, Delft, The Netherlands
e-mail: m.j.devries@tudelft.nl

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_1

be in contact with practitioners in technology in order to find out what conceptual and critical analyses can be of use for them. Technology educators also are potential users of their work. The aim of this chapter is to provide a concise survey of what has been developed so far in the philosophy of technology in terms of ideas about the nature of technology. Introduction of philosophy of technology is often based on the fourfold ways of conceptualizing technology as presented by Carl Mitcham in his well-known book *Thinking Through Technology*. Because several such texts exist already, I will use a different basis for a survey of the philosophy of technology, namely, the Handbook *Philosophy of Technology and Engineering Sciences*, edited by Anthonie Meijers. This handbook is more recent (2009) than Mitcham's "classic" book (1994), so it provides a more up-to-date overview of where philosophy of technology stands now.

There are clear communalities between Mitcham's four ways of conceptualizing technology and the section headings in Meijers' Handbook. Mitcham identifies the following four ways of thinking through technology as a set of artifacts, as a knowledge domain, as a set of activities (designing, making), and as a feature of humans and society ("homo technologicus," the "technological society"). Both Mitcham and Meijers have artifacts, knowledge, and design as major structuring elements in their surveys. The fourth Mitcham element (the human and social dimension) are also present in Meijers' Handbook but more focused on ethics and values. Meijers has a separate section that is dedicated to models in engineering, which is an issue that Mitcham did not pay much attention to, and understandably so because in 1994, not much had yet been published about that in the philosophy of technology. Also new in the Meijers Handbook is the extensive attention for engineering sciences. Mitcham did write about the relation between technology/ engineering and natural sciences, but not much about the nature of engineering, which, again, is a matter of timing, as the philosophy of engineering science is one of the latest developments in philosophy of technology.

Following Meijers division in sections, I will present the survey of philosophy of technology for this handbook in the following way: I will first discuss the struggle to define technology, engineering, and engineering sciences. Then I will continue with a more or less "standard" element in the philosophy of technology: the reflections on the nature of technological knowledge. I will skip the reflection on the nature of artifacts (particularly the dual nature approach as developed in Delft, the Netherlands, as that has already been described extensively elsewhere). As suggested by the Meijers Handbook, I will pay separate attention to models and modeling in technology. Modeling is also one of the most prominent concepts that came out of a Delphi study into relevant concepts for technology and engineering education. Then the ethical issues will be discussed, starting from reflections on technological normativity in general. In the final section, I will briefly indicate how the future of philosophy of technology would fit best with the needs of technology education.

Defining Technology and Engineering

In his introductory chapter for the Handbook of *Philosophy of Technology and Engineering Sciences*, Anthonie Meijers shows that both the term "technology" and the term "engineering" originate from words that indicate a practice-oriented type of knowledge. The Greek word τέχνη in Plato's later works referred to knowledge related to making. The Latin word *ingenera* meant to generate or produce, and the term "engineering" indicated the discipline of generating or producing (Meijers 2009). In the course of time, the notions associated with these terms have shifted. Technology is generally seen as the development and use of the enormous variety of artifacts and systems that we find around us. The impact of this on our lives is so important that we speak of "technological literacy" as a requirement for every citizen that should be learned at school. Not all people, though, need to be educated in technology in order to participate in the development of new artifacts and systems. That is, not all people need to become engineers. Engineering is nowadays seen as the professional domain related to technological development. Another related term is engineering sciences. That is the systematic acquisition of knowledge that is needed for engineering. Engineering sciences are similar to natural sciences in that they have processes for assessing whether or not the produced knowledge can be regarded to be "scientific." But in the natural sciences, the main criterion is the likeliness between the developed knowledge (in the shape of formulas, theories, and models) and the observed reality ("truth"), and in engineering sciences, the main criterion is "proven usefulness."

Apart from these theoretical perspectives on technology and engineering, there are general perceptions of what they are. Carl Mitcham has presented a set of four different ways in which people can perceive technology (Mitcham 1994). This set has been used widely by other philosophers of technology and in the context of technology education. The way of seeing technology is as the whole collection of artifacts and systems around us. When we say that we use "technology" to communicate, move around, prepare food, etc., then in fact we mean all these artifacts and systems. The second perspective is that of knowledge: technology as something you can learn and study. For a long time, the "technology as applied science" paradigm has blocked our view on this perspective. Now we realize that technology does have its own knowledge content and there is more at stake than just applying the knowledge that science has produced. The third way of seeing technology is that of processes: technology as something you do. This comprises designing/developing, making/producing, and using/evaluating. The fourth perspective on technology is that of the human and social value we see in changing the world around us: technology as something that you are ("homo technologicus"). This is where ethics of technology enters the scene. It is also the way STS (science, technology, society) studies perceived technology.

Technological Knowledge and Relations with Natural Science

In his contribution on the nature of technological knowledge in the Meijers Handbook, Wybo Houkes gives a survey of the problems one runs into when trying to identify distinct characteristics of technology (Houkes 2009). Meijers and de Vries in the *Companion to Philosophy of Technology*, edited by Jan Kyrre Berg Olson and others, list four of such possible characteristics (Meijers and de Vries 2009): (1) the context-dependent nature of technological knowledge, (2) the often nonpropositional nature of technological knowledge, (3) agreements as an origin for technological knowledge (e.g., agreements on technical standards), and (4) normativity in technological knowledge. The last-mentioned feature is one that Houkes sees as perhaps the most promising for being distinctively technological and different from science knowledge. Normativity features in various forms: in technical standards, rules of thumb, good practices, and also functions. Functions are particularly interesting as they play a key role in engineering and have a normative nature in that they do not describe what the artifact actually does but what it should do. A car has the function of bringing me from A to B, even when it is in the garage for repair and cannot bring me from A to B. If the notion function was descriptive, the broken car would have lost its function, but due to the normative character of functions, it has not. This normativity is related to the context relatedness that is claimed by Meijers and de Vries, as what is useful in one context may not be in a different context. Also the notion of agreements as a source of knowledge is related to this normativity and what should be can be agreed on freely, as an agreement on what is should always be based on a discussion in which arguments about the fit between the claimed knowledge and reality is crucial. So the normativity in technological knowledge seems to be a core feature in knowledge that is present in technological knowledge and not in, e.g., natural sciences.

Normativity also features in reasoning in engineering. Reasoning is an epistemic activity that is very important, both in natural science and engineering. Much reasoning in natural sciences is cause-effect reasoning. That is the type of reasoning that enables a scientist to derive from a hypothesis what will happen in an experiment if the hypothesis is correct. It runs like: if I switch on the experiment, then this and that will happen. In technology this type of reasoning is also used, namely, to derive from the realized product or prototype what its behavior will be when I put it into use (switch it on or whatever). In other words: the functioning of a device can be derived from its physical realization by cause-effect reasoning. Note that this is not the same as its function. I can derive from the physical realization of an old-fashioned light bulb that it will generate both light and heat when I switch it on. That is its functioning. But that still leaves the options of using it primarily as a light source or a heat source. To identity relations between physical realization and function, I need a different type of reasoning: means-ends reasoning (Hughes 2013). This type of reasoning is not deductive like cause-effect reasoning mostly is, and therefore it is not one to one (one functioning uniquely related to one physical realization). For one means, I can think of different ends, and for one end, I can think of different means. Means cannot deductively be derived from ends and vice versa. Means-ends reasoning does feature also in natural sciences but in a different way. Explanations ("theories") cannot be deductively derived from phenomena and vice versa. That can be understood when we realize that in fact theories are a sort of equivalent of artifacts in science: they are human constructs for a certain purpose (explaining the observed phenomenon).

Models and Modeling

As Sjoerd Zwart in his introduction to Part IV of Meijers' Handbook indicates, modeling in engineering has a characteristic that makes it different from modeling in natural sciences: the purpose of contributing to the development of new artifacts and systems (Zwart 2009). In natural sciences, models only play a role in developing knowledge about reality (as it is, not as we would like it to be, as in technology and engineering) (Zwart 2009). In natural science, models can even be a goal in themselves because they provide an understanding of reality, at least in a simplified version (but this is always the case in natural science). In engineering, models always feature in the process of technological innovations, but still they can have different functions, depending on the phase in which they feature. In the early phase of design, engineers can use, for instance, conceptual models of an artifact-in-design, like a system representation. Such a model helps designers to figure out the structure of the system: how should different components be related so that the system as a whole will fulfill the overall function? Also for planning the whole design process, a conceptual model can be used. Such a model represents the consecutive phases of the design process. Later on in the design process, models can be used to communicate with customers and/or users. Architects, for instance, make a physical model of a house to demonstrate to the client what the house will look like. Physical models can also have a more dynamic character. Sometimes engineers want to show the functioning of a device-in-design, and they make a model that contains not just the shape of the device but also can fulfill its function (though often in a simplified mode). For simulating the functioning of an artifact-in-design, also formal models are used. These models consist of symbols. Those can be the 0's and 1's in a computer model, but also formulas are an example of formal models. In engineering we find formal models in the form of, e.g., CAD and CAM models, FEM models, and numerous other models in which a process is simulated in a computer. FEM models are an example of a model that heavily leans on natural science models. The behavior of, let us say, an engine-in-design is simulated in a FEM model by using the formulas for relations between stress, heat, and forces as they have been found in natural science.

An important feature of models in engineering is that they can have a normative character: they do not represent a simplified version of the world as it is but as how we want it to become. In fact, this is the way we use the term "model" sometimes in daily life also: a "model" teacher or pupils. By that we mean a teacher or pupils as we would like them all to be, even if that model does not even refer to a real teacher or pupils, but one that we imagine. In engineering models, normative models are widely used. Some examples were mentioned already before: the model that represents a system-in-design and the model of the "ideal" design process. This normative character of models is related to the normativity that also features in engineering knowledge. Boon and Knuuttila call models "epistemic tools" (Boon and Knuuttila 2009; see also the section on technological knowledge in this chapter).

Modeling is the process of creating a model. Almost by definition, this process entails abstraction. This term literally means peeling off, and it is used to indicate that certain aspects of a situation are left out. In a certain way, this is the very basis of any type of science: by focusing on one aspect of reality (e.g., the physical aspect, the economic aspect, or the social) and leaving out all others, a scientific discipline can investigate that aspect in depth without being "distracted" by the other aspects. Also within a scientific aspect, abstraction takes place, for instance, when friction is left out. Leaving out whole aspects of reality is done also in engineering sciences but less so than in engineering. This is because leaving out aspects of reality is not problematic for just studying the situation, but it will be when we want to interfere with reality, because then all the aspects of reality need to be taken into account as they all play a role in the failure or success of the product. An engineer cannot afford to focus only on the physical aspect of the artifact (s)he designs, as it can only be successful if it does not only fit with the "laws" of the physical aspect of reality but also with the constraints that are generated by the psychic aspect (how users will perceive the artifact), the economic (what they are prepared to pay for it), and the legal (is there a patent that can be infringed?), just to mention a few of the other relevant aspects. This is why engineers in particular have to be aware of the differences between their models and the real world. An example of this is using model airplanes in a wind tunnel. In reality the ratio between the size of the air molecules and the plane is different than in the wind tunnel situation as the plane is much smaller and the air molecules have their normal size. In choosing what from reality to keep and what to leave out in the model, analogies play a role. Analogies are certain features in reality that are kept in the model, while others are left out. An electric circuit can be used as a model for a water circuit as it has elements that are analogous to those in the water circuit (e.g., a battery in an electric circuit is analogous to a water pump in the water circuit). Engineers can use such analogies to develop models. Different types of analogies can be distinguished. The function of a part in a device can be analogous to a part in a different device (as in the example with the battery and pump). But also the shape of a part can be analogous in that of a different part. For instance, the shape of a wheel is analogous to the shape of a CD. That creates the possibility of modeling a car by using CDs instead of real wheels. Also the configuration of a system can be analogous. The configuration of an electrical circuit (with a battery, a switch, and some resistors can be analogous to a central heating system with a water pump, a water switch, and radiators).

Apart from abstraction, idealization is a tool for modeling. Idealization is not leaving out something but changing (usually changing something irregular to something regular). This is what engineers do when they go from a measured curve in a graph to one that fits with a mathematical formula. This approximation enables them to use mathematics to manipulate the data and make predictions. Idealization for modeling purposes often builds the bridge between data and mathematics.

Norms and Values

Traditionally, ethics has been an important domain within the philosophy of technology. Particularly philosophers in the Continental line have contributed to this. Prominent names are Don Ihde, Andrew Feenberg, Albert Borgmann, and Langdon Winner. Their ideas have been described in previous reviews of philosophy of technology literature (Vries 2016; Verkerk et al. 2016). Ethics is the field where norms and values play a dominant role. As Van de Poel argues in his introductory chapter to the Norms and Values section in Meijer's Handbook, there are several ways of showing that technology is inherently value laden. Perhaps the most basic way is to claim that proper functioning is a value in itself. But most philosophers see that as a variant of the claim that technology is in fact neutral and that it is the user who determines for what values artifacts are used, for good, or for bad purposes. Obviously stating that the drilling machine functions well is a value statement. But it is still way from what non-philosophers tend to see values, namely, ethical values. Perhaps the small distance between the functioning value and the ethical value can be illustrated by asking the question what it means when we say that "this is a good car?" It can have a purely functional meaning: it is suitable for bringing me from A to B. But the way the car does this is not far from this meaning: it may be good in bridging the distance, but I feel totally shaken when I exit the car again. So comfort may also be seen as part of the claim that "this is a good car." But that is not far from a next claim: it brings me from A to B in a safe way. And this again can be seen as close to: it is not only safe for the people inside the car but also for the pedestrians and other people outside the car. And it does not pollute more than necessary. By then we have already entered the domain of ethical values. In a similar way, the same can be shown for norms. Norms are in fact a sort of concretization of values. A norm related to the function of bringing me from A to B can be the desired range of the car: what is the distance that I can travel with a full tank of fuel?

Van de Poel also shows that there are not only values and standard related to technical artifacts but also to technological practices (Van de Poel 2009). I can think that he or she is a "good" engineer. What does that mean? Here we can go through a similar range of meanings, starting from "(s)he is good in developing artefacts" to "(s)he is a morally good engineer." Practices are a philosophical concept that is very useful to illustrate the role of values and norms in technology. This concept was used by ethicist Alasdair MacIntyre to provide a new impetus for virtue ethics (MacIntyre 1981). Aristotle, one of the founding fathers of this type of ethics, always asked the question: what would a good human do? MacIntyre argues that this question needs to be refined: what would a good teacher do, what would a good judge do, what would a good engineer do, etc. Each of these functions in a particular "practice" with its own norms and values. Those determine what is good and bad. A surgeon and a butcher both cut in meat. But cutting meat morally good means different things in the different practice in which they function. For a butcher, it is morally wrong to cut in such a way that a lot of meat is wasted unnecessarily. For a surgeon, it is morally wrong to cut in such a way that the patient will be left with visible scars and tissue damage. Likewise what is morally good for engineers is determined by the norms and values that hold in the engineering practice. Several types of norms can be distinguished: norms that define the practice (e.g., what it means to be a certified engineer) and norms that are related to the higher goals of engineering (e.g., norms for sustainable engineering). The former can be called constitutive or structural norms, and the latter can be called regulative or directional norms.

A challenge to the discussion on norms and values in technology is that this practice is a multi-actor practice. Often many stakeholders are involved, each with their own practice and related norms and values. When an industrial company and a government work together on stimulating a certain technological development, they have both different constitutive and different regulative rules. Governments have different tasks and responsibilities (those are examples of constitutive norms) than business people. Likewise they have different higher values (e.g., public justice for a government and making money for a company). Clashing norms between different practices can hamper technological developments. But also clashes of norms within a practice can cause problems. When an industrial company has customer satisfaction as a regulative rule, but there is no department or there are no individuals that have a responsibility for dealing with customer requirements and concerns (a lack of constitutive norms related to the claimed regulative norm), this will not work. Another challenge that comes with the multi-actor character in technological developments is the problem of responsibilities. This is sometimes called the "many hands" problem or the issue of collective responsibility. When a company produces a car that is inherently dangerous (like the famous and "classic" Ford Pinto case that features in many books for engineering ethics), this is the result of decisions taken by engineers, managers, technicians, etc. It is difficult to tell whom to blame when something goes wrong with those cars, as many people were involved and each of them contributed in his/her own way to the overall outcome of a dangerous car being produced and sold.

The designing of an artifact has everything to do with values. Whether or not the car is a "good" car in the wide sense of the term is largely determined in the design process (not only, because the way the car is used also determines whether or not it is a good car in the wide sense). The challenge for designers is to "translate" values into the physical realization of the artifact. Some philosophers claim that thus the artifact becomes a moral actor as it influences the behavior of the user also in a moral sense (Verbeek 2014). The speed bump that slows down traffic in a residential area forces the driver to behave morally well (at least, as far as traffic safety is concerned) in that area. Likewise it is possible to design cars that simply do not start when the inbuilt sensor "smells" that the alcohol percentage in your breath is too high. Technically speaking this is very simple, but as a society, we are still inclined to leave responsibility with humans and not delegate that to devices as they cannot be held responsible because they lack freedom of choice (one of the conditions for moral responsibility, next to knowledge of norms and knowledge of the situation). Design processes in which a systematic reflection on values is an integrated element are called value-sensitive design. The focus on values is one that may become even more important in the future of philosophy of technology that it currently is already. I will now turn to that perspective.

Conclusion

In the 1990s, the philosophy of technology went through what was called "an empirical turn." This turn was introduced in a seminar that was organized by Kroes and Meijers in Delft, the Netherlands. In 2016, Kroes and Meijers proposed a next turn for the philosophy of technology: an axiological turn. Axiology is the sub-domain in philosophy that is concerned with values. As was described in the previous section, values did already play a role in philosophy of technology. Kroes' and Meijers' proposal is to enhance that role. They are motivated by the fact that by taking this "turn," the philosophy of technology can become (even) more relevant in social debates about new technologies. A fundamental reflection on the nature of the values that are at stake in new technologies could be a valuable support for the development of such technologies but also for responsible use and for policy making with respect to such technologies. This would be different from an "applied" turn in which philosophers would only deal with practical issues concerning values. It is the philosophers' task to focus on more fundamental reflections and for the values discussion the importance of such reflections can hardly be overestimated. Hansson also suggested seeking a broader embedding for the philosophy of technology. Normativity and value issues are also found in other domains in which humans intervene in reality (such as medicine). According to Hansson, the Middle Age concept of "mechanical arts" would be worth revisiting and used as a broader context for the philosophy of technology (Hansson 2016). The axiological turn can also be part of a "social turn" in the philosophy of technology, as suggested by Breij. Such a turn would require more intense collaboration with relevant social actors (industries, governments, users). At the same time, the relation with "hard-core" philosophy must not be forgotten, according to Pitt (Pitt 2016).

Seen from the perspective of technology education as a "user" of philosophy of technology, it would be good if the philosophy of technology keeps the broad perspective that it had so far. On the one hand, more and more attention is paid to concept learning in technology education (see ► Chap. 8, "Technology Education: An International History" in this volume), which could benefit from the more analytical approach in the philosophy of technology (reflection on the nature of artifacts, design, values, etc.) as proposed by Kroes and Meijers (Kroes and Meijers 2016). On the other hand, the importance of technological literacy as a goal in technology education would benefit from a (continued) attention for the interaction between social and technological developments, as in the "social turn" proposed by Breij (Breij 2016). Of course technology educators are not in the position to determine the future of philosophy of technology, but if relevance is a criterion for future philosophy of technology, then the impact on technology education should be seen as one type of relevance that is perhaps even important as the relevance for engineers and policy makers. The philosophy of technology has a great potential to provide a sound conceptual basis for technology education if both philosophers of technology and technology educators recognize that potential and use it to make strategic choices for the future of their disciplines.

References

Boon, M., & Knuuttila, T. (2009). Models as epistemic tools in engineering sciences. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 693–726). Amsterdam: North-Holland.

Breij, P. (2016). Constructive philosophy of technology and responsible innovation. In M. Franssen, P. E. Vermaas, P. Kroes, & A. W. M. Meijers (Eds.), *Philosophy of technology after the empirical turn* (pp. 127–143). Dordrecht: Springer.

de Verkerk, M. J., Hoogland, J., van der Stoep, J., & de Vries, M. J. (2016). *Philosophy of technology: An introduction for technology and business students*. New York: Routledge.

de Vries, M. J. (2016). *Teaching about technology. An introduction to the philosophy of technology for non-philosophers* (2nd ed.). Dordrecht: Springer.

Hansson, S. O. (2016). Technology as a practical art. In M. Franssen, P. E. Vermaas, P. Kroes, & A. W. M. Meijers (Eds.), *Philosophy of technology after the empirical turn* (pp. 63–81). Dordrecht: Springer.

Houkes, W. (2009). Introduction to part II. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 187–190). Amsterdam: North-Holland.

Hughes, J. (2013). Instrumental artefact functions and normativity. In M.J. de Vries, S.O. Hansson & A.W.M. Meijers (Eds.), Norms in technology, (pp. 137-153). Springer, Dordrecht.

Kroes, P., & Meijers, A. W. M. (2016). Toward an axiological turn in the philosophy of technology. In M. Franssen, P. E. Vermaas, P. Kroes, & A. W. M. Meijers (Eds.), *Philosophy of technology after the empirical turn* (pp. 11–30). Dordrecht: Springer.

MacIntyre, A. (1981). *After virtue: A study in moral theory*. Notre Dame/Indiana: University of Notre Dame Press.

Meijers, A. W. M. (2009). General introduction. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 1–22). Amsterdam: North-Holland.

Meijers, A. W. M., & de Vries, M. J. (2009). Technological knowledge. In J. K. Berg Olsen, S. A. Pedersen, & V. F. Hendricks (Eds.), *A companion to the philosophy of technology* (pp. 70–74). Chichester: Wiley-Blackwell.

Mitcham, C. (1994). *Thinking through technology. The path between engineering and philosophy.* Chicago: University of Chicago Press.

Pitt, J. C. (2016). The future of technology: A manifesto. In M. Franssen, P. E. Vermaas, P. Kroes, & A. W. M. Meijers (Eds.), *Philosophy of technology after the empirical turn* (pp. 83–92). Dordrecht: Springer.

van de Poel, I. (2009). Introduction to part V. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 883–886). Amsterdam: North-Holland.

Verbeek, P. P. (2014). Some misunderstandings about the moral significance of technology. In P. Kroes & P. P. Verbeek (Eds.), *The moral status of technical artefacts* (pp. 75–89). Dordrecht: Springer.

Zwart, S. D. (2009). Introduction to part IV. In A. W. M. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 633–636). Amsterdam: North-Holland.

Nomadology: A Lens to Explore the Concept of Technological Literacy

3

John R. Dakers

Abstract

How does one learn to become technologically literate – and how does one teach a young person to become technologically literate? These are the questions that this chapter will consider. There have been many attempts over the past few decades, to incorporate the concept of technological literacy into the various extant technology education paradigms around the world. It appears from research, as well as a variety of anecdotal evidence, that this appears to be a universal goal for technology education. However, despite the many publications that offer a variety of ways and means as to how this might be achieved, something or many things appear to get in the way of the augmentation of technological literacy in the classroom. This chapter will discuss what these barriers might be and in so doing, offer a new and alternative pedagogy that attempts to overcome some of these roadblocks. Deleuze and Guattari's concept of Nomadology will be fused with the educational philosophy of Célestine Freinet, to offer a potential pedagogic framework that, if adopted, may help resolve the problems associated with the delivery of technological literacy in the classroom.

Keywords

Nomadology • Technological literacy • Affect • Pedagogy • Freedom of expression • Induction • Interscholastic exchange • Deleuze and Guattari • Célestine Freinet

J.R. Dakers (✉)
Delft University of Technology, TUDelft, The Netherlands
e-mail: dakers@orange.fr

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_2

Contents

Introduction

There have been many attempts over the past 20 years to define, teach, and assess the concept of technological literacy. Most attempts have been associated with technology education, or to a lesser extent, science education curricula from around the world.

Publications include, but are not limited to: Technology and Literacy in the Twenty-First Century (Selfe 1999), Technically Speaking: Why all Americans need to know more about technology (Pearson and Young 2002), Advancing Excellence in Technological Literacy (ITEA 2003), Technological Literacy for All (ITEA 2006), Tech Tally: Approaches to Assessing Technological Literacy (National academy of Engineering 2006), Standards for Technological Literacy (ITEA 2007). Technological Literacy: A multiliteracies approach for democracy (Williams 2009), Defining Technological Literacy (Dakers 2014a) New Frontiers in Technological Literacy (Dakers 2014b). Towards a reconsideration of technological literacy (Hasse and Wallace 2015).

While all of these publications offer a variety of important perspectives with respect to the concept of technological literacy, no universal or unified consensus appears evident, one that can be articulated into technology education curricula around the world, taught, and then assessed accordingly. Only partial definitions seem possible. What appears to be viable for the USA does not seem to articulate with technology education curricula in France or Finland or England or Germany. Even local definitions cause dissension.

The USA, for example, has been making a supreme effort, one carried out over many years, to identify, quantify, standardize, and, ultimately, assess technological literacy (ITEA 2003, 2006, 2007). Moreover, they have gone to great lengths to list content standards, student assessment standards with guidelines, together with long range goals and expectations, in order that students might become technologically literate. The three volumes cited above combine to total 436 pages that claim to present “a vision of what students should know and be able to do in order to be technologically literate” (ITEA 2007, p. vii).

These volumes constitute a well-researched set of criterion for the study of technology and for the development of technological literacy in the USA. However, these standards have also been subject to change, disagreement, reevaluation, and discord when it has come to any form of implementation within the curriculum. According to Becker et al.:

> currently, 49 of the 50 states have technology literacy goals and standards; more than 80 percent of the states have adopted, adapted, or referenced the International Society for Technology in Education's (ISTE) National Education Technology Standards in state department of education documents. As of 2007, based on a survey conducted by the State Educational Technology Directors Association (SETDA), 21 states reported that they use the ISTE NETS definition (i.e., the six categories of the NETS-S), 15 states reported using a unique state definition, eight states reported using the SETDA definition, and seven states reported that they used another method for defining technology literacy. Those varying definitions have been operationalized in the form of technology standards.
>
> That is, states encourage the pursuit of proficiency in technological literacy by promulgating student technology standards. There is no shortage of standards for states to adopt or adapt. The International Technology Education Association (ITEA) has developed a series of standards that point out in great detail how one might achieve technological literacy. Those standards, the third iteration of which was released in 2007, include grade-level goals. Additionally, in 2007, the International Society for Technology in Education (ISTE) released the second iteration of the National Educational Technology Standards for Students (NETS-S). (Becker et al. 2010, p. 2)

Indeed, Rasinen undertook a systematic analysis of the curriculum content for technology education of six countries and found that "although the format and approach in the six curricula studied differ from one another in many ways, common features were found" (2003, p. 42). However, he also reported that the common features found were situated within technology education programmes that were at different stages of development and concluded that, as a result, "a single model cannot be applied to each country" (ibid, p. 45). Significantly, Rasinen found that the concept of "[t]echnological literacy was a universal goal" for all curricula (ibid, p. 45).

In contrast to the conclusion offered by Rasinen is the concept of an international technology education baccalaureate as proposed by Williams (2007). At present this is a functioning international program for the delivery of a universal and unified form of technology education around the world. Any school choosing to adopt this program does so on a voluntary basis. Williams argues that "[t]he reasons for schools adopting the IB [International Baccalaureate] vary, but the main reason is the provision of an internationally accepted pre-university certification that is reputable and transferable." However, the International Baccalaureate Organisation [IBO] syllabus for the subject Design Technology, as it is known in this context, does not appear to feature the concept of technological literacy as an area of study, at least not in the subject areas listed. "The aim of the DP design technology course is to foster the skill development in students required to use new and existing technologies to create new products, services and systems" (IBO 2016). Moreover, the IBO claims to implement "a rigorous assessment process in order to ensure standards remain high." In order to achieve this stated goal "the assessment criteria are standardized [in order that] the aims and objectives are achieved."

It is principally in this respect that I part company with the concept of a universal technology education paradigm, especially one that may purport to include the concept of technological literacy. Standardized assessment protocols, by their very nature, serve to problematize pedagogies that involve critical thinking development, a pedagogy, that is, in my view, essential for the development of becoming technologically literate. Critical thinking about technology involves the development of perspectives that are immanent, multiple, value-laden, and temporal with respect to technological/social/cultural relationships, whether existing or potential. These relationships are formed within the parameters of socially constructed milieus that are complex and local, something that universalized and standardized assessment procedures find difficult, if not impossible, to measure. Standardized assessment protocols, especially, although not limited to, those that involve answers to multiple choice questions, require overwhelmingly conformist criterion within which local interpretation has no place. Only "this or that" responses predicated almost exclusively upon the development of procedural and declarative knowledge prevail.

Becoming technologically literate, or multiliterate as Williams goes on to later argue, involves a more complex and progressive learning space: one that differentiates between the concepts of a universal technology education Baccalaureate as offered the IBO, for example, and that of the very much less instrumental and much more democratic educational concept of technological multiliteracy. Williams suggests that "if technological multiliteracy becomes the focus of technology education through its positioning as a moral rather than vocational or instrumental practice, and the mechanism is available for students to express their beliefs, then the move toward a more democratic technological order becomes possible" (Williams 2009, p. 252).

While I lean strongly toward this perspective, I take issue with positioning multiliteracy exclusively as a moral issue. By way of clarification, I notice that the terms moral and ethical often tend to become conflated, and while I make no claims on Williams' use of the term, I consider the distinction important. Jun (2011) makes a significant and important distinction between the concept of morals and ethics. He considers morals to be coextensive with normativity; they are about expressing what is right or asking the question "how should/ought one act?" or "how should/ought one behave?" What is thus revealed in the concept of normativity is a structure of hierarchy, a set of transcendent laws that are designed to regulate our lives by creating boundaries that contain us and control us under the guise of morality.

The problem with this is, however, that we can never be certain of how things will unfold over time, and no transcendent rule or law can account for that. There are those who will argue the case for a future that is determined in advance by some metaphysical power. I have discussed this in some detail in (Dakers 2016). Furthermore, the arguments presented by Deleuze are that prescribed values (morals), whatever they may be, can never be taken to be fixed and immutable, they can never be considered as universal and transcendent. They can only ever be relevant within the context that they are presented. They can only be subject to interpretation and as such, are open to reinterpretation over time (ethics). Deleuze thus rejects transcendent forms of normativity (morals) on the grounds that they are not self-reflexive. They cannot, by their very nature, "provide self-reflexive criteria by which to question, critique, or otherwise act upon themselves" (Jun 2011, p. 101).

In summary, it appears that technological literacy is considered to be a universal goal, or perhaps more accurately, a much sought after goal for inclusion within the technology education paradigm. However, while much has been written in support of its inclusion, it appears, for the most part, to continue to remain stubbornly absent from being made manifest in the classroom.

Why Does Technological Literacy Appear to Evade Actualization Within the Classroom?

Considered from the perspective of many of those who have the power to design, regulate, and implement the delivery of technology education, it is apparent from the way it continues to be delivered and subsequently perceived by the general populace, that it is an initial training ground designed to meet the perceived needs of industry. In other words, technology education is perceived to be a vocationally orientated subject. Moreover, the emphasis leans very much toward male-orientated vocations. O'Riley offers a somewhat dystopic but nevertheless accurate account of the experience of a female undertaking her initial teacher education preparation in technology education. The teacher asks:

> How has it come to be that in spite of recent revisions, technology education remains limited to technical and trades-orientated technologies? How has it come to be that a critical and urgent conversation on gender, cultural, socioeconomic, global, and environmental issues in relation to technology is not at the foreground of technology curricula? (2003, p. 3)

The questions raised above may not only shed some light on the situation but may help to deconstruct it somewhat. Being perceived as a subject that is more orientated toward serving the needs of industry clearly locates technology education as an initiating base for training future workforces. Dewey finds this model of education repugnant:

> Its [vocational education's] right development will do more to make public education truly democratic than any other agency now under consideration. Its wrong treatment will as surely accentuate all undemocratic tendencies in our present situation, by fostering and strengthening class divisions in school and out. . .Those who believe the continued existence of what they are pleased to call the 'lower classes' or the 'laboring classes' would naturally rejoice to have schools in which these 'classes' would be segregated. And some employers of labor would doubtless rejoice to have schools, supported by public taxation, supply them with additional food for their mills. . .Everyone else should be united against every proposition, in whatever form advanced, to separate training of employees from training for citizenship, training of intelligence and character from training for narrow, industry efficiency. (Dewey in Apple and Beane 1999, p. 50)

I would add gender divisions to Dewey prophetic insights.

Conversely, conversations relating to gender, cultural, socioeconomic, global, and environmental issues in relation to technology are ethical, and so political. They are value-laden and so personal. They have no definitive answers, only expressions based upon personal experience. I suggest that most would agree that this model of technology education more closely approximates what might be considered to be technological literacy. The problem is, however, that the two images outlined for the delivery of technology education do not appear to articulate. One seeks freedom of expression the other seeks conformity with the perceived needs of industry.

To be Technologically Literate, or Not to be: That is the Question

Technology education cannot simply be reduced to what is essentially propositional logic; a set of propositions that are lodged within the divisions between either right or wrong, either correct or incorrect, either good or bad, either true or false, and either this or that. "[T]his is because the 'either-or' in contemporary education is reinforced and structurally determined by many dualistic processes that involve knowledge, the truth, language [policy determinations, assessment] and the philosophical edifices of thought from a Western perspective" (Cole 2015, p. 78). Technology education considered thus promotes the formation of dualisms; either-or perspectives. One principle, dualism, lies in perspectives about what actually constitutes technology education. This binary reflection is situated somewhere between two viscerally held political perspectives, perspectives that continue to dominate; technology education as either vocational or academic. These perspectives are manifestations of Descartes famous cogito that argues for the separation of mind and body; vocational education relating more to the development of technical skills associated with the body whereas the academic promotes development of the mind, the latter being perceived as superior to the former (see Dakers 2007 for an expanded discussion on this).

These can be strongly held perspectives situated, in extreme instances, at either one end of this continuum, or the other. However, most reasonable perspectives tend to be positioned somewhere between the two. I would contend, however, that most perspectives lean more toward the vocational. Whatever perspective is held, particularly by the teacher, will serve to (re)orientate the emphasis on the way technology education is perceived, and the subsequent pedagogy then employed in the classroom. These perceptual forces can serve to subvert the actual presentation of subject matter, no matter what the curriculum demands. The teaching of design, for example, can be seen as implementing the requirements of the design element of any given curriculum. However, the pedagogy employed might emphasize the development of prior learning in the form of procedural and declarative knowledge. In so doing, it can demand that skill sets relating to the development of workshop fabrication and technique are a necessary prerequisite before any design process may be attempted; one cannot design something if one does not know how to make it. In contrast, the emphasis might orientate toward the promotion of design as an entirely creative process, one that is not restricted by the limitations of available resources nor the need to go on to fabricate the design in the workshop (see, e.g., the Young Foresight project. Available at: https://dandtfordandt.wordpress.com/resources/young-foresight/ This project promotes design without fabrication, albeit to a limited age range).

Becoming Technologically Literate

Technologically literate is something that one never actually becomes. One is, rather, always in a process of becoming, just as technologies are always in a process of becoming (the next version of a mobile phone, for example). The concept of becoming, as in becoming technologically literate is, thus, not something that can be prescribed in advance. Nor can it be assessed in terms of right or wrong and good or bad. If it is, who is it that ultimately decides what is right or wrong, good, or bad? Certainly not the person being assessed. They are assessed in order to become confirmed into a particular dogmatic image of thought, a dogmatic image that is determined, in advance, by some transcendent figure of authority. Nietzsche offers a succinct opposition to this philosophy: "The surest way to corrupt a youth is to teach him to respect those who think as he does more highly than those who think differently from him" (2006, p. 153).

Becoming technologically literate can only ever be from a personal perspective, one set within the particular milieu that the perspective holder occupies at any given time, very much in line with Nietzsche's claim that meaning and value are dependent on point-of-view rather than any pre-existing universal order (Haines 2016).

This problematizes any technology education paradigm that wishes to incorporate the concept of becoming technologically literate. It is simply not possible to set assessment criteria that are standardized in order that predefined aims and objectives are shown to have been achieved. This is simply because we all have differing perspectives about the way we value and perceive technologies, values, and perspectives that may well change over time.

Is it possible, therefore, to incorporate the concept of technological literacy into the variety of different technology education paradigms that currently exist? To do so without radical change to the status quo? Deleuze and Guattari offer an alternative multiple option-one that is located somewhere between the aforementioned dualities, not as a fixed point resting somewhere between two opposing perspectives, but rather, as a dynamic force of perpetual movement. One "that can be expressed through the concept of 'educational nomadology,' which retains the power to think through problems to their deepest philosophical levels, [ ] whilst simultaneously initiating practical measures to change matters on the ground" (Cole 2014, p. 80).

Educational Nomadology

> Nomadicism allows the maximum extension of principles and powers; if something can be thought, then no law outside thinking, no containment of thought within the mind of man should limit thinking's power. (Deleuze 1994, p. 37)

The idea of educational nomadology can be explained by offering a distinction between the concept of logos and nomos. The Greek term logos can be considered in terms of laws of the state, laws applied from the outside that can form rigid, externally formulated boundaries that serve to control behavior, activity and in terms of schools, even thought, or at least directing thought through the apparatus of the received wisdom of the state, what Deleuze and Guattari refer to as the dogmatic image of thought (2008). If those in power consider technology education to be a subject that serves the needs of industry, this perception will form rigid boundaries that leave little room for freedom of alternative expression, such as my own, for example. Nomos, on the other hand, represents the nomadic space that exists beyond state-imposed boundaries. This is a space where no transcendent commandments exist that define our lives. This is a space for alternative perspectives, a space for free thinking, for speculative thinking (See Dakers 2014b and 2016).

The concept of nomadism can inform a progressive form of technology education that offers a way of facilitating the process of becoming technologically literate. This is a way that exists outside organized conventional educational paradigms that utilize the biological metaphor of the tree of knowledge as their guiding principle. The nomadic classroom, in contrast, is characterized as a dynamic learning space where learning is rhizomatic, an alternative biological metaphor offered by Deleuze and Guattari (2008). From a rhizomatic perspective, knowledge is not fixed. Knowledge is constructed within a social milieu. As such, it is subject to interpretation and reinterpretation, or in the terminology of Deleuze and Guattari, deterritorialization and reterritorialization (2008). Knowledge is always changing from one phase to another and yet another. It is chaotic, dynamic, and complex. In a nomadic classroom, knowledge cannot be transferred from expert to novice. Knowledge is co-constructed by everyone present in the classroom with each, in turn, bringing their own lifetime experiences upon the subject matter in question. It will be different again with another class, who may well reach other conclusions. Becoming technologically literate, therefore, does not have a starting point or a finishing point, it is a never-ending process. "A rhizome has no beginning or end; it is always in the middle, between things, interbeing, intermezzo. The tree is filiation, but the rhizome is alliance, uniquely alliance. The tree imposes the verb 'to be,' but the fabric of the rhizome is the conjunction 'and. . .. and. . ..and'" (ibid, 2008, p. 27). Thus, to begin something in the middle is every time a new beginning.

Célestine Freinet: BD&G (An Unwitting Educational Nomadologist)

> In opposition to logos, nomadology defines a way of thinking that, rather than rooting itself down in defence of one place or perspective, attempts to remain mobile and open to alterity and difference. (Haines 2016)

Felix Guattari was very influenced by the pedagogy devised by the French educationalist Célestine Freinet (Before Deleuze and Guattari). In their seminal book entitled *A Thousand Plateaus* (*Mille Plateaux*), published in 1980, Deleuze and Guattari have one particular chapter that explores the concept of nomadology: "1227: Treatise on Nomadology." While his work is never specifically acknowledged, Freinet's influence is clearly evident.

Freinet (1896–1966) was an educationalist and philosopher considered to be the equal of Montessori, Piaget, Dewey, Friere, Giroux, Illich, Vygotsky, and Rousseau. However, he is virtually unknown, even to this day, by those in the English-speaking world (Acker 2007). He developed a methodology that put learning into the hands of the learners while simultaneously removing hierarchies such as textbooks and rigid pedagogical structures designed to direct the flow of learning. While Freinet's methodology offers a radical departure from conventional pedagogies of knowledge transfer, I believe it can offer a way to connect traditional technology education together with the facilitation of becoming technologically literate, as actualized within a classroom context. I believe that it can be made to accomplish this, without causing too much disruption to the extant procedures already in place.

Thought from the perspective of technology education, Freinet argued that:

> Like all social entities, the school must perforce adapt itself to the changing needs of the environment. Such adaptation is a fact of life: it can be observed even in the area of philosophy, which allows a kind of perpetual humanization of technology and of life. Progress has always been redefined by the best among these thinkers. And thanks to them–at least to a certain extent – material development has been able to evolve into intellectual, moral, and human development. (1967, pp. 100–101)

Clearly, for Freinet, technology and human development are synchronous and as such, technological development will affect humans differently. In order to better understand this relationship, I have, for some considerable time, argued that the development of technological literacy is a vital and necessary component within any educational setting. Young people need to develop a critical awareness of the technologically textured world they inhabit and the way in which their future lives are and will be shaped by it (Dakers 2006, p. 1). The concept of nomadology devised by Deleuze and Guattari, together with the philosophy of Freinet, offers the potential for a new progressive methodology for teaching technology education that enables the facilitation of becoming technologically literate.

Exploring the Concept of Technological Literacy Through the Lens of Educational Nomadology

> We aspire to teach men how to live in a democracy, but this democracy is not a herd. It cannot survive unless all of us learn how to live it, serve it and devote our lives to it. (Acker 2007, p. 1)

Freinet argued that young people could be better motivated if they had some say in their own leaning. To this end, his philosophy of education can be summarized as follows:

Student work must be productive and useful.
Cooperative learning is necessary in the productive process.
Group enquiry-based learning is based on trial and error (what Deleuze and Guattari call “experimentation”).
The natural method is based on an inductive, global approach.
Centers of interest are grounded in children’s learning interests and curiosity (Cole 2014, p. 87).

When Freinet was a teacher, he realized that anything he wrote upon the chalkboard, which was often based upon classroom discussions, disappeared after he erased it. “There would be no record of this event in his students’ life” (Acker 2007, p. 13). This led him to acquire a small printing press that the students could learn to use in order to record their own learning. This led on to become one of the two major initiatives that were to form his progressive and democratic forms of education. The second major initiative he developed was the concept of Inter-scholastic exchanges; the exchange of newsletters as well as the newspapers written and printed by the students.

These initiatives gave the students the impetus to engage in lively and critical classroom discussions, as well as being able to develop the more technical skills associated with printing. As part of the process, students were involved in developing their own learning.

Commenting in 1996 upon Freinet’s method, Jean Haccuria, an inspector of schools in Brussels, summarized the basic tenets of Freinet’s pedagogy. In a letter to the Belgian publication *L’Education Popular*, Haccuria pointed out some of Freinet’s domains as including:

> free expression, free text, the printing in the school, freehand drawing, engraving on linoleum, free theatre, and current events. (In Acker 2007, p. 7)

> Moreover, “Freinet powerfully distrusted anything like a ‘patent method’ or a ‘teaching formula.’ He knew only too well how centrally imposed textbooks and courses of study could undermine teachers’ best efforts to tap their pupils’ natural interest in regional events or activities that central planners would never take seriously”. (Freinet 1999, p. 3)

It should, therefore, be no great leap to articulate these initiatives into a modern technology education paradigm. The printing press can be replaced by computer technology in the forms of graphic communications, digital photography, word processing, spreadsheets, computer-aided design, 3D printing, and many others beyond. The interscholastic exchanges can easily be accommodated through the Internet.

Affect

Affect differs from effect. Affect, as used by Deleuze and Guattari, is not a personal feeling such as *affection for a loved one*, for example. It is the ability to affect and to be affected. Considered in terms of the multiple interactions that occur between human beings and their technologies, affect denotes the passage from one experiential state of the body to another, one that will imply either an augmentation or diminution in that body's capacity to act. A mobile telephone can augment communications or diminish a child's state of mind through the medium of cyberbullying. The bully affects another child; the bullied child is affected. Technology is the medium used in the interaction (Massumi in Deleuze and Guattari 2008, p. xvii).

Affect in Nomadology

Freinet believed that the teacher must act as facilitator, not as dictator. *Logos* must give way to *nomos*. Power over both content and learning must be distributed. Technology affects virtually every aspect of our lives today, including the lives of young people, and, through its development and utilization, human beings, in turn, affect the ongoing development of technology. This symbiotic relationship between human beings, the natural world, and the development of technology is not a linear process. It is complex and chaotic. Becoming technologically literate is not a process involving the absorption of already established information. It is, rather, a process involving the ongoing development of a critical capacity, one that considers the way the development of technology is affected by human beings, which in turn, reveals the affect technology has upon human beings. In other words, it is a learning environment that facilitates, indeed encourages, the freedom to express individual's perspectives about their own relationships with technology and how they feel affected by that relationship, or, how they feel that relationship enables them to affect others. In order to facilitate this, teachers must recognize that while they "have an indispensable role to play, they should not monopolize classroom time since students should have a strong voice in classroom life" (Freinet in Acker 2007, p. 10).

Free texts enable learners to record, in both their own words and in their own style (which may include, sketching and photographing, for example), their personal perspectives regarding their own relationships with technologies. It is important that context is chosen by the learner and is not imposed. Classrooms should be part of the actual world according to Freinet, not a synthetic representation. These free texts can then be used to aid each individual, in a cooperative setting, to express, freely, their recorded thoughts – thoughts that are focused upon issues relating to the way that they feel affected by technology and how they may affect others through the medium of technology. The teacher's role is to facilitate, not to impose.

> Freinet's educational method allows children to discover the vastness and the exigencies of freedom as it reduces what is 'forbidden in a classroom.' It allows them to choose a

> method of working: Either an individual work plan or a collective work plan. Students discover real freedom – one that is not a whim or fancy but is engaged in a self-expression. (Acker 2007, p. 12)

Freinet proposed that interscholastic exchanges, mediated through the use of printed illustrated school journals, as written and formatted by the learners themselves, should form part of this new pedagogical framework in order to expand a young person's view of the world. Rural children, for example, could exchange information about technology with those living in urban or industrial areas. Today, with the advent of mass communication, the Internet can expand the scope and speed of this. Journals can be formatted online and sent electronically to other participating schools. This method can facilitate cultural exchanges where alternative perspectives about technology, technology education, and the ethical and political dimensions relating to technology can be revealed and further discussed.

One delightful example that sums up Freinet's progressive methodology is given in a record posted by a teacher in Algeria:

> One day, in my Second Grade classroom of 40 students, two of my young girls bring various texts on the Festival of the Sheep, and we very enthusiastically decide to prepare a document regarding the last night of Ramadan (known in Arabic as Eid El Kebir) to send to our correspondent in France. Quickly, in teams of two, the students divided the assignment: they wrote down what they knew, researched and questioned their parents and other elders on what they were unaware of. They filled out informational cards on the following subjects:
>
> Origins of the festival
> Purchase of the sheep and its arrival at the house
> Slaughtering the sheep at the festival
> Washing the sheep's fleece
> Use of the meat and preparing the couscous
> Various other dishes prepared on this occasion
> Drying and storing the sheep's meat
>
> On the assigned day, each team presented the results of their research in front of an engrossed audience. After the students did all the necessary corrections, they carefully recopied the work, illustrated on cardboard the product of their research, put on a simple binding, adding a colorful cover and voila . . . their work was ready to be sent. As the teacher, what was my cost? Negligible. I directed their work a little and spent some of my personal time investigating the same thing they were investigating to make sure of its accuracy. I also got to know my students better. (In Acker 2007, p. 46–47)

It is my belief that this methodology, which articulates with the philosophy of Deleuze and Guattari's concept of nomadism, can universalize the local. In other words, the concept of technological literacy can become part of the various local technology education curricula around the world by, ironically, utilizing modern technology as a platform that will enable students to express their various perspectives on technology in a global format. A modern adaptation of Freinet's methodology, using journals and interscholastic exchanges to facilitate freedom of expression, could provide the motivation for young people to engage with the technologically textured word they inhabit by becoming aware of alternative perspectives at the local level. The various existing technology curricula, whether heavily predicated upon the concept of *logos* or not, can continue to be assessed in whatever way the relevant hierarchies of power insist upon. Becoming technologically literate, facilitated by a democratic pedagogy of freedom, can articulate seamlessly into any given technology education curriculum, if those at the working end of technology education are keen enough to implement it.

Production of electronic journals, in whatever format as agreed between participating schools, can become guides, written and produced by the learners themselves, giving an account of their experiences, learning and deliberations regarding issues relating to technology and technology education. These guides, not prescriptions, can be adapted, not adopted, by future generations of learners. The journals, which can be made available to all in the participating schools as well as other interested parties such as parents or industry (young people influencing industry rather that the other way round), can be produced regularly, perhaps every month or two. Freinet found that because the journals were made available to a much wider audience than might otherwise be normal, and produced on a regular basis, had the effect of focusing the learners' attention on producing high quality work, which enabled learning to take place over a wide range of subjects. Moreover, this learning took place on a voluntary basis, rather than by way of imposition.

Assessment of technological literacy can also form part of the nomadological approach. Aspects of technology education that fit more neatly into the domain of *logos* can retain their extant assessment protocols. Those that relate more to becoming technologically literate can be assessed formatively, where students, teachers, and significant others contribute to the process.

In Conclusion

This approach, I suggest, which may be considered as a pedagogy of freedom of expression, encourages young people to become more confident in expressing their own perspectives on issues that are important to them. An environment can be created in which learners are encouraged to work cooperatively in any endeavor relating to technology, something that can be achieved by removing the imposition of formal examination structures that serve to isolate the individual. The world of dualities (right or wrong, good or bad) gives way to experimentation based upon learning through trial and error. Inductive reasoning becomes the natural method, whereas the deductive reasoning of certainty is abolished. This facilitates a learning space that encourages freedom of expression, while simultaneously, being open to changing any deeply held perspective when reasonably challenged by others. Learners can learn to share and record their perspectives with others in the class, the wider school and indeed, in the world. They can be exposed to other cultures, other languages, and other alternative perspectives relating to the changing technologically textured world that they, and many others, inhabit. Perhaps, as an ongoing process of becoming technologically literate, future generations will become more informed and better able to engage in critiques on gender, cultural, socioeconomic, global, and environmental issues.

References

Acker, V. (2007). *The French Educator Celestin Freinet. An enquiry into how his ideas shaped education*. Latham: Lexington Books.

Apple, M. W., & Bean, J. A. (1999). *Democratic schools: Lessons from the chalk face*. Buckingham: Open University Press.

Becker, J. D., & Hodge, C. A. (2010). Assessing technological literacy: The case for an authentic, project-based learning approach. California: Creative Commons. http://studylib.net/doc/18431003/assessing-technology-literacy. Accessed 16 May 2016.

Cole, D. R. (2014). Inter-collapse. . . Educational nomadology for a future generation. In M. Carlin & J. Wallen (Eds.), *Deleuze and Guattari, politics and education* (pp. 77–94). New York: Bloomsbury Academic.

Cole, D. R. (2015). Inter-collapse. . . Educational nomadology for a future generation. In M. Carlin & J. Wallin (Eds.), *Deleuze and Guattari, politics and education: For a people yet to come* (pp. 77–94). New York: Bloomsbury Academic.

Dakers, J. (2006/2014a). *Defining technological literacy: Towards an epistemological framework* (2nd ed.). New York: Palgrave MacMillan.

Dakers, J. (2007). Vocationalism – Friend or foe to technology education. In D. Barlex (Ed.), *Design and technology: The next generation* (pp. 90–107). Shrewsbury: The Nuffield Foundation in association with TEP.

Dakers, J. (2014a). *Defining technological literacy: Towards an epistemological framework* (2nd ed.). New York: Palgrave MacMillan.

Dakers, J. (2014b). *New frontiers in technological literacy: Breaking with the past*. New York: Palgrave MacMillan.

Dakers, J. R. (2016). Taking a bicycle ride into the virtual with Simondon, Deleuze and Guattari. In M. C. A. Van der Sanden & M. J. de Vries (Eds.), *Science and technology education and communication*. Sense Publishers: The Netherlands.

Deleuze, G. (1994). *Difference and repetition*. (P. Patton, Trans.). New York: Columbia University Press.

Deleuze, G., & Guattari, F. (2008). *A thousand plateaus*. (B. Massumi, Trans.). London: Continuum Press.

Freinet, C. (1967). *Education through work: A model for child centred learning*. (J. Sivell, Trans.). Lewiston/Queenston/Lampeter: The Edwin Mellen Press.

Freinet, C. (1999). *Cooperative learning and social change: Selected writings of Célestine Freinet*. (D. Clandfield & J. Sivell, Ed. & Trans.). Toronto: OurSchools/OurSelves OISE Publishing.

Garmire, E., & Pearson, G. (2006). *Tech tally: Approaches to assessing technological literacy.* Washington, DC: National Academy Press.

Hasse, C., & Wallace, J. (2015). Towards a reconsideration of technological literacy. Technucation. http://technucation.dk/en/concepts/technological-literacy/. Accessed 16 May 2016.

IBO. (2016). *International Baccalaureate Organisation. Website for design and technology.* Accessed 25 June 2016. Available at http://www.ibo.org/programmes/diploma-programme/curriculum/sciences/design-technology/

ITEA. (2003). *Advancing excellence in technological literacy.* Reston: International Technology Education Association.

ITEA. (2006). *Technological literacy for all* (2nd ed.). Reston: International Technology Education Association.

ITEA. (2007). *Standards for technological literacy* (3rd ed.). Reston: International Technology Education Association.

Jun, N. (2011). Deleuze, values and normativity. In N. Jun & D. W. Smith (Eds.), *Deleuze and ethics* (pp. 89–107). Edinburgh: Edinburgh University Press.

Nietzsche, F. (2006). *Daybreak: Thoughts on the prejudices of morality.* Cambridge: Cambridge University Press.

Pearson, G., & Young, A. (2002). *Technically speaking: Why all Americans need to know more about technology.* Washington, DC: National Academy Press.

O'Riley, P. (2003). *Technology, culture and socioeconomics: A rhizoanalysis of educational discourses*. New York: Peter Lang.

Rasinen, A. (2003). An analysis of the technology education curriculum of six countries. *Journal of Technology Education, 15*(1), 31–47.

Selfe, C. L., & Burns, H. (1999). *Technology and literacy in the 21st century: The importance of paying attention*. Carbondale: Southern Illinois University Press. Project MUSE.

Williams, P. J. (2007). A global curriculum: Design technology in the international baccalaureate. *Design and Technology: An International Journal, 12*(3), 47–57.

Williams, P. J. (2009). Technological literacy: A multiliteracies approach for democracy. *International Journal of Technology and Design Education, 19*, 237–254.

Teaching Science and Technology

4

Joseph C. Pitt

Abstract
Science and technology are often taught independently. This, however, does not reflect the reality of science and technology. Technology has contributed significantly to the development of science. This is illustrated by two examples: Galileo's telescope and the Laser Interferometer Gravitational-Wave Observatory (LIGO). Both also had social implications that need to be highlighted in education, if we want to present a proper image of science and technology.

Keywords
Aristotelian approach • Big science • *Dialogue on the two chief world systems* • Galileo • Laser Interferometer Gravitational-Wave Observatory (LIGO) • Queen Elizabeth I of England • Science and technology, teaching • Scientific revolution • *Siderius Nuntius*

Contents

Introduction

I have never understood the reasoning behind North American curriculum design (I am restricting my comments here to the North American educational system.). We deal with *subjects*. Our students study arithmetic, precalculus, geometry, biology,

J.C. Pitt (✉)
Department of Philosophy, Virginia Tech, VA, USA
e-mail: jcpitt@vt.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_3

chemistry, physics, English (of course), Spanish or German or French, possibly Latin, social studies, sometimes offered as world history, (meaning Western Europe), American history, government (meaning ours), economics, etc. But we do not teach them how these subject areas are related to one another or to the lives we lead. Occasionally we may give them a math exercise to calculate the time a train will arrive in Chicago from New York City traveling at 50 miles per hour with two 42-min stops. But we rarely, if ever, explain how chemistry and physics are related. Nor do many, if any, students know that Galileo and Queen Elizabeth I of England were contemporaries or that Bach and Newton overlapped (I do regular surveys in my 300-person introductory course asking questions like “Who else who is famous lived when Galileo did?” I am always sorely disappointed at the answers.). They should know these things in order to get a better sense of the dynamics of both history and culture. No one knows how the art of the day influenced science or how political considerations influenced historical writing (see, e.g., Hume’s 1985 *History of England*). In short we should stop teaching subjects. In an increasingly technological world, our students need to see and understand our technologies in the integrated world in which they live.

In an earlier paper (Pitt 1990), I suggested teaching the sciences by teaching the history of science, starting in the first grade. The idea was to have the student’s intellectual development parallel the development of science. So, in the first grade, the student is a free agent exploring the world around her, reporting back what she finds. In grade two, they are introduced to the idea that they can improve their exploration by employing some principles, and they start becoming little Aristotles, until the Aristotelian approach and assumptions fail, and they are given some of the tools to figure out a different approach, and so on until they are studying the world in a Newtonian fashion by their final year of high school. One of the ideas here is to let them play with a theoretical framework until it breaks down, and they have to find some other set of principles to guide their explorations. There are several lessons to be taken away here. The first is that science is an ongoing process that changes in many ways over time. The second is that one of the major forces affecting changes in the sciences is the introduction of novel technologies. When they get to the period known as the scientific revolution, they learn that Galileo used his telescope to discover the moons of Jupiter forcing a revision of the theory of the structure of the universe, but they rarely spend any time on the fact that without the technology of the telescope, those changes would not have come about as they did. The same is true for the use of the microscope in biology and the Bunsen burner in chemistry. They also learn that the history of science is the history of failed theories but that they should not be afraid to fail because all the great minds have failed. But the most important idea is that of process and process as a process of processes and that all is change.

But we don’t teach the fundamental truth of change. Nor do we teach our students how to look at the big picture and how the parts are integrated and mutually interdependent. We teach out of our intellectual silos and demand that they learn only what is in the silos and not how the silos are related. But even within those silos, we do not teach how and, most importantly, why the content changes. This latter problem arises, I suspect, because we really don’t have a theoretical framework for dealing with change. Several members of the history and philosophy of science community have developed theories of scientific change. But, I submit, these are not theories of scientific change. Rather they are theories of rational decision-making. Kuhn (1962) lays out the structure of scientific revolutions, but in so doing, he sweeps over the dynamics of the practices of scientists, especially their use of novel technologies. We replace our paradigms when we discover anomalies. What is the mechanism for revealing anomalies? Laudan (1977) tells us to pick theories that have the potential to solve the greatest number of problems. But how do predict future problems for an unknown theory? Lakatos (1978) looks at research programs and how to choose among them. But past performance is not necessarily an indicator of future successes. Further, none of these approaches look at what causes the result that leads to the need to modify or change theories.

The proposal I am putting forth here is that technological innovations open up horizons never imagined or not previously accessible. I am not defending the view that every scientific change is caused by technological innovations. I will, however, argue that many are, and that by ignoring that aspect of the scientific process, we have undermined our ability to develop our sciences more fully. Further, I propose that these innovations are rarely predictable. It is the case that we can set out to build devices to achieve specific results, like smash atoms. But more often than not, we cannot predict what we will find when we use the device, like a new, previously unpredicted particle.

To develop the thesis outlined above a bit more, I will look at two specific cases, Galileo's telescope and the impact of the detection of gravity waves by the Laser Interferometer Gravitational-Wave Observatory (LIGO). There should be no objection to citing Galileo's telescope as a technological innovation, despite the fact that he did not invent it. Rather it is the use to which he put it that was innovative. There may be some objection to the LIGO example, since some of the results are still out – however, I would argue that not just the LIGO but the techniques surrounding its use are technologies, following on my account of technology as *humanity at work* (Pitt 2000).

Galileo's Telescope

Galileo built his first telescope in 1608 (The very first telescope was made by Hans Lippershey.). Galileo heard about a device that could allow one to see far away objects closer, some say from an itinerant peddler. But no matter where he got the information from, the important point here is that there clearly was communication and trade between central Italy and Holland – so, you might ask your students, what else was going on in Europe at the time Galileo was figuring out the principles behind the telescope? The second important point concerns what Galileo did next and the consequences of those actions.

First, beginning in 1608, Galileo trained his telescope on the heavens, first on the moon and then on other objects in the heavenly sky. Second, he published the results of those observations in a little book entitled *Sidereus Nuncius* or *The Starry*

Messenger in 1610. The book contained his observations and conclusions concerning the surface of the moon and his discoveries of the moons of Jupiter.

The claims about the surface of the moon were controversial, to be sure. Galileo argued that the surface of the moon resembled the surface of the earth having both mountains and valleys. This could be used to explain the luminosity of the moon, but more importantly, it could be used to start undermining the long-standing Aristotelian cosmology that maintained there were two basic domains in the universe, each with their own laws governing their behavior: celestial and terrestrial. The heavens were eternal, pure, and unchanging. Terrestrial affairs were marked by their imperfections and changing nature. Further, the Earth was the center of the universe, with all other objects in the heavens rotating around it. The discovery of the similarity of the moon's surface to that of the earth disturbed the claim that the objects in the heavens were pure and perfect, for clearly, if Galileo was correct, the moon had an imperfect surface. But perhaps more disturbing was the discovery of the moons of Jupiter, which Galileo named the Medicean Planets. If there were, in fact, objects rotating around Jupiter, that meant that there was another center in the universe. These two revelations, made possible by a technological innovation, shook the scientific world to its core. They set off a number of events. First, there was the expected attempt to discredit Galileo's observations. The telescope was attacked as unreliable. How could a device made of terrestrial, imperfect stuff provide reliable information about the perfect heavens? Some scholars refused to look through the telescope, fearful that it was a work of the devil. Second, there was the attempt to discredit Galileo himself, a crusade that culminated in the condemnation of his next book, *Dialogue on the Two Chief World Systems (1632)*, and ultimately his trial and sentence to house arrest for the rest of his life. Despite Galileo's misfortunes, the damage to the Aristotelian worldview had been done, thanks, fundamentally to a technological innovation. The fallout was extensive, and a new worldview did not come into play until Newton *published* his *Principia.* But the world view that finally replaced the Aristotelian view was far less integrated and led to much intellectual uncertainty about the world we live in and our place in the universe.

The take-away here is the world of science is dynamic, immersed in the society in which it operates, pushed this way and that by the introduction of novel technologies, and its revelations can have revolutionary effects. But those effects involve more than just jettisoning a disproven theory. Galileo's case is, granted, dramatic. But to study it in depth is to discover how scientific, technological, religious, and social considerations are intertwined. The second take-away is that to teach science well, one needs to know a lot about the history of cultural development, especially the technologies that support it.

The Laser Interferometer Gravitational Wave Observatory

The second example I present has to do with a different aspect of the dynamics of science and technology. In the present, beginning after World War II, there arose something that came to be known as *big science* (The phrase was made popular by

Derek De Solla Price in 1965.). Big science is science that relies heavily on large technological infrastructures such as a super-colliding super-conducting to allow scientists to explore what they cannot do on their own using little instruments. The case here involves the construction and use of the Laser Interferometer Gravitational-Wave Observatory (LIGO). LIGO was built with the hope of detecting gravitational waves – a phenomenon predicted by Einstein. There was no empirical evidence for the existence of gravitational waves, and it was certainly not clear what confirming their existence would do other than give us increased confidence in the general theory of relativity. With our newfound understanding of social complexities surrounding science, one can begin to fill in the kind of social, political, and economic arguments that surrounded the proposal to build such a large, expensive machine with no practical results anticipated.

> Computer models showed that LIGO's signal came from two black holes, 29 and 36 times as massive as the sun, spiraling together 1.3 billion light-years away. No one had ever seen a pair of orbiting black holes or detected "stellar mass" black holes so heavy. Astrophysicists say – and they are hard to fit into current theory. (*Science, 351*(6275), p. 796)

The device that was used was both manipulated by computers and its findings rendered by computer models. Additionally these findings did not fit into current theory. So we "find" gravity waves (actually the machines and computers do), but in a context that does exactly do what they are supposed to do, i.e., confirm Einstein's theory. We start on a hunch that these things, gravity waves, should exist, and when we find them, they turn out not to actually be the kind of things we thought they would be.

This is a case in which the technology and the technological infrastructure both aid and confuse the science. But the social consequences are also worth considering. Yes, we got a result. No, it is not what we expected. Therefore, we need more money to augment the technological system we have constructed to help us figure out what we discovered. Having students exposed to the chaos of big science where big technology is crucial is important considering the amount of money involved, the rationales for spending that money, and the fact that it is public money. This should raise questions about the justification for spending public money on toys for scientists as opposed to training and finding jobs for our citizens – is science worth it?

Conclusion and Future Directions

Putting science and technology back into society makes it a very messy business, especially in the age of big science, which really means big technology. But our job as teachers is to tell the truth and provide our students with the tools to find it out for themselves (As to the question of who determines the truth – well, that is what science is supposed to do, but as we expand and complicate our technological infrastructures, it is going to be increasingly difficult to know when we have found it.). I am not suggesting we don't fund big science – but I want us to consider the consequences.

References

Hume, D. (1985). *The history of England* (edited: Miller, E. F.). Indianapolis: Libery Classes.

Kuhn, T. (1962). *The structure of scientific revolutions* (2nd ed.). Chicago: University of Chicago Press.

Lakatos, I. (1978). In J. Worrell & G. Currie (Eds.), *The methodology of scientific research programmes*. Cambridge/England: Cambridge University Press.

Laudan, L. (1977). *Progress and its problems*. Berkeley: University of California Press.

Pitt, J. C. (2000). *Thinking about technology; foundations of the philosophy of technology*. New York: Seven Bridges Press. http://www.phil.vt.edu/Pitt/jpitt.html

Pitt, J. C. (2006). The myth of science education. *Studies in Philosophy and Education, 10* (1990), 7–17.

de Price, D. S. (1965). *Little science, big science*. New York: Columbia University Press.

From Crit to Social Critique

5

Stephen Petrina

Abstract

This chapter addresses the problem of moving students from critical self-reflection to the critique of design and technology. How and why do students become skeptical or critical of the designed world or more specifically of practices and products created for unsustainable consumption or planned obsolescence? After reviewing the history of the crit in D&T classrooms and workshops, this chapter addresses how students transfer dispositions from the crit to social critique of design practices and products. Conceptually, Schön's work, especially *The Reflective Practitioner*, provides key insights into this problem. This is a problem of transferring activity to activism, from school facilities to everyday life external to schools.

Keywords

Crit • Critique • Design • History of Design education • Schön

Contents

An unresolved question of curriculum is "to what degree does design and technology education (D&T education) (D&T education for this chapter refers to the scope of computer, craft, design, engineering, HCI, industrial, media, technical, and technology education) move students to critique their products and effects?" The design critique or "the crit" is common practice in various forms, but it is unclear how well

S. Petrina (✉)
Faculty of Education, The University of British Columbia, Vancouver, BC, Canada
e-mail: stephen.petrina@ubc.ca

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_5

this transfers to social critique and action outside or beyond classrooms, laboratories, makerspaces, studios, and workshops. Indeed, it is unclear how well students are assisted with this transfer from crit to social critique. This problem of transfer is primarily a problem of how well the purposes of D&T education are articulated. Apropos is the timeworn fable of three masons asked by a curious observer, “What are you doing?” The first quickly said “laying brick,” the second “earning a wage,” while the third, with a pause, answered “building a cathedral” (Woodruff 1922, p. 32).

Perhaps becoming critical depends on how conscious students are in moving from crit to critique. This is, after all, the point of *The Reflective Practitioner* (Schön 1983). Like a mason who does not automatically transfer from the brick to the building, it is neither easy nor natural to transfer from a crit of a technological device to critique of technological determinism. The process of moving from a crit of applications to a critique of implications is no small feat, but, increasingly, the stakes are high (Williams and Stables 2017).

This problem of transfer is philosophical. As often as it is said that craft, design, engineering, and technology are problematic, it is countered that they are pragmatic. Implicit in this counter is a resolution that crafters, designers, engineers, and technologists should not be expected to express or act on social critique. As Kranzberg (1962) observed: “What the technologist asks is: do the means effectively reach the ends?” Somewhat sympathetically, he emphasizes, “This pragmatic formulation has been implicit in technological development since the time of the first stone implements” (p. 522). From time immemorial then, we are taught that “design is a practical activity” or “engineering is a pragmatic and practical discipline” (Dilnot 1984, p. 12; Harrison 1998, p. 182). Similarly, we are reminded that “science is a pragmatic, operational tool” (Rolston 1991, p. 389). In STEM education, if not the cognate disciplines, theory is subordinate to practice. What then, do pragmatism and the pragmatic outlook accommodate, allow, or hold for D&T education? Does pragmatism disallow or disavow critique?

Recall that an important archetype is the skeptic, including the “technological skeptic” (Costanza 2001, p. 464). Bronowski (1973/2011) captures this role: “It is important that students bring a certain ragamuffin, barefoot irreverence to their studies; they are not here to worship what is known but to question it” (pp. 341–342). On the other hand, D&T educators face stereotypes such as the economic charge of facilitating “technological indoctrination,” now begun in the cradle with products such as the “Newborn-to-Toddler Apptivity Seat” (Hetzler 1969, p. 191; Miller 2014). An implicit assumption is that by virtue of teaching D&T, educators are complicit in fulfilling students’ functional and technocentric roles in the economy. Might it otherwise be said that in D&T education, students are not here to worship what is made but to question it?

This chapter addresses the social critique of technology with a specific focus on how students become critical. How and why do students become skeptical or critical of specific technologies or more generally D&T? The chapter begins with a premise that social critique was explicit and inherent in D&T education from its formal inclusion in educational systems in the nineteenth century. The first section explores initial purposes of D&T education and a brief history of the crit. Neither peripheral nor secondary to other purposes, such as making and remaking, critique requires practice. The chapter proceeds to address the problem of transfer from the crit, which is integral to learning within D&T, to social critique. On one level, this is a problem of transferring activity to activism, from D&T's internal school facilities to life after or external to schools. The chapter raises critical questions for pragmatists. As Schön (1983) concludes, a detached or distanced social critique of D&T "cannot substitute for (though it may provoke) the qualified professional's [or student's] critical self-reflection" (p. 290). Schön attended to practices moving students "from technical rationality to reflection-in-action" (p. vii); this chapter attends to processes moving students from critical self-reflection to social critique.

Purposes and Practices

Historically, D&T education was founded on a critique of prevailing purposes and practices of education (Dewey 1904, p. 443; Woodward 1882, pp. 627–628). Responsive to the aims of arts and crafts (A&C) and modern design in the nineteenth and early twentieth century, this critique of prevailing education was extended to a critique of apprenticeship practices in the trades and ultimately to modern industry. Like A&C, D&T education was established on a premise that it could humanize the machine (Triggs 1902, pp. 147–158, 184–185). Through the nineteenth century, discontent with prevailing aims of education was fairly resolved with an inclusion of material, practical, and social aims. Defenders of classical aims felt helpless against trends. "The last demand of the industrial spirit is that all education shall be lowered to its material aims," one classicist bemoaned in the mid-1880s; "for lowered it will be if all distinction is removed in academic honor between an education for the sake of the mind itself and an education dependent on and limited to material and practical aims" (Warner 1884, p. 223). However, advocates of manual training at the time established aims more lofty than base. "The labor question" of capital's ill-distribution of wealth would be "settled by nothing short of revolution," an analyst reasoned. "This revolution, however, will be peaceful: there will be no lawlessness, no destruction of property, nobody would be maimed, nobody would be killed. The revolution is to be effected through the manual training school" (Jacobson 1888, pp. 24–25; *Science* Editors 1887, p. 197).

Manual training (MT) specialists had nonetheless reconciled with prevailing aims (McKinney 1919). The aims of manual training were formalized through *Slöjd* (i.e., dexterity, skill) in Sweden, primarily through the work of Salomon (1888, pp. 185–188), who differentiated between the "formal" (e.g., development of "mental and physical powers") and "material" (e.g., "acquisition of general dexterity") (p. 202) (Butler 1887, p. 256). Similarly, in establishing and sustaining the first MT school, the United States (US) in 1880, Woodward wanted to balance cultural, social, and vocational aims (Coates 1923, pp. 71–75). As he emphasized in 1882: "it is my intention to improve every opportunity to declare that in educating the hand we do not neglect the mind" (quoted in Coates 1923, p. 75). "We do not manufacture articles for sale," Woodward (1882) asserted, "nor do we pretend to fully teach particular trades" (p. 629). Downplaying the practical, Woodward (1903) later clarified that "manual training, as we have it in the high school, is a culture study" (p. 72).

By the turn of the century, as Woodward (1903) suggests, the cultural and social purposes of D&T education were as important as the practical purpose (McKinney 1919). Dopp (1902) clarified that D&T education "will train the child to control machinery rather than be controlled by it" (p. 171). Understanding a machine, she emphasizes, requires teaching a student "its purpose, how constructed, how controlled, and how used for the amelioration of society." She continues: "these are the problems that the school should undertake to teach him to grapple with, rather than to occupy him with activities that tend to render him as automatic, as unfeeling, as a part of the machine itself" (p. 171). Dopp clarifies that this particular "intelligence" includes recognition of how the material relates to the cultural or social and implications of products (p. 172). The Massachusetts Commission on Industrial and Technical Education referred to this as "industrial intelligence," meaning "mental power to see beyond the task which occupies the hands for the moment to the operations which have proceeded and to those which will follow it – power to take in the whole process, knowledge of materials, ideas of cost, ideas of organization, business sense, and a conscience which recognizes obligations" (Wright et al. 1906, p. 5).

"Industrial intelligence," or what was reframed as "technological literacy" (Dakers 2006, 2014; Petrina 2014), was basically developed through two interrelated instructional methods: demonstration (the demo) and critique (the crit). On the first method, D&T educators generally concurred: "In any attempt to describe the practice of an art [or technology] the briefest demonstration is of more value than the most elaborate statement. The demonstration can be made concrete and specific, the statement must often be general" (Haney 1905, p. 179). Sentiment held that "before manual work of the true type can be given its rightful place in the schools, the general public must cease its idolatrous worship of the book" (Hervey 1908, p. 328). The demo also manifested as a model, proof of concept, or demonstration of a design idea, which is integral to D&T education as well.

Like the demo, the crit has a history dating back to antiquity and was made core to D&T education in the nineteenth and early twentieth centuries. Popularized in the Ecole des Beaux-Arts in France and refined in the Bauhaus in Germany (Anthony 1991, pp. 8–26; Flynn 2005), the crit found common practice in the schools. In MT the crit was documented in 1886 as follows:

> When the lesson is concluded the whir of the machinery ceases, and a great silence falls upon the class as the students assemble about the instructor, each presenting [her or] his piece of work. This is the moment of friendly criticism. The instructor handles each specimen, comments upon the character of the workmanship, points out its defects, and calls for criticisms from the class. These are freely given. There is an animated discussion, involving explanations on the part of the instructor of the various causes of defects, and suggestions as to suitable methods of amendment. (Ham 1886, p. 44).

Teachers were often trained in giving and receiving a crit or “a lesson which is to be criticised by competent authority for the benefit of her [or his] fellow-students” (Teachers in training 1888, p. 517). According to an observer in the United Kingdom (UK) in 1888, “criticism lessons, familiarly termed ‘crits,’ are a weekly institution in the Training College, and are looked forward to with dread by the victims. It is an ordeal to stand there and give your lesson in the presence of critics” (Teachers in Training 1888, p. 519). This insight acknowledges power and tension in the crit among the student, peers, and teachers (Anthony 1987, 1991).

For primary school D&T, the crit was adjusted to the recitation, which, as Dewey (1900) defined it, “becomes the social clearing-house, where experiences and ideas are exchanged and subjected to criticism, where misconceptions are corrected, and new lines of thought and inquiry are set up” (p. 65). Through the crit, “specific effort should be made to develop power to judge according to definite standards,” an expert advised (Haney 1905, p. 190). Ideally, depending on the aim and level, students and teachers adjusted as necessary in a spirit of mutual improvement. In the demo, the teacher models design or production practices while in the crit models criticism or critique (Haney 1905).

From Crit to Social Critique

Schön (Schön 1983) defines design as “a reflective conversation with the materials of a situation” and distinguishes between “language of designing” and “language about designing” (pp. 80, 81, 172). Through what processes do students become conversant with both the materials *and* the situation, however limited and expansive? While Schön’s (1983, 1984, 1985, 1992a) exemplar or paradigmatic case is the architecture studio or workshop, the concern is with language of and about design *and* technology used as crafters, designers, engineers, technicians, and technologists learn and work. This resolves in debates over emphases on making versus knowing or procedural knowledge versus declarative (or propositional) knowledge (Martin and Owen-Jackson 2013). Schön observes that the language *of* designing includes “names of elements, features, relations, and actions, and of norms used to evaluate problems, consequences, and implications” (pp. 95–97). This repertoire is meant “to fulfill a variety of constructive, descriptive, and normative functions” (p. 97). The language *about* designing is metacognitive and often articulated as “fragments of a theory about the design [and make] process” (Schön 1984, p. 7). He (Schön 1984) elaborates: “In the passages back and forth among the languages of appreciation, performance and theory of designing, student and studio master pass, in their reciprocal reflection-in action, from one domain of attention to another, and from one level of description to another” (p. 7). Labs, makerspaces, studios, and workshops require “students to spend a great deal of time talking about their design, talking to other students, talking to professors [or teachers] at desk crits [individual crit], and, of course, talking at jury [group crit] presentations” (Stevens 1995, p. 118).

Schön (1984) reiterates that the “passages back and forth among the languages” of designing and making become relevant and specific in the “context of action” (p. 7). He emphasizes that:

> There is no magical dividing line between the studio [or workshop] and the world outside it. The student does not suddenly understand, when she steps into the studio, what she had found obscure while she remained outside it. Nevertheless, master [or teacher] and student can begin their reflective dialogue about design, designing and learning to design, once the student has begun to design [and make]. What happens to make this possible? (p. 7).

In an example drawn from Simmonds’ (1978, 1981) case study, Schön (1984) notes how in the process of a crit, the teacher “Quist has reflected critically on [the student] Petra’s framing of the problem. He has conducted an on-the-spot drawing experiment in reframing the problem” (p. 5). Although the crit can be Kafkaesque at times, without the teacher’s feedback or modeling, one student acknowledged “you don’t know where you are and have no basis for evaluation. You hang onto the inflection of the tone of voice in your crit to discover if something is really wrong” (p. 5). Schön (1984) continues:

> Only as he or she immerses him or herself in the studio experience, the experience of trying to design [and make], can he or she create the conditions in which to begin to understand what the studio master says and does. But this immersion carries, often, a perceived risk of a high order. Immersing oneself in the strange and demanding world of the studio, the student tends to experience a loss of competence, control, and confidence. And he or she cannot judge the value of taking such a risk until having actually taken it. (p. 6).

Like the demo and project, the crit is important for D&T learning. The concern here is with the language of designing and making that addresses “norms used to evaluate problems, consequences, and implications” and how the crit proceeds to social critique.

If the process of designing and making is defined as “a reflective conversation with the materials of a situation” (Schön 1983, p. 172) then questions are raised about the scope of a design and make “situation.” Schön (1983) begins *The Reflective Practitioner* by recognizing the changing scope of “situations of practice” for designing and making, which are increasingly characterized by “uncertainty, instability, uniqueness, and value conflicts” (p. 14). “Practitioners are frequently embroiled in conflicts of values, goals, purposes, and interests,” he acknowledges. For instance, “teachers are faced with pressures for increased efficiency in the context of contracting budgets, demands that they rigorously ‘teach the basics,’ exhortations to encourage creativity, build citizenship, help students to examine their values” (p. 17). Given increasingly problematic situations, including global warming and waste generation, crafters, designers, engineers, and technologists invariably face a “crisis of confidence” that focuses ethics on decisions to reduce “‘messes’ to manageable plans” (p. 18). Ockham’s razor is necessary for finding, managing, and resolving design problems but at what price? Within a crit, students and teachers can quickly rule out social critique but at what cost to ethically anticipating consequences and implications of D&T?

> Beyond learning processes of ethical reasoning, design students are to be assisted in seeing that such reasoning processes are embodied in larger structures of action. In the delineation of reasons, the role of the design instructor is critical. Causes are constituted as the design student defines a design project. Situations are not simply the objective conditions or facts; rather, situations come into being as the student questions the facts from some point of view. (d'Anjou 2010, p. 103).

Situatedness is problematic (Gregg 1994). What is included and excluded from a situation and crit involves a series of decisions that raise questions of ethics at each step. Demystifying these decisions, Schön's work (Schön 1983, 1984, 1985, 1987) can be understood as an empirical inquiry into moving students from crit to situated critique of D&T.

Beginning with a critique of technical rationality, Schön (1983) demonstrates how readily practitioners and students fall into traps of its mystique (Waks 2001). Technical rationality suggests that "professional activity consists in instrumental problem solving made rigorous by the application of scientific theory and technique" (p. 21). Practitioners have an interest in preserving this "mystique of practical competence," but this comes at a cost (p. vii). "Many practitioners, locked into a view of themselves as technical experts, find nothing in the world of practice to occasion reflection," Schön (1983) argues. "They have become too skillful at techniques of selective inattention, junk categories, and situational control, techniques which they use to preserve the constancy of their knowledge-in-practice" (p. 69). Observing and recording practices, such as crits, demystifies what students and teachers actually do and say in in laboratories, makerspaces, studios, and workshops. Schön (1983) is nonetheless skeptical of "radical demystification" or social critique, which tends to have "a utopian vision, one of liberation from the domination of established interests and professional elite" (p. 288). By stripping away the "emperor's new clothes" of D&T knowledge to reveal its "empty claims," social critiques basically dismiss the fact or potential that D&T practitioners "do know something worth knowing, a limited something that is inherently describable" (pp. 288, 289). Social critique may mystify D&T practice that much more. "In this sense," Schön (1983) cautions, "both professional and counter-professional may be mystifiers. And in this sense, demystification is not a showing up of the falsity of the practitioner's claims to knowledge but a bid to undertake the often arduous task of opening it up to inquiry" (p. 289) (see also, Latour 2004).

Critique as intellectual work is "an attempt to give a meaning to our experience – that is, to make life more practicable" (Wilson 1941, p. 241). As the critique of relations among people and things, social critique begs action, however mundane, radical, or revolutionary (Adorno 1945; Marx 1867, pp. 72–74). Marx observed that capitalist production creates "material relations between persons and social relations between things" (p. 73). Social critique focuses on how and why these relations are forged, broken, restored, or reinforced in the processes of designing and making as well as how appearances distort the reality of relations. How do we learn and teach to reduce the use value of specific design and technologies? For example, if we critique automobility, what do we do next?

> Most modern land development strategies have wastefully and unfairly dispersed residences, employment, and social opportunity. It became difficult to live in many cities without a car. Such spatial dispersion— also called sprawl— subsequently led to increased land consumed for development, auto dependency, poor quality public transit, and the spatial isolation of many, but particularly less affluent urban residents and people of colour. (Crane and Schweitzer 2003, pp. 240–241).

At what moments in D&T education is critique most anticipatory or necessary? Like universal critiques, situated critiques, social or otherwise (e.g., environmental, feminist, indigenous, spiritual, etc.), are germane to the purposes and practices of D&T (de Vries 2005, 2017; Petrina 2017; Williams and Stables 2017). Again, the challenge is moving students from the crit to critique.

Conclusion

Following Schön, researchers have attended to the arduous task of opening up D&T learning and teaching to inquiry (Compton and Harwood 2005; Benson and Lunt 2011; Kimbell 1997; Kimbell and Stables 2008). The state of research in D&T, however, suggests a disconnection between the empirical task of documenting practice and the conceptual task of theorizing how this practice might lead to critique (de Vries and Mottier 2006; Jones and de Vries 2009; Williams and Stables 2017). Despite Schön's (1983, p. 315) proposal for "repertoire-building research," we do not yet have clear cases or documentation of how D&T education moves students to critique their products and effects or, more specifically, how the crit transfers to social critique. An implication is that D&T educators have not sufficiently addressed Schön's "critique of technical rationality." Perhaps fair enough, nor did Schön (1991, 1992b) or researchers in other disciplines attend to the process of moving students from crit to critique. In contrast to becoming creative, we simply do not have empirical descriptions of students becoming critical (Carr and Kemmis 1986; Goldstein 2007; Selfe 1999). Part of the challenge is overcoming assumptions that compared to creativity, criticism and critique are easy and can be taken for granted (Latour 2004). If the process of designing and making is a reflective "dialogue with the phenomena of a particular site," then how does the crit incorporate critiques of D&T as phenomena for discussion over a setting, site, or situation (Schön 1988, p. 182)? What is transferred from classroom, studio, or workshop crits?

The problem of transfer from school to everyday design and technological practices is mirrored in most disciplines, including the arts, sciences, and social studies (Martin and Schwartz 2013). The reverse problem is transferring what is learned in everyday activities to classrooms. The problem of transfer from crit to critique is similar to transfer from ethical case study to ethical practice (Pettifor 2002). But as Schön (1983) notes, a student's "move from technical expertise to reflective practice" finds resistance at various levels (p. 329). D&T researchers are challenged to document whether, when, and what students transfer from crit to critique. Like any other curriculum practice, what is learned in the crit or transferred is not necessarily what is intended. The crit induces problems, be they culture, gender, or power, and is subject to reform in one way or another (Anthony 1987, 1991; Flynn 2005). However, if the crit is a bridge, then researchers will have to account for the critical thinking skills that are activated and move students to critique design and technological practices and products (Halpern 2014, appendix).

Albeit with much more to be done, researchers have criticized the crit, on one hand, and critiqued designing and making, on the other. Similarly, "staying close to the phenomena of inquiry," as Schön (1992b, p. 137), recommends, researchers have critiqued the practices of learning and teaching how and why to design, make, and unmake things. They pointed out contradictions inherent in conservative or naïve learning and teaching about D&T processes and products that have disruptive or radical consequences (Dakers 2006, 2014). For instance, eco-critiques address parallels between overproduction in D&T workshops and overconsumption in the world (e.g., Elshof 2009; Pavlova 2009; Petrina 2000; Stables and Keirl 2015; Wicklein 2001); feminist critiques detail the gendered nature of D&T curriculum and built environments (e.g., Braundy 2012; MacDowell 2015; O'Riley 2003; Zuga 1999); indigenous critiques juxtapose the ironic stagnation of projects in D&T against the novelty of wisdom found in the land (e.g., Cole and O'Riley 2015; Gumbo 2015; Seeman 2015); and critiques of curriculum and instruction indicate the potential of critical pedagogy, awareness, and critical thinking (e.g., Barlex 2015; Keirl 2015; McLaren 2012). These types of critiques are essential to avoid reproducing the old in the "new shop class" (Horvath and Cameron 2015). How and why should students become skeptical or critical of specific designs and technologies?

References

Adorno, T. W. (1945). A social critique of radio music. *Kenyon Review, 7*(2), 208–217.

Anthony, K. H. (1987). Private reactions to public criticism: Students, faculty, and practicing architects state their views on design juries in architectural education. *Journal of Architectural Education, 40*(3), 2–11.

Anthony, K. H. (1991). *Design juries on trial. The renaissance of the design studio*. New York: van Nostrand Reinhold.

Barlex, D. (2015). Developing a technology curriculum. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education* (pp. 143–168). Dordrecht: Springer.

Benson, C., & Lunt, J. (Eds.). (2011). *International handbook of primary technology education: Reviewing the past twenty years*. Dordrecht: Sense.

Braundy, M. (2012). *Men & women and tools: Bridging the divide*. Halifax: Fernwood.

Bronowski, J. (1973/2011). *The ascent of man*. London: BBC Books.

Butler, N. M. (1887). The Nääs seminary for teachers of manual training. *Science, 10*(251), 255–256.

Carr, W., & Kemmis, S. (1986). *Becoming critical: Education, knowledge and action research*. Melbourne: Deakin University Press.

Coates, C. (1923). *History of the manual training school of Washington University*. Bureau of Education Bulletin No. 3. Washington, DC: Government Printing Office.

Cole, P., & O'Riley, P. (2015). In(di)geneity in design and technology education. In K. Stables & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 67–85). Dordrecht: Springer.

Compton, V., & Harwood, C. (2005). Progression in technology education in New Zealand: components of practice as a way forward. *International Journal of Technology and Design Education, 15*(3), 253–287.

Costanza, R. (2001). Visions, values, valuation, and the need for an ecological economics. *Bioscience, 51*(6), 459–468.

Crane, R., & Schweitzer, L. A. (2003). Transport and sustainability: The role of the built environment. *Built Environment, 29*(3), 238–252.

Dakers, J. (Ed.). (2006). *Defining technological literacy: Towards an epistemological framework*. New York: Palgrave Macmillan.

Dakers, J. (Ed.). (2014). *New frontiers in technological literacy: Breaking with the past*. New York: Palgrave Macmillan.

d'Anjou, P. (2010). Beyond duty and virtue in design ethics. *Design Issues, 26*(1), 95–105.

de Vries, M. J. (2005). *Teaching about technology: An introduction to the philosophy of technology for non-philosophers*. Dordrecht: Kluwer.

de Vries, M. J. (2017). Philosophy as critique. In P. J. Williams & K. Stables (Eds.), *Critique in design and technology education* (pp. 15–30). Dordrecht, NL: Springer.

de Vries, M. J., & Mottier, I. (Eds.). (2006). *International handbook of technology education*. Rotterdam: Sense.

Dewey, J. (1900). *The school and society*. Chicago: University of Chicago Press.

Dewey, J. (1904). Significance of the school of education. *The Elementary School Teacher, 4*(7), 441–453.

Dilnot, C. (1984). The state of design history, part I: Mapping the field. *Design Issues, 1*(1), 4–23.

Dopp, K. E. (1902). *The place of industries in elementary education*. Chicago: University of Chicago Press.

Elshof, L. (2009). Toward sustainable practices in technology education. *International Journal of Technology and Design Education, 19*(2), 133–147.

Flynn, P. (2005). *Critting the crit in the education of architects: From Bauhaus to Bolton Street* (Unpublished MA Thesis). Dublin Institute of Technology, Dublin.

Goldstein, R. A. (2007). The perilous pitfalls of praxis: Critical pedagogy as "regime of truth.". In R. A. Goldstein (Ed.), *Useful theory: Making critical education practical* (pp. 15–29). New York: Peter Lang.

Gregg, B. (1994). Possibility of social critique in an indeterminate world. *Theory and Society, 23*(3), 327–366.

Gumbo, M. T. (2015). Indigenous technology in technology education curricula and teaching. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education* (pp. 57–76). Dordrecht: Springer.

Halpern, D. F. (2014). *Thought and knowledge: An introduction to critical thinking* (5th ed.). New York: Psychology Press.

Ham, C. H. (1886). *Manual training: The solution of social and industrial problems*. New York: Harper.

Haney, J. P. (1905). The teaching of applied design. *The Elementary School Teacher, 6*(4), 179–191.

Harrison, N. E. (1998). Why science and technology require political guidance to sustain development. *Politics and the Life Sciences, 17*(2), 179–188.

Hervey, H. D. (1908). Manual training. *Journal of Education, 67*(12), 328–329.

Hetzler, S. A. (1969/2002). *Technological growth and social change*. London: Routledge.

Horvath, J., & Cameron, R. (2015). *The new shop class: Getting started with 3D printing, arduino, and wearable tech*. Dordrecht: Springer.

Jacobson, A. (1888). *Higher ground: Hints toward settling the labor troubles*. New York: A. C. McClurg.

Jones, A., & de Vries, M. J. (Eds.). (2009). *International handbook of research and development in technology education*. Rotterdam: Sense.

Keirl, S. (2015). 'Seeing' and 'interpreting' the human-technology phenomenon. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education* (pp. 13–34). Dordrecht: Springer.

Kimbell, R. (1997). *Assessing technology: International trends in curriculum and assessment*. Buckingham: Open University Press.

Kimbell, R., & Stables, K. (2008). *Researching design learning: Issues and findings from two decades of research and development*. Dordrecht: Springer.

Kranzberg, M. (1962). The technical act. *Technology and Culture, 3*(4), 519–523.

Latour, B. (2004). Why has critique run out of steam? From matters of fact to matters of concern. *Critical Inquiry, 30*(2), 225–248.

MacDowell, P. (2015). *Empowering girls as change-makers in maker culture: Stories from a summer camp for girls in design, media, and technology* (Unpublished Doctoral Dissertation). University of British Columbia, Vancouver.

Martin, M., & Owen-Jackson, G. (2013). Is design and technology about making or knowing? In G. Owen-Jackson (Ed.), *Debates in design and technology education* (pp. 64–73). New York: Routledge.

Martin, L., & Schwartz, D. L. (2013). Conceptual innovation and transfer. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 447–465). New York: Routledge.

Marx, K. (1867/1967). *Capital* (S. Moore & E. Aveling, Trans.). New York: International Publishers.

McKinney, J. (1919). The what and the why of manual training. *Industrial Arts Magazine, 8*(8), 293–297.

McLaren, S. V. (2012). Considering some big issues and the role of technology education in transformational change. In P. J. Williams (Ed.), *Technology education for teachers* (pp. 231–260). Dordrecht: Springer.

Miller, F. L. (2014). The iPad bouncy seat: 'An embarrassment for humankind.' *Huffington Post*, Retrieved http://www.huffingtonpost.com/2013/12/03/ipad-bouncy-seat_n_4374308.html.

O'Riley, P. (2003). *Technology, culture, and socioeconomics: A rhizoanalysis of educational discourses*. New York: Peter Lang.

Pavlova, M. (2009). Conceptualisation of technology education within the paradigm of sustainable development. *International Journal of Technology and Design Education, 19*(2), 109–132.

Petrina, S. (2000). The political ecology of design and technology education: An inquiry into methods. *International Journal of Technology and Design Education, 10*(3), 207–237.

Petrina, S. (2014). Postliterate machineries. In J. Dakers (Ed.), *New frontiers in technological literacy: Breaking with the past* (pp. 29–43). New York, NY: Palgrave Macmillan.

Petrina, S. (2017). Critique of technology. In P. J. Williams & K. Stables (Eds.), *Critique in design and technology education* (pp. 31–50). Dordrecht, NL: Springer.

Pettifor, J. L. (2002). Preferred strategies for learning ethics in the practice of a discipline. *Canadian Psychology, 43*(4), 260–277.

Rolston, H. (1991). Review of *The justification of science and the rationality of religious belief. Journal of the American Academy of Religion, 59*(2), 389–392.

Salomon, O. (1888). *The Slöjd in the service of the school* (W. H. Carpenter, Trans.). New York, NY: Industrial Education Association.

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Schön, D. A. (1984). The architectural studio as an exemplar of education for reflection-in-action. *Journal of Architectural Education, 38*(1), 2–9.

Schön, D. A. (1985). *The design studio: An exploration of its traditions and potentials*. London: RIBA.

Schön, D. A. (1987). *Educating the reflective practitioner*. San Francisco: Jossey-Bass.

Schön, D. A. (1988). Designing: Rules, types and worlds. *Design Studies, 9*(3), 181–190.

Schön, D. A. (Ed.). (1991). *The reflective turn: Case studies in and on educational practice*. New York: Teachers College Press.

Schön, D. A. (1992a). Designing as reflective conversation with the materials of a design situation. *Knowledge-Based Systems, 5*(1), 3–14.

Schön, D. A. (1992b). The theory of inquiry: Dewey's legacy to education. *Curriculum Inquiry, 22*(2), 119–139.
Science Editors. (1887). Review of *Higher ground: Hints toward settling the labor troubles*. *Science, 10*(254), 296–298.
Seeman, K. (2015). Designing for cultural groups and humanization. In K. Stables & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 101–117). Dordrecht: Springer.
Selfe, C. L. (1999). Technology and literacy: A story about the perils of not paying attention. *College Composition and Communication, 50*(3), 411–436.
Simmonds, R. P. (1978). *Learning to learn and design: The development of effective strategies in a graduate school of architecture* (Unpublished Doctoral dissertation). Massachusetts Institute of Technology, Cambridge.
Simmonds, R. P. (1981). A first year studio in a graduate school of architecture. In W. Porter & M. Kilbridge (Eds.), *Architectural education study, Volume II: The cases* (pp. 5–206). Cambridge, MA: Consortium of East Coast Schools of Architecture.
Stables, K., & Keirl, S. (Eds.). (2015). *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures*. Dordrecht: Springer.
Stevens, G. (1995). Struggle in the studio: A Bourdivin look at architectural pedagogy. *Journal of Architectural Education, 49*(2), 105–122.
Teachers in Training. (1888). Teachers [in crits]. *Irish Monthly, 16*(183), 517–525.
Triggs, O. L. (1902). *Chapters in the history of the arts and crafts movement*. Chicago: Bohemia Guild of the Industrial Art League.
Waks, L. J. (2001). Donald Schon's philosophy of design and design education. *International Journal of Technology and Design Education, 11*(1), 37–51.
Warner, C. D. (1884). The demand of the industrial spirit. *North American Review, 139*(334), 209–223.
Wicklein, R. (Ed.). (2001). *Appropriate technology for sustainable living*. New York: Glencoe.
Williams, P. J., & Stables, K. (Eds.). (2017). *Critique in design and technology education*. Dordrecht, NL: Springer.
Wilson, E. (1941/1963). The historical interpretation of literature. In W. Sutton & R. Foster (Eds.), *Modern literature: Theory and practice* (pp. 234–242). New York: Odyssey.
Woodruff, C. R. (1922). Wanted: Civic dramatists. *National Municipal Review, 11*(11), 379–385.
Woodward, C. M. (1882). The functions of an American manual training school. *Popular Science Monthly, 21*(37), 621–634.
Woodward, C. M. (1903). The opportunity and function of the secondary school. *Proceedings and Addresses of the National Education Association, 42*, 60–71.
Wright, C. D., Reed, W. A., & Golden, J. (Eds.). (1906). *Report of the commission on industrial and technical education*. New York: Teachers College.
Zuga, K. F. (1999). Addressing women's ways of knowing to improve the technology education environment for all students. *Journal of Technology Education, 10*(2), 57–71.

Religion and Technology

6

Dennis Cheek

Abstract

Technology in all its varied manifestations and religion throughout its many traditions and expressions exhibit a long and complex interrelationship from prehistoric times to the present. Continuously evolving formal systems of religious thought and more informal daily practices among the religions of the world present a wide array of issues, understandings, attitudes, and values toward technology as well as demonstrate the complex influences that varied technologies have exerted directly or indirectly on the religious impulse. Technology and design education needs to explicitly engage religious thought and praxis as it relates to the technology curriculum for the sake of learners and for the future of society.

Keywords

Buddhism • Christianity • Design • Education • Folk religion • Hinduism • Islam • Judaism • Religion • Shintoism • Sikhism • Taoism • Technology

Contents

D. Cheek (✉)
National Creativity Network, Jacksonville, FL, USA

Entrepreneurship and Innovation Track, IÉSEG School of Management, Paris, France
e-mail: ststoday@gmail.com; d.cheek@ieseg.fr; Dennis@nationalcreativitynetwork.com

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_6

Why Religion and Technology?

It might at first glance seem quite odd that an international handbook on technology education would have a chapter coupling religion and technology. Academics and others might be excused for thinking that there are few explicit relationships to be found between religion and technology, and those that do exist primarily are unidirectional. After all many influences in the late twentieth and twenty-first centuries seem to run in the direction of technology inexorably asserting its influence and power over the realm of religion and spirituality just as it has seemingly done across commerce and economies, institutions (cultural, educational, social), social life, politics, sports, and other realms of human endeavors and activities. But if by *technology* we mean the human activities that seek to meet human needs and human wants by taking materials of various kinds and imaginatively and creatively combining, reconstituting, reconfiguring, and engaging in myriad other transformations to produce the ever-evolving, human-designed environments that we inhabit for most of our lives, we may immediately perceive some ways in which religion, the technological world, and the goals, skills, and methods associated with technological design, making, and evaluating are inescapably and continually interacting.

Consider the following excerpts from the English national curriculum in design and technology for Key Stages 1, 2, and 3 (Department of Education 2013a, b):

- Overall the national design and technology curriculum requires that students ". . . work in a range of relevant contexts," and includes the non-mandatory examples of "home, school, leisure, culture, enterprise, industry, and the wider environment." Industrial contexts at Key Stage 3 include " . . . construction, food, agriculture (including horticulture) and fashion."
- Key Stage 2 requires students to engage in design that includes seeking to determine " . . . fit for purpose, aimed at particular individuals or groups" and active making of things that among other aspects "uses a wide range of materials and components . . . according to their functional properties and aesthetic qualities."
- Key Stages 1, 2, and 3 recognize the importance of cooking and nutrition as a mandatory component at all three levels, noting that "learning how to cook is a crucial life skill."
- Key Stage 3 requires students to design in ways that "use research or exploration, such as the study of different cultures, to identify and understand user needs." It also requires that students learn how to skillfully evaluate technological designs, processes, and systems including the ability to "analyse the work of past and present professionals and others to develop and broaden their understanding,"

"test, evaluate and refine . . . taking into account the views of intended users and other interested groups," and to "understand developments in design and technology, its impact on individuals, society and the environment, and the responsibilities of designers, engineers, and technologists."

It should be clear to even a casual observer that learning requirements like these unavoidably engage aesthetics, values, needs, desires, and uses related to technology on the part of teachers, students, and wider communities that both invoke and involve religious traditions, religious practices, and specific groups within society whose primary identification is with one or more particular religions which embrace, for example, dietary requirements, particular aesthetics for attire, sensibilities about human beings and other creatures (both the large and very small), and teachings viewed by adherents as integral to how they engage the wider world and values that likely will profoundly influence their own future inputs into that wider world.

Religion as an Important Sphere of Human Activity

Religion, like the word "technology," has proven difficult to define in a manner that commands universal assent and fits the variegated landscape of academics and practitioners around the globe. One reasonable working definition posits that "a religion is a unified system of beliefs and practices about life and the world relative to the supernatural that unite the believers or followers into a social organization or a moral community" (Yang 2011: 36). As Yang noted in his Presidential Address to the Society for the Scientific Study of Religion on October 24, 2015, "this definition includes four essential elements of a religion: (1) a belief in the supernatural; (2) a set of beliefs regarding life and the world; (3) a set of ritual practices manifesting the beliefs; and (4) a distinct social organization or moral community of the believers and practitioners." (Yang 2016: 15).

Secularists since the dawn of literate societies have predicted the utter demise of organized religions of all types in the face of what is envisioned as the inevitable progress of science and technology as it deconstructs, reconceptualizes, and commodifies the world. Demographic data from over 2,500 censuses, surveys, and official population registers were collected and analyzed to determine the current state of the world's religions by the Global Futures Project of the Pew Research Center's Forum on Religion and Public Life in 2010. The resultant final report issued in 2012 (Pew Research Center 2012) documents that 84% of the world's people identify with one or more particular religions. About 32% identify with various forms of Christianity, 23% with Islam in its varied manifestations, 15% with various branches of Hinduism, 7% with various Buddhist movements, 6% with different folk religions, 0.2% with forms of Judaism, and 0.8% with other religions such as Jainism, Sikhism, Baha'i, Shintoism, Taoism, Tenrikyo, Wicca, or Zoroastrianism. Only 16% of the world's current population fails to identify with a particular religion. Even within this category of no current affiliation, the report notes that the majority of these people describe themselves as, for example, believing in God or a universal spirit, or articulate other beliefs that would be characterized as religious or spiritual ideas, despite not identifying with any particular religion.

Such massive evidence of identification with religion does not mean that the affiliate in question routinely participates in the formal expressions of these various religions in a public manner or that they are necessarily knowledgeable or at all an active practitioner of their religion. In terms of nominal identification and affiliation, however, these recent findings have changed relatively little since social scientists have been measuring such matters, despite overt identification with a distinct religion declining by single digits since measurements began. Even here, the data demonstrates that the rate of what might be termed "unbelief" in any religion's precepts has held virtually steady throughout the twentieth and early twenty-first centuries.

This data-rich contemporary understanding by scholars is consistent with how historians and religious scholars have documented the widespread followings and impact that various religions have evidenced in the past. People switch religions, move in and out of active practice, articulate beliefs at times highly variant within the distinct religion with which they identify (at least according to widely recognized religious scholars and theologians of that particular religion), and engage in overt behaviors sometimes completely opposite to what is advocated as normal and even required for fidelity to that tradition by leading spokespersons (both dispassionate scholars and leading practitioners) within that religion past and present. Nevertheless, the power of religion remains as one clear and persistent marker of human self-identification despite the most rapid scientific and technology changes the world has ever witnessed. Its very pervasiveness within human societies suggests that technology and design educators must make more effective connections between the religious ideas and orientations active within the lives and minds of learners and the technology and design curriculum – especially with its contemporary focus on design for varied users and purposes, values and technology, and the wider importance of culture and society as they both influence and are influenced by technology and technology education.

Religion and the Realm of Technology

Religions in general, especially those thought of as *major* world religions due to their number of adherents, are characterized by a narrative and philosophical orientation that seeks to bring all of life under the explanatory power and influence of the religion in question. For religious people in large part since prehistoric times, nature itself is the forum through which the mysterious aspects, attributes, and desires of a higher, unseen world are mediated through "signs and symbols." These signs and symbols could include the surface of the Earth itself, things underneath the surface or that emanate from it, objects that fall from the sky, perceptions from the human senses, and thoughts and dreams within the mind – including "communion" with one or more other realms that are mediated through language (an ability that is not infrequently itself seen to also be a gift from this unseen, mysterious realm). In this sense, nature serves as the bridge between our world and world(s) that do or might exist outside of our own realm of existence. Even religions that seem to be very other-world centered are taking up that positioning via the physical reality within which they currently reside and which they value for what it reveals to them about that which lies beyond their ken (Bellah 2011).

The three influential monotheistic religions of Judaism, Christianity, and Islam that share some common religious texts and outlooks have traditionally held the view that there is a distinct separation between the Earth and the physical universe within which it dwells and God. God himself needs no physicality to exist and dwells outside time "within" the realm of eternity. At the same time, God brings into existence the world and has an intimate relationship with the created order, including the human beings that inhabit that order – yet the visible universe neither encapsulates or fully expresses the divine being nor subsumes the created order into the divine being. Creator and creation are intertwined just as an artist or craftsman has a relationship with their work products – a view that has also been expressed by some twentieth-century scholars such as Aurobindo Ghose within Hinduism, another scripturally based religion (Ward 1996). One of the stories from the book of *Genesis* (Chap. 2) in the Hebrew Torah that all three religions share and interpret as part of their traditions relates the creation of human beings, the bestowing of names on various creatures which are "brought to '*ādāṯm*" by God, and the human couple cultivating the garden of "Eden." Chapter 3 of *Genesis* describes how this gardening duo are tempted by the serpent and in violation of God's command seek to know as God knows and become his coequals. Following this "fall" from divine favor, the ground is cursed, the created order is affected, and humans are forced to leave idyllic Eden. The subsequent descendents of Cain are identified as the builders of cities and progenitors of technical arts and crafts among the Hebrew people (Genesis 4: 17–22).

To varying degrees in all four of these scriptural religious traditions, there is a strong thread of explicit commentary and teaching about the need for practitioners, in partnership with God, to remake the world, repairing damage from the past and ameliorating its effects upon subsequent human beings, societies, and the world at large (Ward 1996; Brown 2010). Judaism is one of several religions that has a distinct phrase for this kind of activity, *tikkum olam*, "repairing the world" (Shatz et al. 1997). Devout practitioners of these faiths recognize an explicit relationship between human activity, including design and technological making, and their spiritual calling to effect positive changes in the world around them. Religions such as Christianity and Judaism, with their strong emphasis on historical particularity and change over time, have seen technology as a means for making up for deficiencies in the world and in society as it is, a particularly effective means to do things that positively affect the common good and undertaken in a manner consistent with their overarching spiritual values.

Consistent with this religious worldview, there can be no secular/sacred divide for many of these practitioners nor should there be, even though there is a recognition going back to its clear exposition by Augustine in *The City of God*, that the principles of the kingdom of God are quite distinct from the principles of those who choose to continue to live in the world outside of proper recognition of God as the needful guide and supplier of grace and help to all who call upon his name. The city of man and the city of God are distinct yet within this fallen world; positive forward progress is not only possible, it is doing the very work of God as a divinely appointed co-laborer with God to repair the world. Attaining perfection is not fully achievable due to the continuing aftereffects of sin and continuing human pride, but vast improvements can occur – foreshadowing the perfect world which is to come in an anticipated eschatological revealing of a new realm of coexistence in the very (tangible) presence of God.

All technology and design activity is to be consistent with this coherent worldview that embraces the spiritual/religious foundations of all of human life. Technological activities themselves are part of the active worship of the creator embodied within the concrete instantiations of human engagement with the materials of the world and fashioning and deploying them in ways that are homages to the God who brought the world into being, continually upholds it by divine will, and has commissioned human beings to be cocreators of order, beauty, truth, and other fundamental values. This earthen materiality aspect of religion finds the sacred mediated through objects and other human creations such as language (in spoken, written, chanted, or choral form) that invokes an interaction among texts, bodies, minds, and hearts that influence both the religions themselves and the technological practices, objects, and systems that both serve the internal purposes of religion and extend its positive influence within the wider world (Koslowski 2001; Levy 2014 provides examples from within Judaism; see Kieshnick, Kieschnick (2003) for an exploration related to Buddhism).

Possible Relationships Between Religion and Technology and Design Education

The continuing vibrancy of organized religions is consistent with the ample and largely unrecognized relationships between religion and technology that run across the world's well-known and even many lesser-known religions. Documentation of these relationships is quite rich in classic major religions such as Christianity, Islam, Hinduism, Judaism, and Buddhism. So how might these beliefs, ideas, orientations, and daily practices relate to technology and design education? Here are just a few key concepts that could enrich the technology and design curriculum and classroom in a manner that makes connections among religion and technology more explicit for learners while at the same time avoiding sectarianism; building greater understanding of the cultural underpinnings of technological artifacts, systems, ideas, and processes; and explicitly acknowledging and potentially further clarifying the power and even utility of religious ideas and beliefs within the lives of both students and teachers and within technological praxis.

Religion Can Be a Stimulant to Technological Innovation

Technology and design curriculum standards and materials across many nations have large units that deal with aspects of agriculture, food safety, and cuisine. Several major world religions have dietary laws such as *kosher* food production and preparation in Judaism (Blech 2009) and *halal* food production and preparation within Islam (Fischer 2015). These furnish good case studies to explore how arenas of daily life and global markets for food goods are heavily impacted by a series of interactions among religious ideas and beliefs, culturally conditioned practices, technological practices, and ongoing innovations (including copyrights, patents, and trademarks to protect intellectual property that emerge within these tradition on a continuing basis). More specifically, these examples demonstrate how effects of religious beliefs influence technological products, practices, and systems since articulating and enforcing food quality standards, evolving clear food labeling systems, developing efficient distribution systems that maintain product consistency, creating packaging innovations that ensure durability and requisite shelf life of the products, and creating and maintaining free trade systems that promote rapid movement of needed food staples required by millions of practitioners of these two global religions. It has also created staunch, savvy, religiously inspired advocates for government and private industry standards, written protocols, treaties, uniform and effective inspection systems, etc. The benefit to all members of society is that these orientations have helped improve global technical systems of food production, trade, quality control, transportation, logistics, marketing, and relevant financing.

A further example from Islam is the focus on engaging in one's activities with a desire to attain and maintain extreme accuracy since such efforts are rendered as part of one's service to Allah (analogous ideas occur in several other world religions). This attitude engendered serious attention to accuracy in scientific and technical endeavors that promoted the construction of timekeeping devices and astrolabes and the accurate keeping and curation of detailed astronomical observations – all hallmarks of modern science and technology praxis worldwide (Al-Hassani 2012). More broadly, metrology has been influenced since ancient times by religious needs for accurate calendars, astronomical (astrological) charting of the heavens, and accurate record keeping of other natural and human-made phenomena which has not only influenced the measurement tools themselves but also the construction of technological instruments such as astrolabes, telescopes, observatories, and timekeeping devices and technological processes associated with curation, historic preservation, translation, and education.

Religion Can Serve as a Moderator of Technological Diffusion

Researchers have studied the ways in which assistive reproductive technology, birth control methods, and practices associated with pregnancy have been heavily influenced by technological changes, medical advances, legal innovations, scientific insights, and religious beliefs in an interactive manner that has been explored across religions such as Hinduism (Bhattacharyya 2006), Islam and its concept of *shariah* (Ayduz and Dagli 2014; Clarke 2009), various forms of Judaism (Feldman and Wollowelsky 1997; Ivy 2009; Kahn 2000), and Shintoism, Taoism, and Buddhism (Ivy 2009). Genetic advances, various medical technologies, and the prospects of transhumanism are examples of topics that have been explored in regard to Islamic religious thought (Nasr 2009), non-Western religions and cultures (Selin 2016), and Christianity (Mercer and Trothen 2014; Deane-Drummond et al. 2015). Burial practices in Japan (Keul 2015) and the veneration of ancestors in some Asian religions by the use of what are known as ancestor veneration avatars or AVAs (Bainbridge 2014) are well-documented cases of the complex influence between human technologies and religious conceptions related to the afterlife and the proper handling of the bodies of those who have passed with considerable variation within and across distinct religions.

Culturally grounded design practices have also been seen as a by-product of religion and IT interactions such as in a set of detailed studies about how educational technology is used in the Islamic world with cases drawn from Malaysia, Saudi Arabia, Pakistan, Turkey, and Islamic education in the USA that feature contrasting branches and forms of Islam, different cultural contexts, and different life experiences and exposures to those different than oneself (Thomas 2016). Whether religion leads or whether technology leads the interaction seems to vary depending on the topic, geographic location, the particular subvariety of the religion which is being practiced, the nature of the technology itself, how much it focuses on the human person, and a myriad of other factors.

Religion Can Inform and Inspire the Work of the Technologist

How scientists and engineers approach and understand the meaning, ethics, purpose, and practice of their respective tasks in laboratories and the wider world has been the subject of extensive investigation within Christianity, Hinduism and Sikhism (Cimino 2014), Judaism, Islam (Ayduz and Dagli 2014), and across these and other religious traditions in a more generalized form of inquiry (Jenkins and Tucker 2016). The historic and contemporary complex interactions among science, technology, philosophy, and religion are the subject of much research and multivolume reference works attest to the vibrancy, depth, and breadth of the relationships through time, across cultures and specific traditions, and within the wider societies within which they are embedded and embodied (Al-Hassani 2012; Ayduz and Dagli 2014; Harrison 2015; Renehov and Oviedo 2013; Selin 2016).

World religions have heavily influenced discussions within the domain of technology proper in the past and the present. Well-known philosophers of technology, inventors of technologies, historians of technology, designers, architects, graphic artists, and other contributors to technological thought and practice have both integrated and thought about technology within a complex personal interaction that includes religious experiences and sensibilities, cultural and family influences, and technological knowledge and experiences. Avowedly, Christian contributors include influential philosophers of technology such as Albert Borgmann (1984), Frederick Ferré (1993), and Carl Mitcham (Mitcham 1994; Mitcham and Grote 1984) and public intellectuals such as Jacques Ellul (1990) and George Grant (1986). Practicing Christian engineers and other technologists have attempted from time to time to articulate guidelines for the creation and use of technologies within society (e.g., Swearengen 2007). They have also formed professional societies where they meet with their peers (e.g., Society of Ordained Scientists, an ecumenical order within the global Anglican communion, American Scientific Affiliation based in the USA and Christians in Science in the UK, and the Christian Engineering Society) and seek to help their parent religious bodies and the public at large to better understand the depth, breadth, and key issues at the nexus of technology and religion (e.g., ECLA Alliance for Faith, Science, and Technology and the Episcopal Church Network for Science, Technology, and Faith).

Other religions have mounted similar efforts to self-organize and promote interactions among religious adherents who make their living in scientific and technical fields (e.g., Center for Islam and Science and the International Society for Science and Religion limited to just 100 members from various religions and scientific and technical fields). For example, Hans Jonas (1984), a practicing Jew and noted philosopher of technology, sought to construct a fully secular form of ethics that could guide technological decision-making, carefully avoiding reference to the religious sources that informed his own understandings and actions. Other religiously aligned scholars have made explicit the many ways in which values, ethics, and theological considerations should inform science and technology practice and policy (Gorman et al. 2005).

A careful study of the eight major types of stupas in the Tibeto-Buddhist tradition demonstrates how distinct religious beliefs influenced the form of these religious objects (Dorjee 2001). Each portion of the structure down to the number of parasols on the *chatravali* has taken on deep and divergent metaphysical meanings across the various schools of thought and practice within the Tibeto-Buddhist tradition. Similarly, Buddhism and other Asian religions have influenced technological developments in countries such as China helping to foster periods of intensive invention and innovation (Deng 2011; Schäfer 2011). Inventions like printing with moveable type, horse stirrups, iron plows, rotary winnowing fans, drive belts, chain pumps, suspension bridges, wheelbarrows, umbrellas, matches, paper money, and spinning wheels are just a few of the multitudinous examples of technological innovations which saw their debut within the vast reaches of the various Chinese empires.

Religion Can Highlight Important Values to Be Considered in Technological Endeavors

Virtually, all technology and design frameworks highlight the role of values in undertaking technological work of various kinds. All formal religions teach general precepts of behavior, prescribe or encourage particular forms of action, and inculcate ideas about self, others, society, and human purpose(s). Well-designed discussions can elicit a wide range of ideas that are religiously inspired as part of the classroom process of deciding what values should undergird various technological activities. Such an approach can highlight the varied sources from which values emanate, the means by which we articulate them within societies, and how groups of people sort through these values to reach mutually agreed upon ways to select, adapt, and utilize values to inform human practices. Aesthetics is a second viable area for exploration in its relationship to both religious ideas and technological endeavors as a multidisciplinary exploration of the many faces of beauty attests (Hösle 2013).

The widespread presence of religious-affiliated institutions within human societies, including those who are part of the formal educational systems of nations around the globe, is yet another reminder of the importance of working harder to make the religion and technology connections more explicit and more deliberate. Religious-affiliated schools and universities may wish to highlight their own particular religious traditions, but quality instruction also requires that we highlight values that come from varied sources, including other religions, philosophies, and diverse groups within society. Most universities worldwide have faculty members with formal educational backgrounds in theology, religious studies, or scholars of cultural or regional studies that make them knowledgeable of the religious beliefs and practices often of several different branches within a particular religion and/or familiar with several different religions. These faculty colleagues can prove valuable allies and dialogue partners to create and deliver balanced discussions that explore the interactions among religions, religious beliefs and practices, and practices and developments related to technology and design. The Roman Catholic Church, for example, has an organized body of articulated, written, and well-organized social doctrine for its churches worldwide available in multiple languages (Pontifical Council for Justice and Peace 2005). Such a document can make such discussions not only easier to start but also help all participants (including teachers) become better informed as to official teachings of the religious group in question and why these attitudes and values are expressed as they are in relation to modern technology.

Along an analogous path, it has been suggested that foundational concepts in Asian thought, most derived explicitly or implicitly from Asian religions, can form the framework for better technological development in the future with a focus on the good, the useful, the beautiful, the true, and the holy rather than relying on standard, rational, Western management approaches that are largely but not exclusively utilitarian in their orientation (Teschner and Tomasi 2016).

Conclusion and Future Directions

Technology and religion exhibit a complex, historic, and continuing relationship (Geraci 2016; Stolow 2012). Religions can corrupt or unnecessarily hinder technological developments and practices or they can help those very practices achieve their fullest potential while limiting the destructiveness that various technologies over time have wrought (Dyer and Gordon 2011). Religion as a widespread phenomenon across time, cultures, languages, and places is part of what makes and keeps us human in the midst of a human-designed world and humble in regard to our progress toward making the world a better place for all creatures (Herzfeld 2009). Appropriately applied, religious discourse can help articulate the ultimate concerns that should inform all technological action (Lewin 2012), thereby enriching culture rather than diminishing it (Newman 1997; Richerson and Christiansen 2013), preserving and enhancing the natural world and our continuing relationship to it (Jenkins and Tucker 2016), and saving us from undue arrogance and hubris – an all too common human tendency among the currently powerful, whomever they may be (Terlizzese 2009).

Religion and technology exhibit complex interrelationships that flow in both directions with positive, negative, and undiscernible effects. Both seek to solve problems, meet needs, and improve the human condition. Each arena is a mature field with established, well-recognized, and continuously evolving bodies of theory, practice, subfields, leaders, practitioners, educational institutions, and interactions with other arenas of human experience such as politics, societal institutions, the environment, finance and economies, international relations, humanities, arts, and the sciences.

We have an obligation to engage religious systems of thought and praxis within the context of the technology and design education curriculum and learning environment. Doing so with careful planning, appropriate preparation, sensitivity, and well-delineated case materials will help prepare present and future generations for the continuing challenges and opportunities that the ever-evolving technological world we inhabit embodies and ensure that new contributions are undertaken in a manner cognizant of the wider milieu within which these contributions occur.

For researchers, very little recent study has been done of student and teacher knowledge and attitudes toward the interaction of religion and technology. There are very few nonsectarian classroom materials for primary and secondary students engaging religion and technology at the depth suggested by this chapter yet hopefully this modest contribution has established their potential importance to high-quality technology and design education.

Cross-References

► From Crit to Social critique
► Food in the School Curriculum: A Discussion of Alternative Approaches
► Nomadology: A Lens to Explore the Concept of Technological Literacy
► Perceptions and Attitudes of Pupils Toward Technology

References

Al-Hassani, S. T. S. (Ed.). (2012). *1001 inventions: the enduring legacy of Muslim civilization* (3rd ed.). Washington, DC: National Geographic.

Ayduz, S., & Dagli, C. (Eds.). (2014). *The oxford encyclopedia of philosophy, science, and technology in Islam* (2 Volumes). New York: Oxford University Press.

Bhattacharyya, S. (2006). *Magical progeny, modern technology: A hindu bioethics of assisted reproductive technology*. Albany: State University of New York Press.
Bainbridge, W. S. (2014). *An information technology surrogate for religion. The veneration of deceased family in online games*. New York: Springer.
Bellah, R. N. (2011). *Religion in human evolution: From the Paleolithic to the axial age*. Cambridge, MA: Belknap Press.
Blech, Z. Y. (2009). *Kosher food production* (2nd ed.). Malden: Wiley-Blackwell.
Borgmann, A. (1984). *Technology and the character of contemporary life: A philosophical inquiry*. Chicago: University of Chicago Press.
Brown, W. P. (2010). *The seven pillars of creation: The bible, science, and the ecology of wonder*. New York: Oxford University Press.
Cimino, R. (2014). *Mystical science and practical religion: Muslim, hindu and sikh discourse on science and technology*. Lanham: Lexington Books.
Clarke, M. (2009). *Islam and new kinship: Reproductive technology and the shariah in Lebanon*. New York: Berghahn Books.
Deane-Drummond, C., Bergman, S., & Szerszynski, B. (Eds.). (2015). *Technofutures, nature and the sacred: Transdisciplinary perspectives*. Brookfield, VT: Ashgate.
Deng, Y. (2011). *Ancient Chinese inventions* (3rd ed.). New York: Cambridge University Press.
Department of Education. Design and technology programmes of study. (2013a). Key stages 1 and 2. National curriculum in England. London: Author. DFE-00172-2013.
Department of Education. Design and technology programmes of study. (2013b). Key stage 3. National curriculum in England. London: Author. DFE-00192-2013.
Dorjee, P. (2001). *Stupa and its technology: A Tibeto-buddhist perspective* (2nd ed.). New Delhi, India: Motilai Banarsidass.
Dyer, J., & Gordon, T. D. (2011). *From the garden to the city: The redeeming and corrupting power of technology*. Grand Rapids: Kregel Publications.
Ellul, J. (1990). *The technological bluff*. Wm. B. Eerdmans: Grand Rapids.
Feldman, E., & Wollowelsky, J. B. (Eds.). (1997). *Jewish law and the new reproductive technologies*. New York: Klav Publishing House.
Ferré, F. (1993). *Hellfire and lightning rods: Liberating science, technology and religion*. Maryknoll: Orbis Books.
Fischer, J. (2015). *Islam, standards and technoscience: In global hala zones*. New York: Routledge.
Geraci, R. (2016). Technology and religion. In W. S. Bainbridge & M. C. Roco (Eds.), *Handbook of science and technology convergence* (pp. 907–917). New York: Springer.
Gorman, U., Drees, W. B., & Eisinger, H. M. (Eds.). (2005). *Creative creatures: Values and ethical issues in theology, science, and technology*. New York: Bloomsbury T & T Clark.
Grant, G. (1986). *Technology and justice*. Toronto: House of Anansi Press.
Harrison, P. (2015). *The territories of science and religion*. Chicago: University of Chicago Press.
Herzfeld, N. (2009). *Technology and religion: Remaining human in a co-created world*. West Conshohoken: Templeton Press.
Hösle, V. (Ed.). (2013). *The many faces of beauty*. Notre Dame: University of Notre Dame Press.
Ivy, T. (2009). *Embodying culture: Pregnancy in japan and Israel*. New Brunswick: Rutgers University Press.
Jonas, H. (1984). *The imperative of responsibility: In search of an ethics for the technological age*. Chicago: University of Chicago Press.
Jenkins, W. J., & Tucker, M. E. (Eds.). (2016). *Routledge handbook of religion and ecology*. New York: Routledge.
Kahn, S. M. (2000). *Reproducing Jews: A cultural account of assisted conception in Israel* (2 revised ed.). Durham: Duke University Press.
Keul, I. (Ed.). (2015). *Asian religions, technology and science*. New York: Routledge.
Kieschnick, J. (2003). *The impact of buddhism on chinese material culture*. Princeton: Princeton University Press.

Koslowski, P. (2001). *A discourse of the world religions. Volume 3: Nature and technology in the world religions*. Boston: Kluwer Academic Publishers.
Levy, G. (2014). *Judaic technologies of the word: A cognitive analysis of jewish cultural formation*. New York: Routledge.
Lewin, D. (2012). *Technology and philosophy of religion*. Newcastle upon Tyne: Cambridge Scholars Publishing.
Mercer, C., & Trothen, T. J. (2014). *Religion and transhumanism: The unknown future of human enhancement*. New York: Praeger.
Mitcham, C., & Grote, J. (Eds.). (1984). *Theology and technology: Essays in christian analysis and exegesis*. Lanham: University Press of America.
Mitcham, C. (1994). *Thinking through technology: The path between engineering and philosophy.* Chicago: University of Chicago Press.
Nasr, S. H. (Ed.). (2009). *Islam, science, muslims and technology: Seyyed Hossein Nasr in conversation with Muzaffar Iqbal*. Selangor, Malaysia: Islamic Book Trust.
Newman, J. (1997). *Religion and technology: A study in the philosophy of culture*. Westport, CT: Praeger.
Pew Research Center's Forum on Religion and Public Life. (2012). The global religious landscape: A report on the size and distribution of the world's major religious groups as of 2010. Washington, DC.
Pontifical Council for Justice and Peace. (2005). *Compendium of the social doctrine of the church*. Washington, DC: United States Conference of Catholic Bishops.
Renehov, A. L. C., & Oviedo, L. (2013). *Encyclopedia of science and religion* (4 Volumes). New York: Springer.
Richerson, P. J., & Christiansen, M. H. (Eds.). (2013). *Cultural evolution: Society, technology, language, and religion*. Cambridge, MA: The MIT Press.
Schäfer, D. (2011). *The crafting of 10,000 things: Knowledge and technology in seventeenth-century china*. Chicago: University of Chicago Press.
Selin, H. (Ed.). (2016). *Encyclopedia of the history of science, technology and medicine in non-western cultures* (3rd ed., 5 Volumes). New York: Springer.
Shatz, D., Waxman, C. I., & Diament, N. J. (1997). *Editors. Tikkum olam: Social responsibility in jewish thought and law.* Jason Aronson, Inc: Lanham.
Stolow, J. (Ed.). (2012). *Deus in machina: Religion, technology, and the things in between*. New York: Oxford University Press in partnership with Fordham University Press.
Swearengen, J. C. (2007). *Beyond paradise: Technology and the kingdom of god*. Wipf and Stock: Eugene.
Terlizzese, L. J. (2009). *Trajectory of the 21st century: Essays in theology and technology*. Eugene: Wipf & Stock Publishers.
Teschner, G., & Tomasi, A. (2016). *Turning toward technology: A glimpse into the asian paradigm*. Piscataway: Transaction Publishers.
Thomas, M. K. (2016). *Islam, technology and education: The case for culturally grounded design*. New York: Routledge.
Ward, K. (1996). *Religion & creation*. Oxford: Clarendon Press.
Yang, F. (2011). *Religion in China: Survival and revival under communist rule*. New York: Oxford University Press.
Yang, F. (2016). Exceptionalism or chinamerica: Measuring religious change in the globalizing world today. *Journal for the Scientific Study of Religion, 55*(1), 7–22.

Part II

Curriculum Perspectives

Curriculum Perspectives in Technology Education: Section Introduction

7

P. John Williams

A range of historical and contemporary perspectives related to curriculum are discussed in this section of the Handbook. It begins with a thematic approach to the history of curriculum, a survey of research related to technology education curriculum and a discussion of action research. Two countries have been selected as exemplars of national technology education curriculum, not because they are internationally representative but because they have important messages to tell regarding curriculum development. The relationship of technology education to other areas of the curriculum is discussed in chapters focusing on Engineering, STEM, and vocational education. There are many influences on the curriculum, and in other chapters Sloyd, Policy and Standards are discussed as major influencing factors. The final two chapters approach curriculum from a student perspective, examining the nature of progression and the enhancing effect of out-of-school experiences.

► Chapter 8, "Technology Education: An International History" by Marc de Vries begins this section with the caveat that writing an international history of technology education is an impossible enterprise, and so he adopted an approach of identifying overall themes that run through the history of technology education in various countries, and took those themes as organizing principles for describing how technology education has emerged as a domain that more and more developed an international dimension. The themes that Marc identified included craft-based origins; vocational and general education; relation with science education; developing centrality of design; development of technological literacy; the search for a philosophical, conceptual, and epistemological base for the subject; technology education's contribution to 21C skills; and the role of technology education in STEM. These themes represent some the challenges for technology education over time, and

P. John Williams (✉)
School of Education, Curtin University, Perth, WA, Australia
e-mail: pjohn.williams@curtin.edu.au

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_68

the resolution of the challenges has resulted in the position of technology education in the curriculum.

Through a review of literature about research in technology education, and a project which reviewed 1,498 journal and conference outputs between 2006 and 2015, John Williams in his chapter ▶ Chap. 9, “Technology Education: History of Research”, indicates that the area of Curriculum (together with Design) has always been a fundamental and common area of research inquiry, and will continue to dominate research in technology education. Areas of research that are becoming less common include that related to Technological literacy, values/beliefs, and sustainability/environmental areas. The areas which are becoming more commonly researched include gender issues, STEM, how students learn, mobile/online learning, and research in the primary and ECE contexts.

Chris Merrill’s position in his chapter ▶ Chap. 10, “Authentic Research for Technology Education” is that all teachers reflect on their practice, and structuring that reflection as action research helps ensure that the outcome are empirically based rather than beliefs. The benefits of action research for classroom teachers include (a) filling the gap between theory and practice, (b) teacher empowerment, and (c) a worthwhile means of professional growth and development. Chris suggests a number of potential areas for action research related to technology education.

The first country technology education curriculum to be considered is England, significant internationally because of the large number of countries, often ex-colonial, which pay attention to developments in England. Recently, countries have tended to take a more enlightened and nationalistic approach to the development of their own curriculum, but the legacy of English influence remains. In his chapter, ▶ Chap. 11, “Design and Technology in England: An Ambitious Vision Thwarted by Unintended Consequences”, David Barlex charts the journey of Design and Technology since its inception in 1990, and highlights the highly political nature of curriculum changes in England. While the complexity of the initial curriculum made it difficult for teachers, it was reviewed and resolved into a well-respected approach to design and technology, and often lauded internationally as a standard. Given this lauded position, the strong professional association and some high-profile support, the recent demise of the subject is stunning; weak epistemological roots and a lack of disciplinary coherence were given as reasons to downgrade the subject design and technology and remove it from the National Curriculum. David proposes a number of conditions necessary for curriculum success: sustained and substantial in-service training for the teachers; realistic ambitions for a new subject; leaders who are effective in communicating the subject’s identity as a coherent assembly of knowledge, understanding, skill, and values; and vigilance in maintaining a strong rationale for its role in the education of *all* young people so that the subject is not misrepresented as suitable only for the less academic or as a vocational option.

Because of the role of the state in funding research and providing professional development, there is a general consensus that the New Zealand curriculum is a positive example of technology Education. Louise Milne, in her chapter ▶ Chap. 12, “Technology Education in the New Zealand Curriculum: History and Rationale”, charts the emergence of the first New Zealand technology education curriculum in 1995 with its emphasis on authentic design informed by the practice of experts, to the 2007 curriculum which, in response to a national curriculum stocktake, aimed to develop a broad technological literacy that would better equip students to actively participate in society as informed citizens, and also give them access to technology-related careers. Contemporary issues which effect Technology Education in New Zealand include a congested curriculum, a Ministry of Education focus on numeracy and literacy, a focus on where learning occurs rather than what learning occurs (modern learning environments), and a topic approach to teaching which dilutes rich technology content knowledge. An additional contemporary challenge is the development of government policy through the “Curious Minds” strategy which promotes Science, STEM, and digital technologies, and may force Technology Education to reexamine its place in the curriculum.

In many contexts, Technology Education has an increasing focus on Engineering. In their chapter ► Chap. 13, “Middle Childhood Education: Engineering Concepts, Practices, and Trajectories”, Cathy Lachapelle, Christine Cunningham, and Martha Davis focus on using engineering to engage children and introduce them to the discipline and its major practices and concerns, so they can develop technological literacy and learn to make informed decisions about technological development as adult citizens, and also spark the interest of a subset of children who may choose to pursue technological careers. Their curriculum considers three bands: ages 7-8 (beginning readers), ages 9-10 (middle childhood), and ages 11-12 (preadolescents). A social constructivist view of learning forms the theoretical base for articulating design parameters that include: narrative context; a real-world storyline that is relevant and interesting; explicit specification of a problem to be addressed; engineering design processes and epistemic practices; scaffold engagement; exploring materials and methods; the purposeful application of science and mathematics content and skills; collaboration and negotiation shared solutions. This chapter provides a resource that can help structure curricular activities and professional development.

Interdisciplinary STEM education is the pedagogical approach by which students learn the interconnectedness of the disciplines of science, technology, engineering, and mathematics and is becoming a focus of many curricula throughout the world. Mike Daugherty and Vinson Carter, in their chapter ► Chap. 14, “The Nature of Interdisciplinary STEM Education”, hold that interdisciplinary STEM education also provides a platform to introduce problem-based learning, cooperative learning, expand problem-solving capabilities, and introduce students to the use of engineering design. Mike and Vinson propose that technology education has the potential to be the discipline that would reduce curricular fragmentation through the integration of content from other disciplines. Advocates for greater integration of the STEM subjects argue that teaching STEM in a more connected way, especially in the context of real-world problems, can make the STEM subjects more relevant to students. The engineering design method of inquiry is regarded by some to be the cornerstone of integrated STEM education; it can be regarded as the core problem-solving process of technology education and is increasingly known as a foundational methodology for all integrated STEM curricula. A chief concern in STEM education is the preparation of educators with both content knowledge and the ability to integrate STEM education learning. The nature of interdisciplinary STEM education is in flux; however, opportunities await those educators seeking to develop and implement interdisciplinary educational programs that center upon core content from the STEM disciplines.

Michael Hacker continues the discussion related to engineering in ► Chap 15, "Engineering and Technology Concepts: Key Ideas That Students Should Understand," and supports the previous chapter by pointing out that in the United States, Engineering and Technology Education (ETE) is seen as a route through which the four disciplines of STEM can be integrated. Mike suggests that revisiting a small set of transferable ETE thematic ideas in different contexts can complement learning of standards-based domain-specific concepts and skills. There is a consensus of expert opinion about the most important ETE competencies high school students should attain within five thematic categories that consistently appear in the literature: (a) design, (b) modeling, (c) systems, (d) resources, and (e) human values. This enables an instruction on recurring and overarching transferable "big ideas" and facilitates a more holistic understanding of engineering and technology. Mike offers two case studies as examples. The first exemplifies how a cutting-edge technology company looks to hire new employees with a broad mix of skills. The second describes a new ETE curriculum model that integrates important concepts within authentic social contexts and supports the fundamental purposes of education.

In ► Chap. 16, "Technical Vocational Education: From Dualistic to Pluralistic Thinking," Nina Kilbrink addresses the various dichotomies that need to be bridged in learning in a vocational context: those between theory and practice, school and workplaces, verbalized knowledge and manual work, head and body, reading and doing, and the what and how aspects of learning. Bridging these gaps involves complex processes, and one solution Nina proposes is to abandon dualistic thinking and instead embrace pluralism, since research shows that there are often complex contexts involved that are not divisible into two different parts – but rather into many different aspects. Too often, it seems that students are left to integrate the different parts on their own. Instead teachers can help students in their learning by creating learning situations where theory (knowledge in) and practice (knowledge about) concern the same object of learning; they can help students connect learning in different arenas, and be clear about what the students need to learn in the interaction about different learning objects. New ways of handling theory and practice, viewing them as different aspects of the same phenomenon is needed in order to reach a holistic learning where theory and practice are intertwined.

Jonas Hallstrom investigates the relationship between Technology Education and Educational Sloyd (*slöjd*) in Sweden since early 1960s in his chapter. He argues that educational Sloyd was an important precursor to, or evolved in close parallel to, Technology Education in many countries across the globe. In Sweden, Technology Education and Educational Sloyd exist as separate subjects in the school curriculum and have done so for decades. During the period of curriculum development in Sweden, the Technology subject domain has modernized and become broader, while Educational Sloyd partly contains modern, technology-related components but also partly remains a subject emphasizing knowledge and skills rooted in a rural society including elements such as manual handicraft, tool management, aesthetic skills, as well as personal development. Jonas notes that the main difference between the two subjects lies in their philosophical foundations. Technology education is about various aspects of the human-made world; Educational Sloyd, on the other hand, is mainly about human development. The kind of technology dealt with in Sloyd is artifacts, whereas in many countries, much of the modernization of Technology Education has been about including a systems component. Technology and Sloyd thus share a common ancestry and, largely, common epistemological ground.

Steve Keirl takes a global approach to the issues faced by D&T curriculum policy makers, considering the *irony*, that despite the ubiquitous and pervasive nature of technologies in our lives, education systems rarely offer curricula that can engage the phenomenon. In his chapter ► Chap. 18, "Design and Technology Education and Its Curriculum Policy Challenges" Steve proposes that much of D&T education is (being) tied to the service of a particular economic model and ignores multiple alternative educational possibilities. Such possibilities are seen here as presenting D&T not as "subject" or being governed by prescribed content but, rather, as a special way of knowing and being – drawing on multiple epistemologies and ontologies. The resultant case is one for a holistic, comprehensive formulation of a critical technological literacy that permeates whole-school curricula and learning. Good D&T curriculum design is core to developing students as global citizens capable of participation in democratic considerations with technological developments. Moreover, good D&T curriculum design is seen as valid and valued contributor to a global common good. Steve proposes engaging with "aims talk" as a way to develop a rich and comprehensive D&T curriculum, *comprehensive* in that it should be a part of the *general education* of every child, and that it be articulated across the whole school as a literacy. The resultant curriculum is not a curriculum of "right or wrong" answers but one of negotiation, understanding, and personal and collective meaning-making. Such a curriculum is not inward-looking but is alive to what is happening in the world at large and what *could be* in the world at large.

In his chapter on ► Chap. 19, "Technology Education Standards in the United States: History and Rationale", Philip Reed discusses the development and iterations of standards in the USA. The early standards tended to be quite prescriptive skill statements, and the recent standards are more general and are oriented toward concepts such as technological literacy. The *A Nation at Risk* report in 1983 focused on the need to increase academic rigor within the USA in order for the workforce to remain competitive in the global economy, and resulted in the creation of standards and assessments in many disciplines. The USA professional technology teachers association (ITEA) has developed a number of iterations of standards in Technology Education and other disciplines such as mathematics, social studies, instructional technology, and science that explicitly have technology standards within their respective sets of standards.

Phil points out that for technology education an issue with standards is their validation. Mathematics education validates itself through the work of mathematicians, and science education maintains legitimacy through the work of scientists.

The multidisciplinary nature involved in the study of technology confounds the validation of content. The impetus to revise and continue to develop standards seems to be decreasing, and the focus within the Technology Education profession is contested as technological literacy, or engineering, or a component of STEM.

In the next chapter which focuses on students, Cliff Harwood and Vicki Compton (▶ The Importance of the Conceptual in Progressing Technology Teaching and Learning) argue that technology education has a key role in enabling young people to actively participate in a world facing complex sociocultural and environmental challenges, and an economy that is shifting from being knowledge driven to being innovation led by developing their technological literacy. While having international application, the discussion in this chapter is supported by research conducted in New Zealand to identify three phases to gauge how students progress their technological literacy: Foundational technological literacy, Citizenship technological literacy, and Comprehensive technological literacy.

The knowledge teachers bring to the learning environment is critical and can be categorized as *Subject Matter* – including both situated topic knowledge and generic domain knowledge; *Strategic Processing* – including surface level and deep processing strategies; and *Motivational Interest* – individual (general/professional) and situational interests. Cliff and Vicki identify functional and practical reasoning as important forms of reasoning, and are considered to underpin and support student decision making when undertaking technological practice, and when analyzing the practice and outcomes of others.

The role that out-of-school institutions such as community organizations, clubs, camps, science centers, and zoos have played in enhancing technology education is growing. In the final chapter Yvonne Spicer explains that the programs offered in these settings provide an opportunity for youth to build upon their own learning and expand their ideas that reinforce technology education content. Yvonne places these experiences in the context of constructivism in which the connection between individual, interpersonal, and cultural historical factors that affect learning enable students to construct new knowledge and understandings in meaningful ways.

Yvonne's chapter indicates that there is a well-established body of research on the impact of out-of-school time activities to foster student engagement, though the research on informal technology education is a relatively new initiative. The resurgence of *Maker Spaces* and *Tinkering Studios* reinforces the value of technology education as a mechanism to support STEM content through the application of knowledge and skills of design, creativity, and innovative experiences in out-of-school settings.

Technology Education: An International History

8

Marc J. de Vries

Abstract
Major themes running trough the history of technology education are: moving from craft to technology education, dealing with the vocational-general education dichotomy, the relation with science education in STS and STEM, the emergence of concept learning in technology education and the contribution of technology education to the 21st Century skills.

Keywords
History of technology education • Craft • STS • STEM • Technological literacy • 21st Centrury skills

Contents

Writing an international history of technology education seems like an impossible enterprise. There are many countries that have technology education, and the developments have been quite varied in different countries. In a previous

M.J. de Vries (✉)
Department of Science Education and Communication, Delft University of Technology, Delft, The Netherlands
e-mail: m.j.devries@tudelft.nl

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_8

international handbook, published by Sense Publishers, there was a special section for historical accounts for individual countries (Jones 2009). In this new handbook, a different approach will be taken. Rather than having descriptions of individual countries, some overall themes that run through the history of technology education in various countries will be taken as organizing principles for describing how technology education has emerged as a domain that more and more developed an international dimension. Due to the series of international conferences and the international journals for technology education, the exchange of ideas and information has led to a certain merger of approaches, and a lot of cross fertilization has taken place over the years.

The bird's-eye view that is offered here focuses on technology education as a school subject. Of course, teaching about technology also takes place in subjects like physics, history, economics, and the like, but here the focus will be on a distinct learning area in the curriculum that is entirely dedicated to technology. The main basis for this rough historiography is the programs of international conferences on technology education, of which the Pupils' Attitudes Towards Technology (PATT) conferences are the most long-standing series. They started in the early 1980s when many countries went through a transition from craft education to technology education and are still ongoing. The table of contents of the proceedings for those conferences form as it were a timetable of developments in technology education internationally. Of course they also form the material for a history of PATT research, but that is the focus of a different chapter in this volume.

The Craft Origin

In most countries, technology education emerged from craft education (either as part of general or vocational education). This background throughout the history of technology education has been a plague for its reputation. Craft education is seen as a subject of low status. It is in the same realm as physical education or religious education. It is nice to have in the curriculum as it offers some "distraction" for pupils in the midst of the more "demanding" and more important subjects. In a way, that is a strange idea, because originally craft education was seen as of generally high educative value (Holdsworth 2006). Pedagogues like Comenius, Fröbel, Montessori, and Pestalozzi emphasized the importance of learning craft skills for the total development of the child. In Scandinavia, the tradition of Sloyd education was developed in the late nineteenth century by Otto Salomon in Sweden and Uno Cygnaeus in Finland. The Sloyd tradition is particularly of interest as here we also find a national-cultural dimension (Olafsson and Thorsteinsson 2009). Making traditional local or national products contributed to the child's and pupil's self-awareness as an inhabitant of a certain area of country. For some time, the Sloyd "paradigm" was influential throughout Europe, and teachers came from all over Europe to Sloyd centers such as Naas (near Gothenburg in Sweden) to learn how to teach Sloyd. Even today, Sloyd is taught in schools.

The purpose of craft and Sloyd education was learning the skills for making useful products. In the beginning, that was done by using hand tools. Later also machines entered the workshop. The machines allowed for production in larger numbers. Thus the effects of the Industrial Revolution also reached education. In some countries, that led to a shift toward "industrial arts" education. Particularly in the USA, this type of education became a fairly stable part of the school curriculum. Along with it came the foundation of a teacher association for this subject: the American Industrial Arts Association (AIAA). Typical for industrial arts in schools was that all pupils in a class would make exactly the same product. The quality of the product was the main criterion for assessing the pupils' performance in the subject. A major step forward in the development of industrial arts education in the USA was the developments of standards for that subject. A group led by Dr. William E. Dugger produced a document in the late 1970s (Dugger 1987). From those standards, and also from the influential Jackson Mills Curriculum Theory document that was published in the early 1980s, it could be read that more than craft was at stake (Starkweather 1992). Other aspects of industrial making processes, like organization and professions, were part of the curriculum. But still the making of useful products, both by hand tools and machines, remained the main activity in the workshop.

The Vocational Versus General Discussion

Another background of technology education that has plagued its reputation throughout its history is its close ties with vocational education. In the previous section, the general formative dimension of craft education was highlighted. But there is a second perceived benefit of the learning of craft skills, which is its contribution to vocational education. The reason that this became an image problem for technology education is that vocational education in itself is seen as lower status than pre-university or pre-college education. Whether or not the origin of this is the ancient Greek preference for cognitive rather than manual labor, it is a fact that in most countries education in which cognitive skills are the primary purpose is valued more than education in which manual skills take that place. One can question if that does justice to the nature of humans, but for technology education, the association that was and often still is made to vocational education causes a lack of appreciation for that subject (Shield 2003).

In most countries, the choice between general and vocational education is not made directly after primary education, but in some countries, like in the Netherlands, it is. Pupils of ages 12 or 13 years make this choice that has an enormous impact on their future school life and beyond. The Netherlands is an extreme case to show how much technology education originally was tied to vocational rather than general education. In the Dutch curriculum, a school subject called general techniques was featured in the curriculum in the 1970s and 1980s but only in the vocational education curriculum (the name of the school type was "lower vocational education," which further decreased the perceived value of that type of education; de Vries

2003). The low status of the subject was further enhanced by the fact that there were no official attainment targets; schools in fact could give it any content they liked. In some schools, it was a woodwork or metalwork course, and in other schools, it could even be a bookkeeping course. The confusion was partially caused by the term “techniques,” which can mean a clever way of doing any kind of activity (the technique of piano playing, for instance). When later, in 1993, the new subject technology was introduced in both general and vocational schools, many people saw it as a sort of continuation of the old subject general techniques, and with that the status of technology education in the Netherlands was problematic from the start.

STS and Beyond

Another problematic issue in the history of technology education is its relation to science education. In the late 1970s, the social critique on science and technology that had emerged in the late 1960s and early 1970s began to get a foothold in education in the form of science, technology, and society education (Cheek 1992; Ratcliffe 2001). In this type of education, the social dimension of science was the main focus. It was obvious from the start of the STS movement that technology would have a prominent place, because most of what we experience in terms of socially problematic effects of science is through technological applications. At least, that was the perception in the “technology as applied science” paradigm, which at that time was still in the mainstream of thinking about the science-technology relationship, both in philosophy and in education. This same paradigm caused the whole design process with all its decision-making based on many other considerations than the use of science knowledge to remain hidden from pupils and teachers. Consequently the effect of the STS movement was that the term “technology” increased in importance in education, but the true nature of technology was still largely absent. Yet, the fact that the term “technology” suggested that now technology was dealt with in education hampered the development of a subject in which that true nature of technology was made clear. Science teachers now could easily claim that they “did” technology and that there was no need for any further attention for technology in the school curriculum. Technology had risen in status because of its association with science rather than craft but at the cost of its real character.

There were major STS projects in various countries. In England, for instance, there were two major projects, one called science in a social context (SISCON) and the other science and technology in society (SATIS). In the Netherlands, the PLON project (Project Leerplan Ontwikkeling Natuurkunde, that is, Project Curriculum Development in Physics; Eijkelhof and Kortland 1988) had an international reputation for being a well-elaborated effort to realize STS education in a very practical way. In the USA, a special association for STS education was founded: the National Association of Science, Technology, and Society (NASTS). This association was very instrumental in disseminating the idea of STS education nationwide.

Unfortunately the whole STS movement was almost entirely unrelated to technology education, for the simple reason that technology education was still in the process of getting out of the craft phase. Besides that, craft or industrial arts teachers usually did not have a background in science, which of course made contact with science education problematic anyway. A rather different approach was taken in Sweden, where social aspects of technology became an important part of the technology education curriculum, but without the dominance of science that had characterized the STS movement.

Design

So far we have seen three problematic background factors in the history of technology education. All three are characterized by a strong reduction of the meaning of technology: either in the sense of technology being mainly handicraft work or technology being the application of scientific knowledge. Neither of these reductions contains what gradually became a core element in technology education, namely, the activity of designing. It was particularly in England and Wales that this dimension emerged as an important component of technology education. This happened in a stepwise process that is reflected in the consecutive names of the subject: craft; craft, design, and technology (CDT) (early 1980s; Penfold 1988); and finally design and technology (D&T) (late 1980s; McCormick 1993). The introduction of D&T was part of the introduction of a national curriculum, which at that time was new to that country. One of the positive aspects of the relative freedom of the previous period in which CDT could be given different content in different schools is that the best schools got every opportunity to develop excellent practice. The flipside of that coin, of course, was that poor schools would give poor content to CDT. The national curriculum provided a means for the inspectorate to maintain a certain minimum level for all schools. The position of design became stronger as the years went on. For CDT teachers, implementing design activities was often still a struggle, but by the time the transition to D&T was made, a sound position for design activities in the classroom practice had been established. The strong emphasis on design had a positive and a negative effect. The positive effect was that England and Wales became a source of inspiration for the rest of the world in the development of technology education. Whole groups of teachers came from the USA to visit schools in England and watch CDT/D&T practice. The negative effect was that the engineering council expressed doubts about the disciplinary status of the school subject, as it seemed to lack knowledge content. Later, a perceived lack of epistemological basis was again brought forward as a critique and then almost led to the change of status in lower secondary education. One of the unique features of CDT and D&T in England and Wales is that they were taught in all levels of primary and secondary education (Key Stages 1 through 4). In the 2000s, the compulsory status of D&T in KS4 was changed to an elective, and the lack of epistemological basis almost led to a similar change in KS3. Fortunately that did not happen, but it showed that the chosen bias toward design had its pros and cons.

Technological Literacy

In the late 1980s, the social concern about science and technology, expressed in the STS movement, turned to a new terminology, namely, that of scientific and technological literacy. The transition was more than a terminological one. Scientific and technological literacy had a less "activist" association than STS had had. The term technological literacy did not only comprise the ability to critique technology, although that was definitely still an important part of it. But it also meant being able to live and work in a technological society by making responsible and sophisticated use of technology. The term became so important that in the USA a Council on Technology Teacher Education (CCTE) handbook was dedicated to this term in 1991 (edited by Dyrenfurth and Kozak; Dyrenfurth 1991). The real importance of the term in the USA (and soon also in other countries) became evident when a new set of standards was developed under the title of Standards for Technological Literacy. Again Dugger led this project, and it was executed under the umbrella of the International Technology Education Association, the former American Industrial Arts Association that had changed its name in 1985 (Dugger 2006). In the 1980s important developments had taken place in the USA that justified this name change for which the before-mentioned Jackson Mills Curriculum Theory document had laid the foundations. Technology education (this was the term that was now used for the subject) was defined in terms of technological systems in four domains: manufacturing, construction, transportation, and communication. It is clear that this approach was much closer to technology as we find it in society than the former approach in terms of industrial production and related disciplines (Foster 1994). Strategically the choice for developing Standards for Technological Literacy than for technology education was very wise. The new term suggested that technological literacy is not only a matter of one subject (technology education) but something that other subjects (like science education) could also contribute to. Another strong point in the development in the Standards for Technological Literacy was that the "blessing" of the National Academy of Engineering was sought. This Academy was a socially strong partner. The NAE had a lot of requirements before acceptance, but in the end these were all met in the final document, and the NAE agreed to support the Standards for Technological Literacy. This link to engineering would later on become even more important (see the section on "STEM").

One of the side effects of the new emphasis on technological literacy was an increased interest into the philosophy of technology. After all, to be a technologically literate person, one must at least have a proper image of what technology is and how it interacts with humans and society. This is precisely what (continental) philosophy of technology is concerned with (see ▶ Chap. 2, "Philosophy of Technology: Themes and Topics" in this volume). One of the ways to promote interaction between philosophers of technology and technology educators was to invite the philosophers as keynote presenters at technology education conferences. This happened at the Jerusalem International Science and Technology Education Conference, organized by Tamir, and later in Glasgow at the International Seminar on Design and Technology Education Research, organized by Dakers and Dow in 2007. The relation with philosophy of technology would also become more important due to a next development that emerged in the 2000s and which is the focus of the next section.

Concept Learning

For many school subjects, there is a disciplinary canon that can be taught. For physics, for instance, this entails basic concepts like energy, force, field, current, voltage, temperature, and pressure, just to mention some of the many. Such concepts and the principles or "laws" that inform about relations between them form the disciplinary core of a subject. As long as technology education remained close to craft, such a disciplinary core had not been a real concern. Even when design became an important activity in technology education, the interest for a disciplinary core of basic concepts could remain modest (as was the critique of engineers on the curriculum in England and Wales as was described in the section on "Design"). But in some countries, concept learning had been a focus for a longer time already. Two prominent examples of such countries are the former East Germany and West Germany, later to be merged into Germany. In East Germany, as in other countries in the former Eastern communist bloc of Europe, polytechnic education was an important school subject. The reason for this was not in the least a matter of ideology. In communism, production is where the social power is, and therefore teaching about this production was seen as a core task of education, not only vocational but also general education. Although practice was often focused on the making process, in teacher education institutes, there was substantial interest in developing theories to be taught in polytechnic education. Blandow was one of the experts who did a lot of work on this (Blandow 1988). Nowadays his schemes have a strong flavor of complexity, but in the 1970s and 1980s, they were seen as important foundations for polytechnic education. Meanwhile in West Germany similar developments took place, be it with a more specific focus on systems thinking. Learning about systems, the system hierarchy, input, process, output, and feedback was at the heart of the curriculum (although here, too, often practice in classrooms was much more making oriented).

In a way, the concept of systems had also found a place in the USA curriculum (see the section on "Technological Literacy") but on a very basic level. The deeper learning of technological concepts caught on in the 2010s when research into how pupils understood systems began (e.g., in the Netherlands and in Sweden). In 2009 an international Delphi study was done by Rossouw, Hacker, and De Vries to identify the basic concepts in technology and engineering according to a panel of engineering educators, technology educators, and philosophers of technology (Rossouw et al. 2011). The outcomes of this study were used in a consecutive project led by Hacker on Engineering For All in which modules were developed for concept learning aa a primary goal. The fact that philosophers were present in the panel indicates that this concept learning development was another reason for seeking contact with this reflective discipline.

Perhaps the most extreme use of philosophy of technology to seek a conceptual basis for technology education curriculum development was found in New Zealand. In the New Zealand curriculum for technology education that was published in 2007, we find explicit references to insights from the philosophy of technology as they had been gained in the technological knowledge and nature of technology project that had been led by Vicky Compton (University of Auckland) (Compton and France 2007). She even went to dedicated philosophy of technology conferences (e.g., one in the Netherlands on the nature of technological knowledge) to speak to philosophers of technology. The New Zealand developments were also of interest because of the way various relevant actors worked together. The ministry worked with technology education researchers and teacher educators to develop a curriculum that was supported by industry and carried out by teachers who met in an active teachers' association (Technology Education New Zealand, TENZ) (Jones and Moreland 2000).

21st Century Skills

In the late 2000s, an old idea revived under the title of "21st century skills." These are broad and general skills that all citizens need to have and that should be learned in education. The idea was old in that skills like creativity, working together, problem-solving, presenting and communicating, and the like were already mentioned often when technology education began to emerge out of craft-like subjects. The claim was often made that technology education would be the best school subject for teaching and learning such skills. In the 1980s in (West) Germany, the term "Schlüsselqualifikationen" ("key competencies") became popular as a primary goal for technology education (Lutherdt 1995; Theuerkauf 1995). This idea was stimulated particularly by industry who realized that education could never be as up-to-date as industrial companies in terms of the latest technologies being taught and that therefore it would be more valuable if schools would concentrate on more generic skills with which the future workforce would be able to keep learning on a continuous basis. Also the industries became increasingly aware of the importance of problem-solving and communication skills for people working in business companies as the lack of these skills had often caused failures on product development and implementation in the past. For some decades, the term disappeared from the programs of technology education conferences but in the late 2000s revived in interest. Although technology educators had become more modest in their claims about what technology education could mean for these skill, it was still clear that at least potentially technology education could play a role in the teaching and learning of those skills (Pavlova 2016; Ritz and Bevins 2016). The interest in 21st century skills among technology educators can be read from, e.g., the series of articles on this topic that appeared in Children's Technology and Engineering, the primary technology education magazine that is published by the International Technology and Engineering Education Association (ITEEA; formerly the ITEA, without the E for Engineering). The National Academy of Engineering in the USA linked the promotion of 21st century skills with pre-university (K-12) engineering education. That brings us to a next issue in the historical development of technology education.

STEM

STEM is the acronym for science, technology, engineering, and mathematics. The term began to catch on in USA politics as a result of a growing concern about the future workforce in what was called the STEM disciplines (mark the plural). In that terminology, STEM is a set of disciplines that are not necessarily connected in content or pedagogy. The term was adopted by UK politicians also. At first there was a grounded suspicion among technology educators that STEM might well be a revival of STS in which the role of technology education had been marginal (Barlex 2011). But in the UK, for instance, a serious influence of technology education was safeguarded, not in the least by the efforts of David Barlex.

STEM clearly has an attractive potential for solving some of the issues that have troubled the position of technology education in the curriculum from the start. STEM would bring technology education in the realm of science and mathematics education that are subjects with a high status from which technology education could gain. Science education has long been searching for possibilities to get rid of its abstract image among pupils, and technological applications were the answer that was exploited in STS, but never really worked because the specific characteristics that make technology attractive for pupils (design activities that allow for real ownership of pupils) mostly remained hidden. If STEM could do better than STS in that respect, it might solve both science (and mathematics) education's image problem and technology education's status problem. The challenge, however, is to find such activities that integrate S, T, E, and M in such a way that it appears a natural combination to pupils. Doing an experiment in a design activity without the outcome of the experiment having any relevance for the design is artificial and pupils have a good sense for that.

STEM also raises the question: how about the E? In primary and secondary education, we have S and M education for a long time already, and since the 1970s, we have the T also, but E is still absent in most countries' primary and secondary curricula (with some exceptions, for instance, in New South Wales, Australia). Is the E different from the T anyway? There are good reasons for answering that question with a firm "yes." Generally speaking, technology education is largely qualitative while engineering is more quantitative. In technology education, there are modeling activities, but the nature of models is never discussed as explicit as in engineering. In engineering, the focus is on the development of products, while technology education also has the consumers' perspective. And finally, engineering is primarily a specific professional domain, while technology education aims at preparing for all possible roles in society. Given these differences, STEM also has the potential to add new content on engineering compared to what technology education has offered so far.

Looking Back to the Future

This brief history of technology education shows some of the challenges the subject has faced through times. Due to these the position of technology education in the curriculum was and still is debated in many countries. It is striking how influential, though, an international lobby for having technology education in the curriculum can be. In more than one instance (Australia, South Africa, Sweden), a call for help by a technology education colleague to his international colleagues helped to save the place of technology in the curriculum. By writing letters to governments and other decision-making organizations, colleagues from around the world were able to convince policy makers that doing away with technology education was not a good idea and certainly not in line with international developments. Still, in some countries, there is every reason for concern. Germany used to have several centers for technology education research and teacher education. Now there are few, although fortunately they are growing in influence, also due to making international connections (as, for instance, in the Centre of Excellence for Technology Education that is led by Mammes in Duisburg-Essen). In the Netherlands, there is a movement in the direction of more and more schools integrating technology into science education, which has deadly consequences for technology education in the case of schools having a weak technology education program, but seems to be beneficial for the status of technology education in the case of a strong technology education program. In Finland, technology education used to have its own inspector (for a long time that was Kananoja, who was very important for the emergence of technology education in that country; Kananoja 1988), but now there is no longer that position. Even in the UK, with its long-standing tradition in having genuine technology education in the curriculum (Wilson and Harris 2004), design and technology use to be compulsory for all stages in primary and secondary education (Key Stages 1–4), but it lost that status in KS4 and it making D&T an elective subject in KS3 was also debated (fortunately the debate was won by those in favor of keeping the compulsory status). In the USA, the position of technology education is not questioned but the struggle for status is still there. In New Zealand, the position of technology education with the new curriculum seemed inconvincible (Ferguson 2009), but the shift toward "reading, writing, and arithmetic" and to the interests of vocational education give reasons for concern. All this shows that technology educators can never sit back and relax. Governments want immediate effects of technology education on enrolment in science and engineering academic programs, even though this is an unrealistic demand for a relatively new school subject and the impossibility of proving causal relations between school subjects and academic enrolment. Such demands are never made to question the position of science or mathematics education in the curriculum. But technology education because of its short history is in a vulnerable position. That sets a challenge to technology educators. Their survival depends on their success in developing and maintaining excellent practices with sound support in high-quality educational research. Such a stimulus perhaps is a blessing rather than a curse. But it certainly provides strong motivation to work on constant improvement of technology education, both in research effort and in curriculum development. Hopefully in due time, there will be a second *International Handbook of Technology Education* with a new chapter in the history of technology education that will show that technology education has been able to overcome the hurdles of survival and flourishes in many countries worldwide.

References

Barlex, D. (2011). The STEM Programme in England – help or hindrance for design & technology education? In M. J. de Vries (Ed.), *Positioning technology education in the curriculum* (pp. 63–74). Rotterdam/Taipei/Boston: Sense Publishers.

Blandow, D. (1988). The system of polytechnic education in the GDR. In J. Raat, R. Coenen-van den Bergh, F. de Klerk Wolters, & M. J. de Vries (Eds.), *Basic principles of school technology. Report PATT-3 conference 1988* (pp. 116–135). Eindhoven: Eindhoven University of Technology.

Cheek, D. (1992). *Thinking constructively about science, technology and society education*. New York: State University of New York Press.

Compton, V., & France, B. (2007). Redefining technological literacy in New Zealand: From concepts to curriculum constructs. In J. R. Dakers, W. Dow, & M. J. de Vries (Eds.), *PATT-18 International Conference on Design and Technology Educational Research* (pp. 259–272). Glasgow: University of Glasgow.

Dugger Jr., W. E. (1987). Standards for the Technology Education Programs project. In R. Coenen-van den Bergh (Ed.), *Report PATT-conference 1987. Vol. 2. Contributions* (pp. 239–256). Eindhoven: Eindhoven University of Technology.

Dugger Jr., W. E. (2006). Twenty years of educational standards for technology education in the United States. In I. Mottier & M. J. de Vries (Eds.), *International handbook of technology education: Reviewing the past twenty years* (pp. 65–82). Rotterdam/Taipei/Boston: Sense Publishers.

Dyrenfurth, M. J. (1991). Technological literacy synthesized. In M. J. Dyrenfurth & M. R. Kozak (Eds.), *Technological literacy. Council on technology teacher education 40th yearbook* (pp. 138–183). IL, Glencoe Division, Macmillan/McGraw-Hill: Peoria.

Eijkelhof, H., & Kortland, K. (1988). Broadening the aims of physics education. In P. J. Fensham (Ed.), *Development and dilemmas in science education* (pp. 282–305). London: Falmer.

Ferguson, D. (2009). *Development of technology education in New Zealand schools 1985–2008*. Ministry of Education: Auckland.

Foster, P. N. (1994). Technology education: AKA industrial arts. *Journal of Technology Education, 5*(2), 15–30.

Holdsworth, I. (2006). Teaching making. A brief history of secondary school craft education textbooks. *Paradigm, 2*(2), 2–11.

Jones, A. (2009). The development of technology education internationally. In A. Jones & M. J. de Vries (Eds.), *International handbook of research and development in technology education* (pp. 13–16). Rotterdam/Taipei/Boston: Sense Publishers.

Jones, A., & Moreland, J. (2000). From technology national curriculum statement through to sustaining classroom practice and enhancing student learning: The New Zealand experience. In I. Mottier & M. J. de Vries (Eds.), *Proceedings PATT-10 conference* (pp. 65–76). Reston/Eindhoven: ITEA/Eindhoven University of Technology.

Kananoja, T. (1988). Technical work as an academic discipline in Finland. In J. Raat, R. Coenen-van den Bergh, F. de Klerk Wolters, & M. J. de Vries (Eds.), *Basic principles of school* *technology. Report PATT-3 conference 1988* (pp. 76–88). Eindhoven: Eindhoven University of Technology.

Lutherdt, M. (1995). Key qualifications - contents of general and vocational education. In K. Langer, M. Metzing, & D. Wahl (Eds.), *Technology education, innovation and management. Proceedings of the WOCATE conference 1994* (pp. 91–100). Berlin/Heidelberg: Springer.

McCormick, R. (1993). Technology education in the United kingdom. In R. McCormick, P. Murphy, & M. Harrison (Eds.), *Teaching and learning technology* (pp. 15–27). Milton Keynes: Open University.

Olafsson, B., & Thorsteinsson, G. (2009). Design and craft education in Iceland, Pedagogical background and development: A literature review. *Design and technology education: An international journal, 14*(2), 10–24.

Pavlova, M. (2016). 21st century skills: How to identify and address them in technology education. In M. J. de Vries, A. Bekker-Holtland, & G. van Dijk (Eds.), *PATT-32 proceedings. Technology education for 21st century skills* (pp. 378–385). Utrecht/Delft: Utrecht University of Applied Sciences/Delft University of Technology.

Penfold, J. (1988). *Craft, design and technology: Past, present and future*. Stoke-on-Trent: Trentham Books.

Ratcliffe, M. (2001). Science, technology and Society in school science education: Some key issues in the development of STS education. *School Science Review, 82*(300), 83–92.

Ritz, J., & Bevins, P. S. (2016). Exploration of 21st century skills that might be delivered through technology education. In M. J. de Vries, A. Bekker-Holtland, & G. van Dijk (Eds.), *PATT-32 proceedings. Technology education for 21st century skills* (pp. 400–410). Utrecht/Delft: Utrecht University of Applied Sciences/Delft University of Technology.

Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–424.

Shield, G. (2003). Vocationalism and accountability: Two threats to design and technology education. In J. R. Dakers & M. J. de Vries (Eds.), *PATT-13 international conference on design and technology educational research* (pp. 277–280). Glasgow: University of Glasgow.

Starkweather, K. (1992). Status of technology education in the United States. In E. A. Bame & W. E. Dugger Jr. (Eds.), *Technology education: A global perspective. ITEA-PATT international conference proceedings* (pp. 17–40). VA, International Technology Education Association: Reston.

Theuerkauf, W. E. (1995). Entrepreneurship and Employment. A didactic dimension of technology teaching. In J. H. Raat, I. Mottier, & M. J. de Vries (Eds.), *Teaching technology for entrepreneurship and employment. Proceedings PATT-7 conference* (pp. 32–46). Via Afrika: Cape Town.

de Vries, M. J. (2003). Technology education in the Netherlands. In G. Graube, M. J. Dyrenfurth, & W. E. Theuerkauf (Eds.), *Technology education. International concepts and perspectives* (pp. 229–240). Frankfurt a/M: Peter Lang.

Wilson, V., & Harris, M. (2004). Creating change? A review of the impact of design and technology education in schools in England. *Journal of Technology Education, 15*(2), 46–65.

Technology Education: History of Research

9

P. John Williams

Abstract

This chapter updates a study that began in 2006 to examine the areas of research that are undertaken in technology education, as represented in the main professional journals and conferences. Each of the resulting 1498 publications has been classified into 1 of 28 topics of research, and the resulting trends over time have been presented and discussed. The research trends include increasing research in STEM, learning and mobile/online learning, and less research about technological literacy, sustainability, and values.

Keywords

Technology education • Research • Research history • Research trends

Contents

Introduction

The assumption of this chapter is that an analysis of refereed conference presentation publications and journal article publications is an indicator of the research that has taken place in technology education. Such studies have been conducted in a range of

P.J. Williams (✉)
School of Education, Curtin University, Perth, WA, Australia
e-mail: pjohn.williams@curtin.edu.au

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_21

disciplines over time in order to indicate patterns (Berryman 1982; Jarvelin and Vakkari 1993; Price and Orman 2001; Reed and LaPorte 2015), some examples of which follow in the review of literature. The patterns may relate to the past or be used to predict future trends or be correlated with other professional developments.

This chapter follows two prior publications which outlined the first two stages of this research and represents the third stage. In 2011 (Williams 2013), I presented a review of journals and conference publications in technology education from 2006 to 2010 as one measure of the nature of research that was being conducted in the area. An element of that review was a prediction of trends, from the findings, to speculate about what research areas may develop and become more significant and more common in the future. This prediction was integrated with personal experiences and understandings to result in a speculative discussion of future trends.

In 2014 (Williams 2015), I extended this review, both in terms of the journals and conferences covered, and the time period to include 2011–2013, in order to evaluate those predictions and refine possible future trends and to answer the research question: What are the developments and trends in technology education research?

In this chapter a review of the years 2014–2015 has been added. It is hoped that this will be useful to researchers in the area of technology education who are planning research and to stimulate discussion about the research that is needed in this area.

Literature Review

There is some, but not extensive literature about research in technology education. Some of this research is presented chronologically in the following section. One of the earliest studies was conducted by Petrina (1998) who reviewed the 1989–1997 issues of the Journal for Technology Education. He found that most research was about curriculum, and very few studies dealt with teaching and learning in technology education. A little earlier, Zuga (1997) reviewed 220 journals and abstract databases from 1987 to 1993, and her conclusion also was that a significant majority of the research was about curriculum content, and very little research focused on students and teachers and the effectiveness of technology education. She concluded that the four areas missing from technology education research were (a) constructivism, (b) integration, (c) inclusion of all students, and (d) cognition. In 2005 Sontos used the same classifications as Zuga to analyze technology education dissertations in the USA between 2000 and 2005 and concluded that there was an increase in *instruction*-related research and a decline in *curriculum* studies.

In an editorial in 2003, deVries surveyed volumes 4–10 of the International Journal of Technology and Design Education with the questions:

- What and why to teach and learn about technology?
- To whom and by whom to teach and learn about technology?
- How to teach and learn about technology?

He identified four groups of “hot topics” in the 99 articles he examined. These were (i) design and problem-solving, (ii) values and pupils and teacher’s concepts and attitudes, (iii) studies related to national curriculum, and (iv) the identity of technology and technology education and its relationship with science. deVries concluded that:

- The field of curriculum goals and content is well covered in the articles surveyed.
- More attention is being paid to educational practice than in the past.
- But research into pupils understanding of technological concepts is very rare, unlike science research into student concepts.

So in a general sense by the mid-2000s, the trend is away from most research being in the area of curriculum and more research on teaching and students. This is confirmed by Middleton (2010a) and Johnson and Dougherty (2008). Johnson and Dougherty reviewed 199 articles published in four journals (the International Journal of Technology and Design Education, the Journal of Industrial Teacher Education, the Journal of Technology Studies, and the Journal of Technology Education) between 1997 and 2007. In this study, the articles were coded according to type of research, research method, primary data source, data type, and research focus. The seven most common foci areas of these articles were teaching, learning, curriculum, opinions-attitudes, design, problem-solving, and assessment-evaluation. Reflecting an American perspective, the authors advocated a need for more studies in engineering, design, creativity, and problem-solving.

Middleton followed this up in 2010b with an analysis of the publications in the *Journal of Technology Education* and the *International Journal of Technology and Design Education,* for the period 2000–2008. He concluded that:

> The most striking shift in the later data is the move from studies on *what to teach* which is down from 58.4% to 27% of all papers, to studies on *to and by whom* (up from 11% to 22%) and *how to teach*, up from 31.7% to 51%. Thus, earlier calls by Zuga and Petrina appear to have been heeded with an increase in research activity on topics such as how teachers and students perceive teaching and learning in technology education and a larger increase in studies examining how learning occurs and what needs to be done to make it effective. (Middleton 2010b, p. 280)

In 2010, Sherman et al. (2010) reviewed 24 research articles published between 1995 and 2008 on middle school technology education from four journals: Journal of Technology Education, Journal of Technology Studies, Journal of Industrial Teacher Education, and the International Journal of Technology and Design Education. This review indicated that a significant number of these articles were focused on the process/content development of new technology education curriculum and to a lesser extent examined methods by which these new curricula can be successfully presented to teachers. They concluded that "relatively little is known about contemporary middle school technology education teaching" (p. 377).

Another analysis of the International Journal of Technology and Design Education was conducted by Christensen et al. (2015) who considered 311 articles published between 2005 and 2014. The topic analysis was based on the article titles and resulted in the five most commonly occurring words being design (22%), technology (22%), education (16%), learning (11%) and engineering (5%).

A consensus on the direction of future research in technology education was developed by Ritz and Martin (2013) through the use of a Delphi technique with a panel of international experts in 20 different countries. They concluded that the five most important issues requiring research related to K-12 technology education were:

- Abilities students develop through the study of technology education.
- There is insufficient understanding of learning that takes place through the technology curriculum.
- Designing for sustainability and global citizenship.
- Technological conceptual knowledge.
- How do students learn in technology education (p. 780).

They also concluded that, related to teacher preparation, the five most important issues requiring research were:

- Lack of understanding about the epistemic beliefs of teachers
- How should design activities, aimed at concept learning, be taught by teachers
- Understanding of pedagogical content knowledge
- Methods of assessment in technology education, particularly of practical work
- How do teachers' beliefs affect program delivery (p 781)

The centenary of the US Mississippi Valley Technology Teacher Education Conference in 2013 was seen as an occasion for reflection on the history of the conference. At this time Wells (2015) conducted a content analysis of the discussion topics as reflected in the presentation titles or descriptions listed on the agendas of the annual meetings of the conference. While not necessarily indicating research trends, the agendas do reflect the professional concerns of the conference membership. Over 104 years there were 819 presentation topics which were grouped into seven themes, three of which (teacher preparation, policy, and epistemology) accounted for 76% of all presentation topics, with 12% attributed to one other theme (Pedagogy), and the three remaining themes (research, conference evaluation, and facilities) accounting for the final 12% of topics. Wells concluded that:

> There is a strong inverse relationship between Teacher Preparation and Policy in which a rise in policy trends precede and are therefore potentially informing Teacher Preparation. The Epistemology theme never falters in its path toward becoming the topical area of greatest concern today and providing a century of discussion that offered direction to the profession. Equally consistent though opposite to epistemological concerns was the lack of attention paid to Pedagogical issues throughout most of the MVC history. However, in the last decade, percent occurrence of presentations addressing pedagogical concerns has risen dramatically, which is an encouraging trend in attention to an area of such importance to the profession. (p. 27)

While not focusing specifically on research, Reed (2015) also conducted a content analysis of 5369 special interest sessions of 37 ITEEA (and formerly

ITEA and AIAA) conferences from 1978 to 2014. These sessions make up the bulk of the conference program and are vetted but not refereed by the conference committee, so some are research, but most are presentations of classroom practice. Thirty one content categories were identified, with the following topics most commonly represented at the conferences: curriculum (28%), design (12%), research (10%), methods (10%), and engineering (9%) and a growing number in the categories of biotechnology, curriculum, engineering, gender, design, distance learning, elementary, leadership, research, technological literacy, and STEM integration.

Apart from journal and conference publications, there are some other sources which provide snapshot indications of research that is being conducted. The *International Handbook of Research and Development in Technology Education* (Jones and deVries 2009) provides a broad overview, including research, of some of the key areas of technology education: international developments, the nature of technology, perceptions of technology, technology and science, learning and teaching, assessment, teacher education, and theoretical and practical approaches. In the final chapter of this volume, Jones looks forward to identify issues such as the need for a closer alignment between research, development, and practice.

> The early work in technology education spent much time defining the field and the curriculum. More recently there has been an increase in the amount of research that has the potential to inform practice... However, although research may be seen to inform practice, how it gets translated into practice is another matter. Involving teachers as research partners rather [than] 'the researched' is a way of breaking down some of these barriers. (p. 690)

Obstacles to the development of research in technology are identified as including limited funding and research assessment exercises which reward publication in "high-level" journals, of which there are few in the relatively new discipline of technology education.

An indicator of research in a particular region is provided in the book *Technology Teachers as Researchers* (Skogh and deVries 2013) which featured doctoral students who were involved in the "Technology Education for the Future" (TUFF) project. The Swedish government funded 12 teachers to research teaching and learning elements of their practice as the pathway to achieving a PhD degree, and each contributed a chapter to the book based on their research.

An alternative approach which focused on the methodology of research can be found in Middleton's (2008) book *Researching Technology Education* which represents a picture of the type of research that has taken place in technology education, rather than the content of the research, which is the focus of this chapter. The research methods described in this book include case studies, collaborative case studies, repertory grids, cultural-historical approaches, action research, comparative research, observations, video-simulated recall, verbal protocol analysis, and design.

There are other sources which also provide an indication of research that is taking place in technology education which have not been interrogated as they are beyond the scope of this study. Reed (2001) assembled an electronic list of postgraduate student research in technology education titled the Technology Education Graduate

Research Database (TEGRD). Incorporated into this database were the results of a search of Dissertation Abstracts Online (ProQuest) using the following terms: manual training, industrial arts, industrial education, technology education, industrial technology, trade and industrial education, and industrial vocational education. The TEGRD initially contained 5259 entries spanning 1892–2000.

Loughborough University in the UK also hosts a database which can be found on the university's Open Journal Systems (OJS) server. All the papers published in *Design and Technology Education: an International Journal* (2005 onwards) and those published in earlier versions including *The Journal of Design and Technology Education* (1996–2004), *Design & Technology Teaching* (1989–1995), and *Studies in Design, Craft and Technology* (1970–1988) can be searched and freely downloaded.

No comprehensive source of information about research in technology education was discovered for this review, indicating a gap in the literature which justifies this as an ongoing area of research. Much of the literature surveyed in this brief review, from the late 1990s on, concluded that the most common area of research has been related to curriculum (Petrina 1998; deVries 2003; Middleton 2010b; Wells 2015; Reid 2015) and that there is a need for research in teaching and learning (Zuga 1997; deVries 2003; Ritz and Martin 2013). The next section of this chapter will indicate that not much has changed.

Review Method

In the 2006–2010 study (Williams 2013), I analyzed research that had been published in three journals and presented each year at four conferences. The journals were:

1. The Journal of Technology Education, edited in the USA and published in paper form and freely available on the Virginia Tech website
2. The International Journal of Technology and Design Education, published by Kluwer in the Netherlands, available by subscription in paper and online
3. Design and Technology Education: an International Journal (journal of the professional association in the UK, available freely to association members in paper and online)

The four conferences reviewed were the:

1. Annual UK Design and Technology Association conference
2. PATT conferences which occasionally have more than one in a year
3. Biannual Technology Education New Zealand professional association conference
4. Biannual Technology Education Research Conference (TERC) sponsored by Griffith University in Australia

This analysis resulted in 472 manuscripts which were either published or presented.

In addition to these sources, for the 2011–2013 period (Williams 2016), I added the Journal of Technology Studies (the journal of the Epsilon pi Tau professional technology fraternity in the USA), the biannual Asia-Pacific International Conference on Technology Education (ICTE), and the Council for Technology and Engineering Teacher Education (CTETE) conference, which is run in the USA each year in conjunction with the ITEEA conference. The UK Design and Technology Association conference was not included in the 2011–2013 period because there have been minimal research papers presented at this conference. This period added another 713 manuscripts to the 472 that had been analyzed previously for a total of 1185.

For this chapter, an analysis of a further 313 publications and conferences in 2014–2015 were added to the data, and one journal was added to those already analyzed, the online Australasian Journal of Technology Education. This provided for a total of 1498 conference papers and journal articles over the 10-year period 2006–2015. These sources of data are summarized in Table 1.

Table 1 indicates that the comparison across the three stages of the research must be analyzed with caution, because the 2011–2013 period included some sources that were not included in the original timeframe: the US-based Journal of Technology Studies (JTS), the Asian-based International Conference of Technology Education (ICTE), and the US Council of Technology and Engineering Teacher Educators (CTETE). For example, the CTETE conference included 32% of papers on the topic of STEM, and

Table 1 Sources of data

	2006–2010	2011–2013	2014–2015
Publications			
Journal of Technology Education	*	*	*
International Journal of Technology and Design Education	*	*	*
Design andTechnology Education: an International Journal	*	*	*
Journal of Technology Studies		*	*
Australasian Journal of Technology Education			*
Conferences			
Design and Technology Teachers' Association (DATTA, UK)	*		
Technology Education New Zealand (TENZ)	*	*	*
Pupils Attitude Toward Technology (PATT, US and International)	*	*	*
Technology Education Research Conference (TERC, Australia)	*	*	*
International Conference on Technology Education (Asia-Pacific)		*	*
Council for Technology and Engineering Teacher Education (CTETE, US)		*	*

this focus is influential in the dominance of STEM as an overall area of research. Then in the final stage, the Australasian Journal of Technology Education was added.

While the journals and conferences selected for analysis are those which focus on technology education, the methodology of sample selection was still somewhat idiosyncratic, as there is research taking place in, for example, South America, Northern and Eastern Europe, and Southern Africa that was not considered in this analysis. There are also a number of related journals which include technology education content but have a broader scope, such as the Journal of STEM Education, the International Journal of STEM Education, the Journal of the Japanese Society for Technology, Techné: Research in Philosophy and Technology, Career and Technical Education Research, the Journal of Career and Technical Education, the African Journal of Research in Mathematics, Science, and Technology Education, Research in Science and Technology Education, and the International Journal of Research in Science and Technology Education.

This represents a limitation of the findings. Within those limitations, the research approach was inclusive and so considered papers which were clearly and identifiably research, posing an empirical question and using quantitative or qualitative methods, but also papers which were more theoretical position papers, retrospective analyses, and presentations of practice. The rationale for this broad approach was that it would provide a more representative indication of academic pursuit within the community of technology educators.

The topic categories were developed initially for the 2006–2010 study through an inductive process of development, which was not predetermined and allowed for flexibility (Braun and Clarke 2006). A qualitative approach was initially used for category development and allocation, followed by a quantitative approach to generate frequency data (Wells 2015). As the source papers were scanned, they were allocated to a topic. A refinement process was utilized initially involving some reallocation and coding adjustment, until a stable situation was achieved in which each new paper clearly fitted to an existing topic. Some papers could be coded based on the title, some required a review of the abstract, and others had to be read more thoroughly in order to classify according to topic. Each paper was coded only in one category, so in some instances, a judgement was made about the main focus of the paper. While coders may subjectively interpret data for coding purposes according to their conceptions, some consistency was provided in this study in that one person did all the coding over the three phases of the study. The coding scheme of 28 topic areas proved to be stable for the second and third stages of the study.

Findings

As a result of the analysis, 28 categories of research were identified. Table 2 presents exemplars of content that were identified in the top 10 categories.

The most productive source of research papers over this 10-year period was the PATT conferences (404 papers) because of their frequency, for example, there were two conferences in many years during this period, one each year in conjunction with

Table 2 Exemplars of content

Category	Exemplars
Curriculum	Elements of the technological knowledge strand, the importance of engineering technology, the Hong Kong TEEN project, Khan Academy curriculum, development of project-based curriculum, holistic and universal technology education
Design	Conceptual foundations of design and other theoretical perspectives, analysis of pupil design decisions, exemplars of and correlations between design practice in school and in industry, design teams, designing and teaching styles and elements of student design
STEM	International vires of STEM, results of an integrated curriculum, when science introduces engineering, teaching STEM to math and science teachers, integrated STEM education
Teaching	The use of physical modeling, problem-based learning, teaching through design, metaphor and pedagogy, and the constituents of effective teaching
Learning	Analysis of spatial visualization ability, collaborative method of learning content, modeling in engineering design processes, the mediator effects of imagination, the role of graphics in learning
Teacher education	Emancipation framework for technology education teachers, the impact of cognition of technology and preservice teachers, technological literacy courses in preservice teacher education
Thinking	Visual thinking and student engagement, fostering extended thinking in the design process, the application of critical thinking to technological issues, scaffolding students' idea generation
Attitudes (PATT)	Pupils' perception of design and technology, Swedish students' views on technology, analyses of PhD's perceptions toward the technology education profession, what is the point of design and technology education
Technological literacy	Technological literacy and technological culture, an instrument to determine technological literacy levels, measuring the influences that effect technological literacy
Mobile/online learning	History of virtual worlds, adapting mobile technology in higher education, meta-analysis of mobile learning research, augmented reality prototypes, online collaboration in a design studio

the International Technology Education Association Conference in the USA and one in another country. Fortunately now, most of the PATT conference proceedings are available through the International Technology Education Association website (http://www.iteea.org/Conference/pattproceedings.htm). The most productive of the four journals was the International Journal of Technology and Design Education (263 papers). This is the only technology education journal consistently cited in international lists of "high -impact journals" and so has a significant status within the profession and has also increased the number of published volumes per year from three to four.

The most common research topics to be covered in the journals over this period (2006–2015) are mostly explicable:

- Journal of Technology Education: the fact that *STEM* topics were covered most frequently (15%) is not surprising given the emphasis that is being applied to

STEM initiatives in the USA. For a similar reason, the conference that had the highest number of STEM research papers (45%) was the CTETE conference, also reflecting NSF-funded STEM projects.
- International Journal of Technology and Design Education: the most frequently published research topic was around *learning* (11%).
- Design and Technology Education: an International Journal most frequently published research related to *design* (10% in 2006–2010 to 13% in 2006–2013 to 26% in 2014–2015); not surprising in a curriculum context where the school subject in England is called design and technology.
- Journal of Technology Studies most common publication topic over the 10 years was related to mobile and online learning (19%).
- Australasian Journal of Technology Education published 15 articles in 2014–2015, and there was no clearly most common topic.

The most common research topics to be covered in the in the conferences over this period were:

- PATT conferences: *Technological literacy* was the most frequently presented topic in 2006–2013 (8%), but in the 2014–2015 period, the most common topic was related to *attitudes* (18%).
- TERC: Research about *values and beliefs* in technology education was most commonly presented at the TERC conferences between 2006 and 2013 (14%), but in 2014–2015, the most frequent topic was STEM (13%).
- TENZ conference: Over the 10-year period, *curriculum* was the theme most frequently presented (19%).
- ICTE (Asia-Pacific): 13% of presentations were focused on the technology education system of an identified country in 2006–2013, but more recently (2014–2015), *curriculum* has been the most frequent theme (25%).
- CTETE conference: The topic of STEM was the most commonly presented, increasing from 32% in 2011–2013 to 53% in 2014–2015.

It was significant that no single topic had an outstandingly high frequency of papers, so a broad spread of research interest within the profession was represented. A meta-analysis indicated that the most common topic across all conferences and journals in the 2006–2015 period was *curriculum* (9.2%). This continues a trend which was identified as early as the late 1990s (Zuga 1997), namely, that curriculum is the most commonly researched area in technology education.

After *curriculum*, in order of frequency, the following topics were the focus of research papers over the 2006–2015 period:

(i) *Design* (8.6%)
(ii) *STEM* (8.1%)
(iii) *Teaching* (7.7%)
(iv) *Learning* (7.6%)

Table 3 Comparative ranks of research topics

	2006–2010	2011–2013	2014–2015	
Top 10 (06–10)	1	3	5	Design
	2–3	2	1–2	Curriculum
	2–3	12–13	16	Tech literacy
	4	8	8	Thinking
	5–7	5	3–4	Teaching
	5–7	9–10	6	PATT
	5–7	6	9	Teacher education
	8	4	3–4	Learning
	9	23	20	Values/beliefs
	10	9–10	14–15	Sustainability/environment
Consistent Move >5	12–13	1	1–2	STEM
	14	11	7	Mobile/online
	20	14	12–13	Primary and ECE
	24	17–18	12–13	Gender

The above summary is for the 10-year period of 2006–2015. Breaking this information down into the three periods of analysis provides an indicator of how the focus of research has changed over time. Table 3 indicates the frequency of the 10 most common research topics over the 2006–2010 period, which was reported in 2013 (Williams 2013), the 2011–2013 period (Williams 2015) and the 2014–2015 period.

It was noted in 2013 that it seemed that the scope of research in technology education during this period was broader than in the past. The papers in the five most common research areas in 2006–2013 constituted 35% of all research papers, but in 2014–2015, 52% of all papers were in the top five most common research areas. This would seem to indicate a consolidation of more research taking place in fewer areas rather than a broadening of scope.

With four exceptions, the top ten topics for the 2006–2010 period and the 2011–2013 period were the same: the exceptions were the areas of *values and beliefs* and *technological literacy* which were out of the top 10 and *STEM* and *ICT* which are now in the top ten. As stated, this comparison must be analyzed with caution, because the 2011–2013 period included some sources that were not included in the original timeframe: the US-based Journal of Technology Studies (JTS), the Asian-based International Conference of Technology Education (ICTE), and the US Council of Technology and Engineering Teacher Educators (CTETE). For example, the CTETE conference included 32% of papers on the topic of STEM, and this focus is influential in the dominance of STEM as an overall area of research.

Table 4 represents the most frequent topics of research during the period 2014–2015, from the extended sources of five journals and five conferences.

The most common 5 topics in 2014–2015 are the same as the previous 2011–2013 period: *STEM, curriculum, design, learning, and teaching*. With regard to the 10 most frequently published topics, *ICT* and *sustainability/environmental* are

Table 4 Frequency of research topics, 2006–2015

Rank	No	Topic
1	122	Curriculum
2	114	Design
3	108	STEM
4	102	Teaching
5	101	Learning
6	77	Teacher education
7	71	Thinking
8	68	PATT
9	57	Technological literacy
10	51	Mobile/online

no longer in the top ten, and *mobile/online* and research which focus on a *country's curriculum* are included.

The three main areas of research within technology education have remained relatively stable for the last 10 years: *curriculum, teaching*, and *design*; these areas have accounted for just over 25% of all research publications in the ten sources cited, and each have over 100 publications. The two other areas which have over 100 publications in this 10-year period are *STEM* and l*earning.*

There is a big gap between these areas and the next most common areas which have between 50–70 publications each: *teacher training, thinking, PATT, technological literacy*, and *mobile/online*.

Table 5 compares the topics of research that have become more common and those that have become less common when the 2006–2010 data is compared with the 2014–2015 data.

The four areas that have become less common (changed more than five rank places) over the total period, in order of greatest rank difference, are *technological literacy*, *values/beliefs*, *teachers' PD*, and *sustainability/environmental*. The five areas that have become more common (changed more than 5 rank places) over the total 10-year period, in order of greatest rank difference, are *gender*, *STEM, primary and ECE*, *mobile/online*, and *learning*.

Discussion

This current research supports the notion that research into areas of *design* and *curriculum* has always been fundamental and common areas of inquiry and will continue to dominate research in technology education. *Technological literacy* is a less common area of research than in the past and that could be because there is a feeling that *technological literacy* is now well established as a significant goal of technology education, and so the research imperative is less.

It is not clear why *values/beliefs* and *sustainability/environmental* areas of research are less common more recently. Environmental and sustainability issues continue to be prominent in national and international discourses and remain an

Table 5 Rank change of research topics, 2006–2010 and 2014–2015

2006–2010 compared with 2014–2015		
Area	Rank change >5	
Less common	From	To
Tech literacy	2.5	16
Values / beliefs	9	20
Sustainability/environs	10	14.5
Teachers PD	11	17
More common		
Learning	8	3.5
STEM	12.5	1.5
Primary and ECE	20	12.5
Mobile/online	14	7
Gender	24	12

integral aspect related to the nature of design and technology. Similarly, no discussion of technology is complete without a consideration of values. It remains to be seen whether the decreasing amount of research in these areas is a trend or an aberration.

The research around gender is generally about the disproportionate number of females involved in elective design and technology education or in technology-related professions, so it is a positive sign to see more research being conducted into this area. This research is also related to the increasing volume of STEM research, in which a common theme is increasing the number of females in the STEM professions.

It is also positive to observe that more research is being conducted into how students learn in technology and the learning processes involved. This has been a suggestion from early reviewers of patterns in technology education research that a more detailed understanding of how students learn in technology is needed in order to inform curriculum and pedagogical approaches. The increasing number of research papers with a focus on primary and ECE levels of technology education may be an outcome of the cessation of the International Primary Design and Technology Conferences (CRIPT), as this conference provided an outlet for research focused at this level of technology education and was not included as a source of data for this analysis.

The area of *STEM* research changed rankings (12.5 to 1.5) more than any other area in this time period. While the research in this area has been driven by the USA in the past, a focus on *STEM* continues to gain prominence in many countries, and this will be increasingly followed by a research agenda. The two largely US-based sources of data considered in this study, the Journal of Technology Education and the Council for Technology and Engineering Teacher Education conference, both have *STEM*-related papers as the most common area of publication. There is no indication that this trend will abate as it continues to gain momentum in other countries; it is likely that it will remain a significant area of research activity as the role of technology education and its relationship to other subjects becomes more clarified or redefined.

Conclusion and Future Directions

The 2015 Horizon Report (Johnson et al. 2015) identified and described emerging technology and the likely timeframes for their entrance into mainstream use for teaching, learning, and creative inquiry. Bring your own device (BYOD) and makerspaces were identified as important developments within the next year, and the increasing use of blended learning and the rise of STEAM learning were identified as key trends in the next 1–2 years. The interest in makerspaces does not yet seem to have yet impacted on research in technology education, despite the obvious synergies with technology workshops and the potential for school technology departments to become an integral part of this movement. BYOD and blended learning, while not directly identified as topics of frequent research in technology education, there is an increasing focus on *mobile/online* learning (ranked 14th in 2006–2010, and 7th in 2014–2015). Research in this area may continue to help clarify the general confusion between educational technology and technology education. *STEM* research in technology education is also reflecting the Horizon Report trends, being the most common (with *curriculum*) area of research.

In conclusion, the research trends in technology education include increasing research in STEM, learning and mobile/online learning, and less research about technological literacy, sustainability, and values. I had predicted in 2015 that a research trend would be an increasing diversity of research topics, but it seems that a consolidation rather than diversity is taking place.

References

Berryman, C. (1982, March). *Undisciplined social studies: An analysis of NCSS programs, 1976–1980.* Paper presented at the Annual Meeting of the American Educational Research Association, New York. Available from ERIC database (ED214850).

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. doi:10.1191/1478088706qp063oa.

Christensen, J., Jones, B., Cooper, J., McAllister, L., Ware, M., & West, R. (2015). Educational technology research journals: International journal of technology and design education, 2005–2014. *Educational Technology, 55*(3), 36–42.

deVries, M. (2003). Editorial. *International Journal of Technology and Design Education., 13*(4), 199–205.

Jarvelin, K., & Vakkari, P. (1993). The evolution of library and information science 1965-2985: A content analysis of journal articles. *Information Processing and Management, 29*(1), 129–144.

Johnson, S. D., & Daugherty, J. (2008). Quality and characteristics of recent research in technology education. *Journal of Technology Education, 20*(1), 16–31.

Johnson, L., Adams Becker, S., Estrada, V., & Freeman, A. (2015). *NMC Horizon report: 2015 K-12 edition*. Austin: The New Media Consortium.

Jones, A., & de Vries, M. (2009). *The international handbook of research and development in technology education*. Rotterdam: Sense Publishers.

Middleton, H. (Ed.). (2010a). *Knowledge in Technology Education*. Proceedings of the 6th Biennial International TERC 2010 Conference. Brisbane: Griffith Institute for Educational Research.

Middleton, H. (2010b). Ch. 14: Recommendations for technology education research. In P. Reed & J. LaPorte (Eds.), *Research in technology education*. Reston: Council on Technology Teacher Education.

Petrina, S. (1998). The politics of research in technology education: A critical content and discourse analysis of the journal of technology education, volumes 1–8. *Journal of Technology Education, 10*(1), 27–57.

Price, H., & Orman, E. (2001). MENC 2000 national biennial in-service conference: A content analysis. *Journal of Research in Music Education, 49*(3), 227–233.

Reed, P. (2001). *CTTE monograph 17: The technology education graduate research database: 1892–2000*. Reston: Council on Technology Teacher Education.

Reed, P., & LaPorte, J. (2015). A content analysis of AIAA/ITEA/ITEEA conference special interest sessions: 1978–2014. *Journal of Technology Education, 26*(3), 38–72.

Ritz, J., & Martin, G. (2013). Research needs for technology education: An international perspective. *International Journal of Technology and Design Education, 23*, 767–783.

Skogh, I., & de Vries, M. J. (Eds.). (2013). *Technology teachers as researchers*. Rotterdam: Sense Publishers.

Sherman, T., Sanders, M., & Kwon, H. (2010). Teaching in middle school technology education: A review of recent practices. *International Journal of Technology and Design Education, 20*(4), 367–379.

Sontos, D. (2005). *Directions of dissertation research at universities preparing future technology education teacher educators*. Retrieved from: http://digital.lib.odu.edu:8000/dspace/handle/123456789/1

Wells, J. (2015). A century of professional organizational influence: Findings from content analyses of MVTTEC annual meetings. *Journal of Technology Education, 26*(3), 3–37.

Williams, P. J. (2013). Research in technology education: Looking back to move forward. *International Journal of Technology and Design Education, 23*(1), 1–9.

Williams, P. J. (2016). Research in technology education: Looking back to move forward. . .again. *International Journal of Technology and Design Education, 26*(2), 149–157. doi:10.1007/s10798-015-9316-1.

Williams, P.J. & Lockley, J. (2012). *An analysis of PCK to elaborate the difference between scientific and technological knowledge*. Pupils Attitude Toward Technology (PATT) 26 Conference: Technology Education for the 21st Century. Stockholm, June.

Zuga, K. (1997). An analysis of technology education in the United States based upon an historical overview and review of contemporary curriculum research. *International Journal of Technology and Design Education, 7*(2), 203–217.

Authentic Research for Technology Education

10

Chris Merrill

Abstract

Technology educators at all grade levels are engaged in research. Some technology educators conduct informal research, while others implement formal, authentic research in their classrooms. The purpose of this chapter is to showcase action research in technology education as a method to authentically investigate problems technology educators may need to address in their classrooms. Action research has been defined for the technology educator, as well as the benefits and challenges of conducting authentic research. Further, the content of this chapter focuses on the approaches of action research, developing a research plan, and contextualizing action research in engineering design.

Keywords

Action research • Technology education • Engineering design

Contents

C. Merrill (✉)
Department of Technology, Illinois State University, Normal, IL, USA
e-mail: cpmerri@ilstu.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_20

Introduction

Technology educators, especially those at the primary and secondary levels, react in various ways to ideas of research. For example, some educators may be intimidated by the process of research and will likely never conduct a research-based study, some educators are intrigued by the idea of research but are not clear on the approach, while other educators embrace and conduct research, especially research that is directly beneficial to their classroom. It is the premise of this author that action research can be conducted in the technology education classroom and that all educators, whether they realize it or not, conduct research in their own classrooms; the challenge, however, is to formalize the research process so the outcomes become empirically based, rather than simply self-belief. Education action research can be defined as "continual disciplined inquiry conducted to inform and improve our practice as educators" (Calhoun 2002, p. 18). It is under Calhoun's definition of action research where the realities of technology education research can be conducted. As a technology educator, you may likely ask questions like: (a) How do I improve my instructional practice, curriculum, or assessment? (b) How can I increase the involvement and success of my technology education students? (c) How can I solve technology education classroom and laboratory problems? So, then, how do we best answer these questions – research.

The purposes of this chapter are to (a) explore the benefits and challenges of action research for technology education, (b) briefly describe action research approaches, (c) identify some topics that can be authentically investigated in technology education, and (d) discuss the process that technology educators can implement for rewarding research.

The roots of action research reside in Kurt Lewin's theory of research that was focused on workplace studies in the 1930s. Lewin's process of action research was described as spiraling because it "included reflection and inquiry on the part of its stakeholders for the purposes of improving work environments and dealing with social problems" (Hendricks 2009, p. 6). Today, education action research is widely utilized, appearing in academic journals and developing into networks in many countries. Action research has been offered as an alternative method of providing empirical evidence for teacher change, leading to the improvement of the educative process (Johnson 2012; Mills 2014). Action research has also been discussed as an avenue for individual professional development, school collaboration, and educational reform. As Calhoun stated, action research "can change the social system in schools and other education organizations so that continual formal learning is both expected and supported" (p. 18).

Benefits of Action Research

Mitchell et al. (2009) describe the benefits of beginning teachers conducting action research as (a) teachers developing their identity as subject specialists, (b) teachers developing their personal levels of self-efficacy and empowerment, and (c) beginning teachers solving problems that are more characteristic of expert teachers. Hine and Laverty (2014), in their research following three classroom teachers over an extended period of time in Australia, described the benefits of action research for classroom teachers as (a) filling the gap between theory and practice, (b) teacher empowerment, and (c) worthwhile means of professional growth and development. Filling the gap between theory and practice results from educators investigating primary and secondary sources based on the particular problem that they are facing in the classroom or school. In order to fill the gap between theory and practice, educators engage in action research that provides answers to their questions. Action research may provide educators with empowerment in the classroom or school because they were the one(s) that directed the action research study, collected and analyzed data, and used the information to make decisions about their classroom or school. Finally, action research is worthwhile professional development because the educator takes ownership in the research, often resulting in an increase in knowledge and understanding of the problem.

Challenges of Action Research

Hine and Laverty (2014), in their discussion of action research, also noted that challenges exist to successful action research. For example, action research is time-consuming, often requiring educators to work on their research outside of the normal work day. It is important for educators to know that any research protocol will take time to plan and execute and time will become an issue if presented as a constraint to the researcher(s). Second, educators may question the validity of their findings and wonder if they may have biased the results. Since some action research places the educator in the middle of the study itself, it is possible for an educator to have unconscious or even implicit biases when either implementing their research protocol, collecting data, or analyzing data. It is important for educators to know that bias, whether implicit or not, may have an effect on the overall success of the research project – educators need to remain objective during research and conduct the protocol, despite the findings. Third, it is easy for educators to not complete an action research study if positive outcomes begin to appear in the classroom or school as the study is taking place. Educators need to do their best not to accept preconceived findings but to complete their study based on their research protocol.

Approaches to Action Research

While the purpose of this section of the chapter is to describe approaches technology education teachers can take to conduct action research in the classroom, you should first investigate what requirements or permissions are needed at your particular school in order to conduct research. For example, do you need to have parental consent and student assent? What permissions are needed by school administrators? Will participants be anonymous, and data collected confidential?

There are multiple approaches technology education educators could use to conduct action-based research; the two most popular approaches are single teacher and collaborative. The first approach is for a single technology educator to formulate and conduct an authentic study based on their classroom (students). Collaborative research is utilized when educators work together on an educational issue; collaborators may be other educators from the school, between or among industry partners, or with college and university faculty. Technology educators may find it more beneficial to use the collaborative approach in conducting action research because of the availability to draw upon the expertise of peers, constraints of time, accountability within and among peers, and to reduce bias.

Whether or not you conduct your own study or collaborate with others, you need to read research studies, especially those that are focused on teacher-based research. After reading action-based research, you should be able to better understand, from the teacher's perspective, what was under investigation and why it was so important for the teacher to investigate the problem, i.e., the rationale for the study. Second, in an action research study, you should be able to understand what steps or processes the researcher (educator) took to complete the study, including the benefits and challenges. Third, how the study was evaluated, that is, what constituted data and how the data was analyzed. Finally, what types of conclusions did the educator make based on the study that helped to better inform their practice or school?

Formalizing a Research Plan

Once you have a topic that is of interest, e.g., a problem is identified in your classroom or school, and you initially deem it doable under your constraints, it is time to formalize a plan of action. Similar to the multitude of design processes students can use in order to solve technological problems, there are multiple ways to formalize and conduct an action research-based study. However, all study approaches start with the same first step: What is the problem? Is the problem defined? Is the problem focused? This may be one of the hardest steps of the research process, but careful attention needs to be placed here because if the problem is not narrowly defined, your investigation may be unsuccessful or you may become easily frustrated.

Next, one of the most time-consuming portions of your study, but one that needs to occur, is the reading of literature that is similar or based on your topic. Your review of the literature will reinforce that the problem under investigation is worth investigating, versus a symptom that is occurring in the school or classroom that may be easily corrected or addressed. Further, conducting literature reviews and reading research studies will likely showcase the research instruments used in the study. Research instruments may come in the form of surveys, focus group questions, case study scenarios, etc. Research-based instruments will also indicate how validity and reliability of instruments were established. Educators may find instruments that can be readily used in their study or instruments that can be easily modified. It is important for educators to know that there is no magical number of articles or studies you need to read based on your topic but, rather, enough information that you know the issues surrounding your topic. Without a literature review, you will mostly likely not have sufficient prior knowledge about the topic or miss out on an appropriate approach to how you might investigate your topic. Based on the outcomes of your targeted literature review, you need to ask yourself or your collaborators how to best collect data based on the problem that you have identified. In some cases, you will be collecting artifacts, while in other situations, you may be creating new instruments, modifying existing instruments, setting up some type of experimental approach, etc. The approach you take will be based on the problem under investigation and findings from the literature review you conducted.

Once the data is collected, you need to be able to analyze and interpret the data you collected into meaningful information. The data you collect may show you that the problem you thought you had in your technology education classroom was really not an issue, while other times, the analyzed data will provide evidence where the problem exists and at what level. From the analysis of the data, you and your colleagues will be able to (a) develop practical strategies to address the problem, (b) develop the necessary instructional steps, which may include, for example, changes in the curriculum, and (c) establish a course of action to measure changes. Finally, you and your colleagues will want to decide how to report your findings. You could create a presentation-type report that could be shared with the school community, you may decide to communicate your study using a traditional research paper format, or you could report the findings by conducting professional development with your colleagues; there is no right or wrong way to communicate your results, but they must be communicated for all to learn. For all to understand your action research project, it is recommended that you (a) state what the problem under investigation was, (b) present the research-based question(s) you utilized, (c) how or what you did to gather data, (d) illustrate what the results were, and (e) communicate your next steps or plan of action to address the problem under investigation.

Below are common aspects of a research protocol to be addressed for the welfare of the researcher, as well as the participants. However, based on your specific setting, you will need to check with your managers to access the specific requirements of conducting a research study. Generally, you will be expected to:

- Provide an overall description of the research protocol, including the benefits of the study for you and your students, goals, objectives, where the study will take place, expected duration, etc.
- Describe how you will control for risks.
- Generate a parental permission letter and obtain parental permission.
- Generate a student assent letter and obtain student assent.
- Discuss how the study will be conducted, including how you will select the participants for the study.
- Discuss how data will be obtained, whether the data will be confidential or anonymous, how the data will be stored, and who will have access to the data;

specific information will likely be asked about audio or video recording of research subjects.

- Discuss what the nonparticipating students will be doing during the study.
- Discuss the provisions in place to minimize coercion.
- Provide copies or descriptions of the instruments being used to collect data.
- Discuss how you will report the findings of the data – who will see the final results.

Potential Technology Education Problems to Investigate

From a technology education perspective, what can technology educators gain from conducting action-based research? Let us take a look at one scenario facing technology educators across the globe where there are benefits of conducting an action-based research study.

Engineering Design

What knowledge, dispositions, and skills are needed for technology educators to effectively design, implement, and assess content that would draw upon engineering design? What technological, scientific, and mathematical pedagogical content knowledge are needed to be an effective technology educator in relation to engineering design? At my particular school, in my particular community, what engineering design knowledge and skills do my students need in order to be successful? Empirical evidence related to engineering design at the classroom level would provide technology educators with evidence of their development as subject specialists, where pedagogical content knowledge and levels of self-efficacy may be deficient. Further, empirical evidence at the classroom level would illustrate how theory and practice are symbiotic, teacher and student misconceptions related to engineering design would be exposed and corrected, and the growth of the technology educators would be measurable. This scenario can be approached in two ways, the first being where an educator would try different approaches most likely leading to some answers but more likely leading to “this is what I thought” type of answer and the second, a systematic approach to answering these questions through action-based research conducted at the school level, where the ultimate focus would be on improving student learning and experiences.

In a 2012 study conducted by Martin and Ritz (2012) where the researchers looked at technology education research priorities from a US perspective, the following topics were recommended to the profession as areas of research needs: (a) technology education’s impact on academic achievement, (b) benefits of K-12 technology and engineering education, (c) engineering content and curriculum, (d) content of technology and engineering education, (e) research related to K-12 education, and (f) student learning. While these topics are certainly rich for research, Martin and Ritz pointed out that some of these topics may be buzzwords and may not be priorities over time. Below are some suggested topics related to technology education that may be more doable and narrowly focused.

- Rather than look at engineering as a large researchable topic, technology education educators could examine how engineering design notebooks are used in the classroom, that is, (a) What constitutes an engineering design notebook? (b) Is the use of an engineering design notebook beneficial for student achievement? If so, why? If not, what could be done by the educator to make them more usable? (c) How are other technology education educators using engineering design notebooks?
- What curricular and pedagogical approaches need to be implemented and assessed in technology education to recruit and retain students from underrepresented populations?
- What types of facilities are needed at the school level to implement safe and engaging technology education?
- What misconceptions do students hold about a certain topic or construct that I, as the educator, need to address?

Conclusion and Future Directions

There are a myriad of topics related to technology education that could, should, or need to be authentically researched at the classroom level, but any classroom-based research needs to be prefaced by how it will help students to better learn and achieve. While there are countless topics related to technology education that could be researched, there are also countless education situations faced by technology educators, such as unique school settings, multiple grade and achievement levels, the school having its own cultural and social norms, and the difference between communities (just to name a few of the differences and unique situations). While research and practice to better inform student learning and opportunities should be the first priority, other priorities of the teacher-researcher need to be (a) a researchable topic that is “doable” under the constraints of the educator, school, and community, (b) the educator needs to be fully invested in the topic – has real interest, and (c) the topic is narrowly focused. During the Hine and Laverty (2014) study, where research was conducted on three classroom educators who engaged in action research projects, Hine and Laverty stated, “Critical to the success of their action research projects was the fact that each participant chose a topic that was decidedly relevant to his or her role in the school” (p. 167).

The purpose of this chapter was not to write a textbook on action research but rather provide technology educators with information on a variety of topics surrounding action-based research, which included (a) the benefits and challenges of authentic research for technology education, (b) action research approaches, (c) identification of topics that could be investigated in technology education, and (d) discuss the process that technology education teachers can implement for rewarding research.

References

Calhoun, E. F. (2002). Action research for school improvement. *Educational Leadership, 59*(6), 18–24.

Hendricks, C. (2009). *Improving schools through action research: A comprehensive guide for educators* (2nd ed.). Upper Saddle River: Pearson.

Hine, G. S. C., & Laverty, S. D. (2014). Action research: Informing professional practice within schools. *Issues in Educational Research, 24*(2), 162–173.

Johnson, A. P. (2012). *A short guide to action research* (4th ed.). Upper Saddle River: Pearson.

Martin, G., & Ritz, J. (2012). Research needs for technology education: A U.S. perspective. *Journal of Technology Education, 23*(2), 25–43.

Mills, G. E. (2014). *Action research: A guide for the teacher researcher* (5th ed.). Boston: Pearson.

Mitchell, S. N., Reilly, R. C., & Logue, M. E. (2009). Benefits of collaborative action research for the beginning teacher. *Teaching and Teacher Education, 25*, 344–349.

Design and Technology in England: An Ambitious Vision Thwarted by Unintended Consequences

11

David Barlex

Abstract

The National Curriculum Design & Technology Working Group Interim Report (DES&WO, *National curriculum design and technology working group interim report*. London: HMSO, 1988) presented a description of the subject for inclusion in the first National Curriculum in England. This description was both complex and ambitious. The ways in which schools and teachers responded, as revealed by the reports of Her Majesty's Inspectorate, indicates that it was perhaps over-ambitious and recently the subject can be seen to be in decline. This has been exacerbated, if unintentionally, by recent government policy concerning accountability measures and attempts to privilege qualifications in those academic subjects needed for entry into Higher Education. Most recently there have been attempts to revive its fortunes through the introduction of a newly formulated examination for pupils aged 16+ years and political intervention to reassess its academic worth.

Keywords

Design & technology • Curriculum • Policy

Contents

D. Barlex (✉)
University of Exeter Associate, Exeter, UK
e-mail: david.barlex@btinternet.com

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_11

Introduction

This chapter will chart of the journey of design & technology in England since its inception in 1990. It will use the National Curriculum Design & Technology Working Group Interim Report (DES&WO 1988) to set the scene, the reports of Her Majesty's Inspectorate to indicate how the subject has progressed and describe in some detail how recent government policy has shaped, and is continuing to shape, its current manifestation. Finally it will speculate briefly about the future of the subject.

In the Beginning – The Parkes Report

The government laid the foundations for design & technology in England in 1988 with the publication of the National Curriculum Design & Technology Working Group Interim Report (DfE&WO 1988). This report became known as the Parkes Report (a reference to Lady Parkes who chaired the working group) and was a seminal document giving the entire first chapter to a consideration of the contribution of design & technology to the school curriculum. The report justified the use of the term design & technology as follows.

> 1.5. . . . Our understanding is that whereas most, but not all, design activities will generally include technology and most technology activities will include design, there is not always total correspondence.
>
> 1.6 Our use of design and technology as a unitary concept, to be spoken in one breath as it were, does not therefore embody redundancy. It is intended to emphasise the intimate connection between the two activities as well as to imply a concept which is broader than either design or technology individually and the whole of which we believe is educationally important. (Page 2 DfE&WO 1988)

The report asked the key question "What is it that pupils learn from design and technological activities which can be learnt in no other way?" The immediate answer was enigmatic to say the least for many teachers.

> 1.10 In its most general form, the answer to this question is in terms of capability to operate effectively and creatively in the made world. The goal is increased "competence in the indeterminate zones of practice." (Page 4 ibid)

The report was clear with regard to the cognitive process involved in design & technology activity

> 1.12 As opposed to scientists, who are concerned to explore and understand what is, designers and technologists are concerned with what might be, the conception and realisation of "the form of things unknown." In describing their work, they talk of "seeing with the

> mind's eye." This is literally a visionary activity, a mode of thought which is non-verbal and which has been a characteristic of design and technology throughout history. Such imaging finds its representation in drawings, diagrams, plans, models, prototypes and computer displays and simulations, before its eventual realisation in a product, which may be an artefact, system or environment. (Page 4 ibid)

The report also stressed the importance of a consideration design & technology in society

> 1.14.... There is, however, an additional dimension to consider and this entails critical reflection upon and appraisal of the social and economic results of design and technological activities beyond the school. (Page 5 ibid)

Hence at the very outset we can see that the report argued for a combination of capability (designing and making) and perspective (considering the consequences of design & technological activity) (Barlex 2014).

Teachers experienced very real difficulties with teaching this new subject from the outset. Her Majesty's Inspectors of School's annual report for design & technology in 1990–1991 (DES&WO 1992) commented on a decline in pupils' ability to design and make since the introduction of the National Curriculum, particularly in the 11–14 age range.

The Report suggested five attainment targets (ATs) to assess a pupil's progress in the subject:

AT1 Explore and investigate contexts for design and technological activities
AT2 Formulate proposals and choose a design for development
AT3 Develop the design and plan for the making of an artifact or systems
AT4 Make artifacts and systems
AT5 Appraise the processes, outcomes, and effects of design and technological activities

Each AT was eventually given a set of descriptions across eight levels of performance. It is important to note that none of these ATs assess a pupil's knowledge; only what he or she might do with any knowledge they possess. This is consistent with the working party's view that the defining feature of design & technology is "taking action." The number of ATs led to considerable confusion. It was possible for pupils to evidence performance in each of the ATs at different levels of performance. How would these be combined to give an overall level of attainment? Many teachers were confused with regard to the difference between the ATs and the associated program of study. It was not uncommon to hear a teacher tell a class "Today we are doing AT1" (Barlex 1990). Eventually this situation was resolved through a series of amendments to the National Curriculum Orders for the subject so that by 1999 there was just a single AT for the subject with eight level descriptors plus a program of study which in addition to identifying significant processes also included knowledge and understanding statements for materials and components, systems and control and structures. A victim of this conflation of ATs was the significance of design & technological perspective. The level descriptors concentrated almost exclusively on procedural competence in designing and making as the descriptor for Level 6 (the attainment of an average 14-year-old) indicates (DfEE &QCA 1999):

> Level 6
>
> Pupils draw on and use a range of sources of information, and show that they understand the form and function of familiar products. They make models and drawings to explore and test their design thinking, discussing their ideas with users. They produce plans that outline alternative methods of progressing and develop detailed criteria for their designs and use these to explore design proposals. They work with a range of tools, materials, equipment and processes and show they understand their characteristics. They check their work as it develops and modify their approach in the light of progress. They evaluate how effectively they have used information sources, using the results of their research to inform their judgements when designing and making. They evaluate their products as they are being used and identify ways of improving them. (ibid Attainment Target Appendix)

Hence the curriculum value of the subject became advocated and justified mainly on its procedural focus, because the activity of designing and making was seen as highly significant in itself.

> The process of trying to create change requires pupils to engage in a challenging, enriching empowering activity. (Kimbell et al. 1996, p. 29)

The products of learning design & technology are:

> . . .not to be seen as the artefacts that learners produce, be they novel furniture, computer mouses, hats or control systems. The real products of design & technology are empowered youngsters; capable of taking projects from inception to delivery; creatively intervening to improve the made world . . . (Kimbell and Perry 2001, p. 19)

This focus on procedural competence, the “can do” implicit in the subject, clarifies to a large extent the phrase in the Parkes Report “competence in the indeterminate zones of practice.”

In 2004 a seemingly innocuous change in the status of design & technology had far-reaching effects. The government of the day classified English, mathematics and science as core subjects, compulsory for all young people until the age of 16 year, and the other National Curriculum subjects as noncore foundation subjects (DfES & QCA 2004). All pupils were “entitled” to study noncore foundation subjects, schools had the obligation to provide such subjects in their curriculum but young people were not compelled to study them. They could opt out. This signaled the beginning of a steady decline in the uptake of the subject.

The Position of Ofsted

The commentary from the Office for Standards in Education (Ofsted) in England almost since the introduction of design & technology into the National Curriculum has been that the teaching of designing has been much less successful than the teaching of making. Over the first 10 years Ofsted consistently reported that skills in designing lagged behind those in making (Ofsted 1998, 2000). Peter Toft (2007), a senior HMI writing in his own capacity, indicated that little changed in the following 7 years.

> Nevertheless, our inspection evidence shows a continuing need to improve the teaching of designing in many schools, as well as a need to improve the way it is externally examined. (p. 279)

The Ofsted report for design & technology covering the years 2007–2010 indicated little progress in the next 3 years.

> However, the quality of teaching about design in secondary schools generally did not enable pupils to evaluate critically and question what they see around them in order to challenge stereotypical and poor design. (Ofsted 2011, p. 6)

The most recent Ofsted pronouncement on design & technology has come from Diane Choulerton (2015), the National Lead for the subject, through a keynote lecture she gave at the Design & Technology Association Summer School in July 2015. She made several interesting and telling points as summarized below.

Curriculum challenge
: It is essential to maintain a balance between procedural knowledge (knowing how) and conceptual knowledge (knowing that) in enabling students to be creative.

Curriculum weakness
: At Key Stage 3 (pupils aged 11–14 years) the curriculum consists of heavily guided making tasks with very limited opportunities to design in 3D. There were very few opportunities to engage in an iterative design process. Disturbingly students are often doing the same projects as their parents did! GCSE teaching focused on ensuring folder content meets grade criteria with controlled assessment taking up most of the course. Electronics and robotics were nowhere to be seen.

Uptake
: The uptake of the subject for students aged 14–16 years is cause for concern. The overall numbers taking GCSEs in the subject while high are falling and this has been a trend since 2007 which shows no sign of changing. In 2008 just over 52% of the total national cohort were taking D&T GCSE; by 2014 this had fallen to 35% of the cohort. The uptake of "modern" D&T GCSE; systems and control and electronic products is particularly low standing at under 2% in 2014.

Performance
: The performance of students at GCSE compared with other subjects is also a cause for concern. Typically students make less progress from starting points in D&T than most other subjects. Disadvantaged students typically make less

progress than nondisadvantaged students, in particular the most able. There is a gender progress gap with girls typically making much better progress than boys.

Workforce

Teacher recruitment is low.

There is the need for significant CPD in both subject knowledge and pedagogy to modernize the subject.

Perception

Key stakeholders do not understand the subject.

As a state of the nation address this might be paraphrased as "naught for your comfort." The high expectations of the Parkes Report and the Design & Technology National Curricula that followed have not been met. This possibility of this was made early on by David Layton (1995) when he warned:

> It would be sad if an exciting and radical curriculum innovation, potentially of great significance, should collapse under the weight of the unrealistic responsibilities being placed upon it. (p. 115)

The Impact of a New Government in 2010

In 2010 the general election in England led to the formation of a coalition government in which Michael Gove was the Minister of Education. In 2011 he appointed an expert panel to decide on a new National Curriculum. The brief for the expert panel was:

> To advise and make recommendations to the Department on the essential knowledge (e.g. facts, concepts, principles and fundamental operations) that children need to be taught in order to progress and develop their understanding in English, mathematics, science, physical education and any other subjects which it is decided should be part of the National Curriculum. (Department for Education 2012)

The advice of the expert panel did not make comfortable reading for design & technology. They advised that the subject should be classified as a basic subject. This meant that schools would be required to teach the subject but there would be no statutory program of study and the schools would be able to determine the specific nature of this provision for themselves. The panel cited weak epistemological roots and a lack of disciplinary coherence as reasons to downgrade the subject design & technology and remove it from the National Curriculum (DfE 2011, foot note 58). The Design and Technology Association mounted a robust campaign to defend the position of the subject as worthy of inclusion in the National Curriculum and the government rejected the advice of the expert panel and included the subject in the National Curriculum. The Design & Technology Association constituted a small committee of advisers to work in complete confidence with the Department for Education to produce a draft program of study as guidance to the Minister. After several months of close confidential consultation, the Association provided the Minister with an advisory document in November 2012. Richard Green, Design & Technology Association CEO, was both disappointed and annoyed when the program of study announced by the Minister for consultation in February 2013 bore no relationship to the advice provided. In his view it was such a hotchpotch of miscellaneous and unconnected content that it seriously lacked disciplinary coherence and compounded the Expert Panel view of weak epistemology (Green 2013). The community of practice was incensed. Some of the anger was directed at the Association for maintaining the confidentiality requested by the DfE but which, to the community, appeared to be keeping developments secret. It was pointed out that the transparent approach taken by those responsible for computing science had led to a program of study much more in line with their views. Of course there was immediately extensive lobbying for the suggested program of study to be completely scrapped. Dick Olver, chairman of BAE Systems, one of the UKs biggest companies, was particularly critical. Olver, who is also chair of E4E, an organization of 36 engineering institutions, said the draft proposals for design & technology did "not meet the needs of a technologically literate society. Instead of introducing children to new design techniques, such as biomimicry (how we can emulate nature to solve human problems), we now have a focus on cookery. Instead of developing skills in computer-aided design, we have the introduction of horticulture. Instead of electronics and control, we have an emphasis on basic mechanical maintenance tasks," he told a conference of educators in March 2013. "In short, something has gone very wrong" (Olver 2013).

The result of such outspoken and authoritative criticism was that Elizabeth Truss (Parliamentary Undersecretary of State at the Department for Education) invited the Royal Academy of Engineering and the Design & Technology Association to develop more advice and guidance. Time was very short and there was less than 1 week in which to prepare this advice. The process that took place was transparent and collegial. Some 50 members of the design & technology community were invited to a 1 day seminar at the Academy to develop further a working draft prepared in advance by a small working party. This group was constrained by the view of the association that the minister's insistence that cooking should be included in the program of study for design & technology should not be challenged. (The impact of this on the future of food technology as part of design & technology is dealt with in ► Chap. 23, "Food in the School Curriculum: A Discussion of Alternative Approaches" of this book)

By the end of the day the group had developed a six-page document detailing a program of study for design & technology for Key Stage 1, Key Stage 2, and Key Stage 3 along with a purpose of study statement and a set of aims. The document was further developed by a smaller group from the Royal Academy of Engineering and the Design & Technology Association and then circulated to all those who had attended the seminar to gain approval that this revised document be submitted to the minister. There was still significant dissatisfaction with the inclusion of cooking but the remainder of the document was such an improvement on the program of study suggested by the minister in February that the majority supported its submission to the minister. There are indications that the minister took note of the submission in her answers given to questions in the House of Commons on Tuesday 23 April 2013 although she remained intransigent on the place of cooking as this extract from the parliamentary proceedings shows.

> **The Parliamentary Under-Secretary of State for Education (Elizabeth Truss):** Following the national curriculum consultation period, which closed on 16 April, we are considering the responses received. We have been engaging with leading figures in industry, such as Dick Olver and Sir James Dyson, schools and academia to ensure that we have world-class design and technology education. We are also committed to providing a curriculum that ensures children receive high-quality cookery teaching and understand the importance of a healthy lifestyle. Hansard 22 April 2013 Column 633

The resulting program of study was published in July 2013 (DfE 2013a) and two points are particularly noteworthy. First, as with all other subjects the attainment targets have been removed and replaced with the statement

> By the end of each key stage, pupils are expected to know, apply and understand the matters, skills and processes specified in the relevant programme of study. ibid page 192

This was in response to the advice of the Expert Panel and the views of Tim Oates (Oates 2014) in particular that assessment should be made in relation to the teaching intention not to a generalized statement of overall performance. Second that there is a separate section entitled Cooking and Nutrition for each Key Stage within the program of study in addition to the other parts of the document entitled Design, Make, Evaluate and Technical knowledge. This has led to food receiving less attention as a material with which to design and make particularly for pupils aged 11–14 years.

The Impact of Government Accountability Measures

In October 2013 the government introduced four new accountability measures (DfE 2013b) which schools are required to publish on their websites so that parents could see how well a school was performing.

The first was Progress across a suite of eight subjects (known as Progress 8). This was devised to show whether pupils performed better than expected at the end of Key stage 4 considering their starting point. Key stage 2 results (for pupils aged 11 years as they are about to leave primary school) are used to predict each pupil's likely grades across eight subjects at the end of Key stage 4. The second was Attainment across eight subjects (known as Attainment 8). This was devised to show the school's average grade across the same suite of eight subjects as the progress measure. This was expected to show achievement across a broad curriculum in a clear way. The third was the percentage of pupils achieving a C grade or better in English and mathematics. This was devised to show whether pupils achieved a good level in the most important subjects.

The fourth was the English Baccalaureate (EBacc) which is not a qualification in its own right. It has been established to provide information to parents, and others, about the achievements of pupils in a core set of academic subjects which are shown to enhance the chances of progressing on to further study. To meet EBacc criteria, a pupil must have obtained a grade A* to C in English, maths, two sciences, history or geography (referred to as humanities), and an ancient or modern foreign language. This accounts for five of the subjects making up the suite of subjects in Progress 8 and Attainment 8 leaving three slots that can be taken up by further qualifications from the range of EBacc subjects, or any other high value arts, academic, or vocational qualification. English Literature counts in this group of subjects. The good news for design & technology is that it counts within the high value academic qualifications. The bad news for design & technology is that the way this plays out in the choices that schools offer pupils aged 14 is that the subject often finds itself in a single option column competing with subjects such as art, art and design, music, and drama. Nick Gibb (2015a) has argued that the structure of these accountability measures are in place to help the most disadvantaged young people:

> If we are to deliver a fairer, more socially mobile society, we must secure the highest standards of academic achievement for all young people, and especially those from the least advantaged background.

And of course this argument is not confined to those on the right in politics. Diane Abbott (2013) a prominent left wing MP offers an almost identical argument

> Precisely if someone is the first in their family to stay on past school leaving age, precisely if someone's family does not [have] social capital, and precisely if someone does not have parents who can put in a word for them in a difficult job market, they need the assurance of rigorous qualifications and, if at all possible, core academic qualifications.

The unintended consequence of this attempt to achieve social justice is that it is likely to limit even further the number of young people that study design & technology to the age of 16 years. However, it would be unfair to blame the decline in numbers solely on these accountability measures. They may have exacerbated the trend but, as Alison Hardy (2016) has pointed out, other subjects have not suffered such a decline. In 2015 Religious Education had almost 300,000 entries, the highest level since 2002, art & design subjects were up by 1.7% to almost 200,000 and music was up by 2.2% to almost 50,000. To put it bluntly as a head of department recently said to the author, "D&T really does need to stop whingeing and up its game if it is to reverse this trend and increase its popularity" (Barlex 2016). A reformation of the public examination in the subject was considered as the means to achieve this and will be considered in the next section.

The Impact of Public Examination Reform

Not content with rewriting the National Curriculum and changing the way pupils were to be assessed Michael Gove also initiated a revision of the public examinations pupils took at ages 16 and 18. He used the argument of grade inflation indicating a serious fall in standards to justify this policy. Inevitably this led to a revision of the design & technology GCSE (the examination taken by pupils aged 16 years). As part of this reform the Department for Education were keen to eliminate the highly fragmented nature of the subject with its focused area based GCSEs – food, textiles, graphic products, resistant materials, product design, electronic products, system and control, etc. The civil servants argued that this was one of the main reasons stakeholders were confused as to the nature of the subject. What was it about – cooking, woodwork and metal work, dressmaking, engineering, designing? The policy coming from the Minister for Schools, Nick Gibb, was that it should be a single subject to achieve clarity. As progress was being made to reducing the fragmentation he is reputed to have asked his civil servants "Is it as hard as physics?" In response to this at the request of the civil servants Torben Steeg and David Barlex wrote him a briefing paper (Barlex and Steeg 2015) which argued that while it was different from physics, it was in its own way just as hard if not more so. This was well received by the minister and he has since gone on record singing the praises of the new GCSE that emerged (Gibb 2015b). However, there was a sting in the tail. He endorsed the position initially adopted by Elizabeth Truss in privileging the teaching of cooking and nutrition over the teaching of food technology as an aspect of design & technology and insisted that the new design & technology GCSE did not include food as a material. This could not be challenged and a separate working party under the leadership of Louise Davies, acting as an independent consultant for the DfE, developed a Food Preparation and Nutrition GCSE. This is discussed in depth in ► Chap. 23, "Food in the School Curriculum: A Discussion of Alternative Approaches" of this book. Ironically Louise was also the Food Technology consultant for the Design & Technology Association at this time.

The Department for Education published *Design & Technology GCSE subject content* (DfE 2015). This had been produced in consultation with senior figures in the design & technology community of practice including: Bob Welch (Senior LEA Adviser), Matt McLean (Head of Secondary Programmes (ITE) Liverpool John Moores University), Andrew Barker (James Dyson Foundation), David Barlex (Director Nuffield Design & Technology), Andy Mitchell and Richard Green of the Design & Technology Association, and Subject Officers from Awarding Organizations. It provided guidelines for the Awarding Organizations that would produce the new GCSE specifications. The document organized the content into two broad areas: technical principles and designing and making principles, required strong links with mathematics and science and introduced the idea of contextual challenges as the basis for assessed course work. For those who supported the move to a single subject not restricted to a single material area this framework was particularly welcome. The technical principles embraced a wide range of materials as well as up-to-date aspects of the subject, e.g., the impact of new and emerging technologies on society and the use of programmable components to embed functionality into products. The designing and making principles required user centered, context-based, iterative designing. The contextual challenges had to meet the following criteria:

- Offer a broad range of real-world contexts, representing contemporary issues and concerns
- Be open-ended, avoiding predetermining the materials or processes to be used to achieve a design solution
- Focus on needs, wants, and values of individuals and groups, leading students to address problems and/or opportunities
- Be accessible and relevant to the full range of design and technology materials and components outlined in the technical principles
- To many this framework marked a welcome return to the original intentions of the Parkes Report (DfE 1988)

At the same time the Office of Qualifications and Examinations Regulation (Ofqual) produced a framework for the assessment to be used (Ofqual 2015). This required that candidates tackle a contextual challenge as course work to be assessed (known as non examined assessment or NEA, worth 50% of the marks) and a 2 h written paper (worth 50% of the marks). There were four assessment objectives as shown in Table 1.

As with the content stipulations from the DfE these are in strong accord with the original intentions of the Parkes Report (DfE 1988).

At the time of writing the Awarding Organizations have just submitted draft specifications to Ofqual. These are available for all to see on the organization's websites. As one might expect there are significant differences between those organizations which have embraced the spirit of modernization driving the move to a single subject and those adopting a minimal change position. The final specifications will be made available to schools in September 2016, to be taught from September 2017 with the first assessment 2 years later in 2019. Hence, there is some time to go before there will be any indications of the uptake and success of this attempt to modernize the subject or the extent to which teachers have opted for those specifications which have grasped the modernization nettle as opposed to keeping to the previous focus area approach as far as possible.

The Future

What does the future hold for the subject? One way to explore this is through scenario building using so-called critical uncertainties. I will build four possible scenarios by using as one uncertainty the extent to which D&T modernizes and as the other uncertainty the extent to which design & technology is seen as a vocational option for the few or as general education for all. This is shown diagrammatically in Fig. 1.

Each of these scenarios has implications for both physical and human resources.

In the scenario in which the subject modernizes but is seen as vocational, the design & technology curriculum would apply to a minority of students, and hence teachers, but could not be achieved without an upgrade in school facilities or related

Table 1 GCSE design & technology assessment overview

	Objective	Weighting (%)	NEA (%)	Written paper (%)
AO1	Identify, investigate, and outline design possibilities to address needs and wants	10	10	0
AO2	Design and make prototypes that are fit for purpose	30	30	0
AO3	Analyze and evaluate Design decisions and outcome, including for prototypes made by themselves or others Wider issues in design and technology	20	10	10
AO4	Demonstrate and apply knowledge and understanding of Technical principles Designing and making principles	40	0	40
	Totals	100	50	50

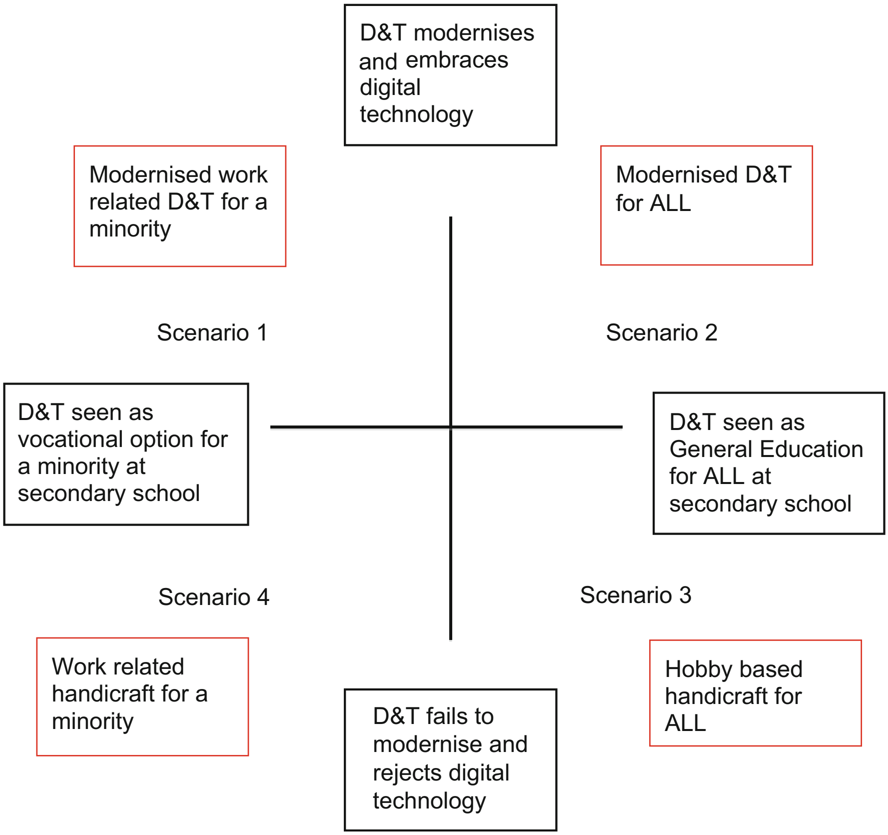


Fig. 1 Possible scenarios for the future of design and technology

professional development for teachers on a small scale. In the scenario in which the subject does not modernize and is seen as vocation, the curriculum would embrace work related handicraft for a minority of students and teachers and would require very little if anything in the way of facility upgrade or professional development. In the scenario in which the subject does not modernize but is seen as part of general education for all, a majority of students and their teachers would be involved in hobby-based handicraft and this would require little if anything in the way of facility upgrade or professional development. The scenario, in which the subject modernizes and is seen as part of general education for all, would apply to the majority of students and teachers. It would require upgrade of school facilities and professional development on a large scale.

As one might expect, the Design and Technology Association is committed to this last scenario. However, the Association is in no way complacent as to the difficulties that need to be overcome to achieve this. The Chief Executive of the Association Richard Green (Green 2016) has likened the current situation of the subject to a perfect storm; the coming together of a crisis in teacher recruitment, the impact of the removal of local authority support for the subject, the demise of established models of high-quality teacher education, the unintended consequences of accountability measures all contributing to the detriment of the subject with the possibility that its continuation in schools is threatened. To combat this situation the Association is proposing a major initiative, D&T2020, which intends to establish regional networks, each coordinated by a subject adviser, providing on line and face-to-face CPD provisions, developing the high-tech curriculum and the subject's contribution to STEM – securing the place of design & technology in the curriculum as a valued subject that meets the twenty-first century needs of young people, industry, and the nation. There is little doubt that this is a highly ambitious undertaking and it will certainly depend on attracting significant funding from key stakeholders in industry and government.

In the early years of the National Curriculum, there was significant ministerial support for design & technology. Charles Clarke when Minister for Education was instrumental in gaining support for CPD concerning CADCAM (PTC 1999) and in 2001 David Sainsbury (Parliamentary Undersecretary for Science and Innovation) with Baroness Ashton (Parliamentary Undersecretary for Early Years and Schools Standards) supported the Young Foresight Initiative which then became included in *Key Stage 3 National Strategy* (Department for Education and Skills 2004). Since those times ministerial support and involvement have waned but it appears there is renewed interest. This is indicated by the current Minister for Schools engagement with and endorsement of the new GCSE in D&T (Gibb 2015b) and most recently in the work of Michelle Donelan MP who intends to send a letter to the prime minister arguing for the new design & technology GCSE to be included within the English Baccalaureate (Donelan 2016). If successful this would remove the temptation for schools to marginalize the subject in response to accountability measures.

To some extent the subject has come full circle. Failure to meet the high aspirations of the Parkes Report compounded by legislative changes and accountability policies with unintended consequences have led to the subject being in the "last chance saloon" on several occasions in the last few years. However the new single title GCSE, renewed ministerial support and lobbying from a highly proactive and supportive MP signals that the future may be brighter than one might expect. The visionary foundations and direction laid down in the Parkes Report have stood the test of time and are being revisited. The Design & Technology Association is making determined efforts to ensure that the subject reflects these and that teachers are given the tools to teach effectively and gain significant stakeholder approval.

What lessons can be learned from the experience of design & technology in England? The introduction of any new subject into the curriculum, albeit one with roots in previously existing subjects will be fraught with difficulty unless certain conditions are met. The first condition is the availability of sustained and substantial in-service training for the teachers who will be required to teach the subject. In the case of design & technology in England, this was not the case. The provision was at best limited and fragmentary and not universally available. The second condition must be realistic ambition for the new subject; the Parkes Report is without doubt visionary and challenging but without the necessary in-service provision its intentions are unlikely to be met. Third it is essential that those responsible for the subject are effective in communicating its identity as a coherent assembly of knowledge, understanding, skill, and values. Until recently those responsible have failed to do this. Fourth it is essential that those responsible for the subject are vigilant in maintaining a strong rationale for its role in the education of ALL young people so that the subject is not misrepresented as suitable only for the less academic or as a vocational option for the few. This is still contested territory in many schools.

Conclusion

The slow demise of design & technology through the unintended consequences of a range of government education policy initiatives is a sorry tale and serves as a warning to those who are concerned with or taking part in curriculum development. Decisions at a high level of general educational policy intended to enhance social justice can have significant impacts beyond their intended benefit. This has been the case in England for the school subject design & technology leading to a significant and on going decline in the numbers of young people aged 14 – 16 years studying the subject.

Future Directions

The reversal of this trend will be a major task for the whole community of practice working with the Design & Technology Association. In February 2017 Richard Green retired as the CEO and the leadership of the Association was taken over by Julie Nugent. Julie has twenty years leadership experience across education, employment and skills, with senior roles held in government and the college sector. The direction in which she will take the subject is still unclear but an important dimension of this task will be to reinstate its significance in the general education of young people aged 14 – 16 years.

References

Abbott, D. (2013). Reported at this url http://www.theguardian.com/politics/blog/2013/jun/11/michael-gove-gcse-reform-live-blog#block-51b71d28e4b0f749db72ad8c. Accessed 28 June 2016.

Barlex, D. (1990). Anecdotal evidence gathered by Field Officers from the Nuffield Design & Technology Project.

Barlex, D. (2014). Developing a technology curriculum. In J. Williams, A. Jones, & C. Bunting (Eds.), *The future of technology education* (pp. 143–167). Springer.

Barlex, D. (2016). Private conversation with a head of department at an independent school which is renowned for its success design & technology curriculum at both GCSE and GCE.

Barlex, D. & Steeg, T. (2015). Design & technology – As hard as physics? A briefing paper for the Minister available at this url https://dandtfordandt.files.wordpress.com/2015/06/dt-gcse-briefing-for-minister.pdf. Accessed 28 June 2016.

Choulerton, D. (2015). The current state of design & technology. Available at this url http://www.slideshare.net/Ofstednews/design-and-technology-association-data-summer-school-keynote-2015. Accessed 28 June 2016.

Department for Education (DfE). (2011). *The framework for the national curriculum. A report by the expert panel for the national curriculum review*. London: Department for Education.

Department for Education (DfE). (2012). *Expert Panel Terms of reference* can be found at this url http://www.education.gov.uk/schools/teachingandlearning/curriculum/nationalcurriculum/a0073091/expert-panel-terms-of-reference. Accessed 28 June 2016.

Department for Education (DfE). (2013a). *The national curriculum in England framework document July 2013*. London: Department for Education.

Department for Education (DfE). (2013b). Reforming the accountability system for secondary schools. DfE. Available at this url https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/249893/Consultation_response_Secondary_School_Accountability_Consultation_14-Oct-13_v3.pdf. Accessed 28 June 2016.

Department for Education (DfE). (2015). *Design and technology GCSE subject content*. London: Crown copyright.

Department for Education and Employment & Qualifications & Curriculum Authority (DfEE & QCA). (1999). *Design and technology the national curriculum for England*. London: Crown copyright.

Department for Education and Science and Welsh Office (DfE&WO). (1988). *National curriculum design and technology working group interim report*. London: HMSO.

Department of Education and Science & Welsh Office (DEF&WO). (1992). *Technology key stages 1, 2 and 3. A report by HM Inspectorate on the first year, 1990-91*. London: HMSO.

Department for Education and Skills (DfES). (2004). *Key stage 3 national strategy foundation subjects design and technology framework and training materials*. London: HMSO.

Department for Education and Skills & Qualifications & Curriculum Authority (DfES & QCA). (2004). *The school curriculum and the National Curriculum*. London: Crown copyright.

Donelan, M. (2016). The letter Michelle Donelan intends to send to the prime minister is available at this url https://www.data.org.uk/media/1772/prime-minister-letter-re-dt-ebacc.pdf. Accessed 28 June 2016.

Gibb, N. (2015a). The social justice case for an academic curriculum. Available at this url https://www.gov.uk/government/speeches/nick-gibb-the-social-justice-case-for-an-academic-curriculum. Accessed 28 June 2016.

Gibb, N. (2015b). New design and technology GCSE will inspire next top designers. Available at this url https://www.gov.uk/government/news/new-design-and-technology-gcse-will-inspire-next-top-designers. Accessed 28 June 2016.

Green, R. (2013). Private communication with the author.

Green, R. (2016). Comments made at the future of design & technology meeting at the Royal Society of Arts and Manufacturing 24 May 2016, London.

Hansard. 22 April 2013. Column 633 available at this url http://www.publications.parliament.uk/pa/cm201213/cmhansrd/cm130422/debtext/130422-0001.htm#1304228000022. Accessed 28 June 2016.

Hardy, A. (2016). Why has the number of teenagers taking design and technology GCSE dropped? Available at this url https://theconversation.com/why-has-the-number-of-teenagers-taking-design-and-technology-gcse-dropped-46361. Accessed 28 June 2016.

Kimbell, R., & Perry, D. (2001). *Design and technology in a knowledge economy*. London: The Engineering Council.

Kimbell, R., Stables, K., & Green, R. (1996). *Understanding practice in design and technology*. Buckingham: Open University.

Layton, D. (1995). Constructing and reconstructing school technology in England and Wales. *International Journal of Technology and Design Education, 5*, 9–118.

Oates, T. (2014). Tim Oates talks about assessment without levels available at this url https://www.youtube.com/watch?v=-q5vrBXFpm0

Office for Standards in Education. (1998). *Secondary education-a review of secondary schools in England 1993–1997*. London: The Stationary Office.

Office for Standards in Education. (2000). *Ofsted subject reports secondary design and technology, 1999–2000*. London: The Stationary Office.

Office for Standards in Education. (2011). *Meeting technological challenges design and technology in schools 2007–10*. London: The Stationary Office.

Office of Qualifications and Examinations Regulation (Ofqual). (2015). *GCSE engineering, GCSE, AS and A level design and technology consultation on conditions and guidance*. London: Crown copyright.

Olver, R. (2013), 1 April. Quoted text from a conference in March 2013, reported in the Guardian. Available at: http://www.theguardian.com/education/2013/mar/31/school-curriculum-cookery-horticulture-before-technology. Accessed 28 June 2016.

PTCE. (1999). The website contains details of the launch of the CADCAM pilot project supported by Charles Clarke, Parliamentary Under Secretary of State for the Department for Education and Employment at this url http://support.ptc.com/company/news/press/releases/19990614dfee1.htm. Accessed 28 June 2016.

Toft, P. (2007). Design & Technology: Seeing both the wood and the trees. In D. Barlex (Ed.), *Design and technology for the next generation*. CliffeCo: Shropshire.

12 Technology Education in the New Zealand Curriculum: History and Rationale

Louise Milne

Abstract

The implementation of technology education in the New Zealand school curriculum has undergone a challenging and extensive period of research, consultation, development, program trials, and curriculum review, culminating in the publication of the 2007 curriculum. This chapter outlines a history of technology education in New Zealand from the very early days of technical education in the 1900s, through to the development of the 1995 and the 2007 technology education curriculum. A brief reflection on the origins of technology is included, followed by an overview of the philosophy of technology and how the beliefs and visions of researchers and curriculum developers have formed and shaped the 2007 New Zealand technology education curriculum. While there may have been missed opportunities along the way, there is much to celebrate. In the immediate future the successes of this forward thinking and exciting subject require further consolidation and a determined effort from the technology community to continue to develop and promote technology education through the opportunities which are presenting in New Zealand in 2016 – and whatever may follow.

Keywords

Curriculum • History • Manual • Technical • Technology • Technology education • TENZ (Technology Education New Zealand) • Techlink

L. Milne (✉)
Faculty of Education, University of Waikato, Hamilton, New Zealand
e-mail: louisem@waikato.ac.nz

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_10

Contents

Introduction

What we now understand as the nature and practice of technology had its beginnings in the discoveries of our very earliest ancestors. Moiduser (2009) argues that technology "is a defining characteristic of humankind" (p. 392) and refers to the early work of Ortega y Gasset (1941, p. 96) stating that "Man [sic] without technology – this is, without reaction upon his medium – is not man." In the mid-1970s, the British Broadcasting Corporation published a book based on the television series entitled *The Ascent of Man*. The author, Jacob Bronowski, a British mathematician and biologist, referred to early man as "a shaper of the landscape," having "imagination, reasoning, emotional subtlety and toughness – not accepting the environment but changing it" (Bronowski 1973, p. 19). Survival of early hominid species depended on their ability to adapt to changing climatic conditions, to draw on knowledge of the environment and available resources, and be guided by the cultural practices of the time to solve problems and address needs (Moiduser 2009). It was the ability of these early species to combine the dual knowledges of "know-that," recognizing that a problem exists, and "know-how," knowing how to solve the problem, that defines what it is to be human (Hope 2009).

Together, these beliefs give credence to Moiduser's (2009) argument to teach and learn technology not only from a socio-technological perspective but also from a cognitive/epistemological perspective. As inhabitants of the twenty-first century, we live in a "technology saturated" environment and it is essential to provide students with the knowledge and skills that will equip them to participate in society as citizens who understand, and have experienced, technology as a field of human activity (Ministry of Education 2007).

In Australia and New Zealand, children enter early childhood centers at the age of three or four years, with a predisposition to include technological practice as part of their collaborative play (Mawson 2011). Specifically, and without adult supervision, these children are able to identify a need, find resources, develop a final outcome, and offer suggestions as to its fitness for purpose (Milne 2002). In effect, these very young students are already responding to their natural desires to manipulate and change their environment. It is a natural continuation, therefore, to develop programs for primary school education that acknowledge and build on these students' preschool experiences and provide them with the skills and opportunities to experience and experiment with the "made" world that they inhabit.

The Philosophy Informing Technology in the New Zealand Curriculum

The relatively "young" philosophy of technology, as described by de Vries (2005) is like "a mosaic of many different ideas and suggestions" (p. 7). Of particular significance in the practice of technology and technological development are the divisions described by Carl Mitcham (1996). He describes technology as objects or artifacts, technology as knowledge, technology as activity, and technology as volition – activity that is fundamental to being human.

These categories, illustrated in Fig. 1, are widely accepted and form the basis of a number of scholarly publications. For example, de Vries (2012) describes similar categories but includes a focus on values as a component of volition. Jones et al. (2013) further investigate this fourth category describing technology "as a characteristic of humanity." These categories provide the foundational structure of the strands and achievement objectives of the 2007 New Zealand technology curriculum, however arriving at this point took a long, and at times, tortuous route.

Figure 2 shows something of this journey stretching from the mid-1880s and the colonization of New Zealand by British settlers, through to the Education Act of 1914 which aimed to provide a more liberal syllabus for schools and better reflect the needs of a new and fast growing society (Egdell 1966). The Manual and Technical Instruction Act that was passed into law in 1900 was a significant development, offering the children of laborers and farm workers the opportunity to incorporate practical, skill-based programs into their schooling, and to prepare them for manual and trade employment once they left school. By the 1940s, subjects such as woodwork, metalwork, sewing, and cooking had been introduced for 13–15 year olds (Jones 1997). The development of technical skills was at the center of these subjects, and while a new focus on design emerged in the publication of the Workshop Craft and Home Economics syllabus in 1986, the focus on skills-based programs continued strongly and failed to significantly embrace the changing needs of a modern New Zealand society.

The publication of the first technology education curriculum in 1995 sought to bring about significant change. It aimed to implement a curriculum that had equal

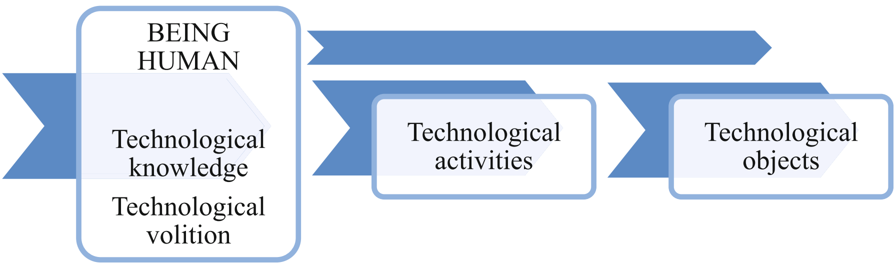


Fig. 1 Modes of manifestation of technology (Mitcham 1996, p. 160)

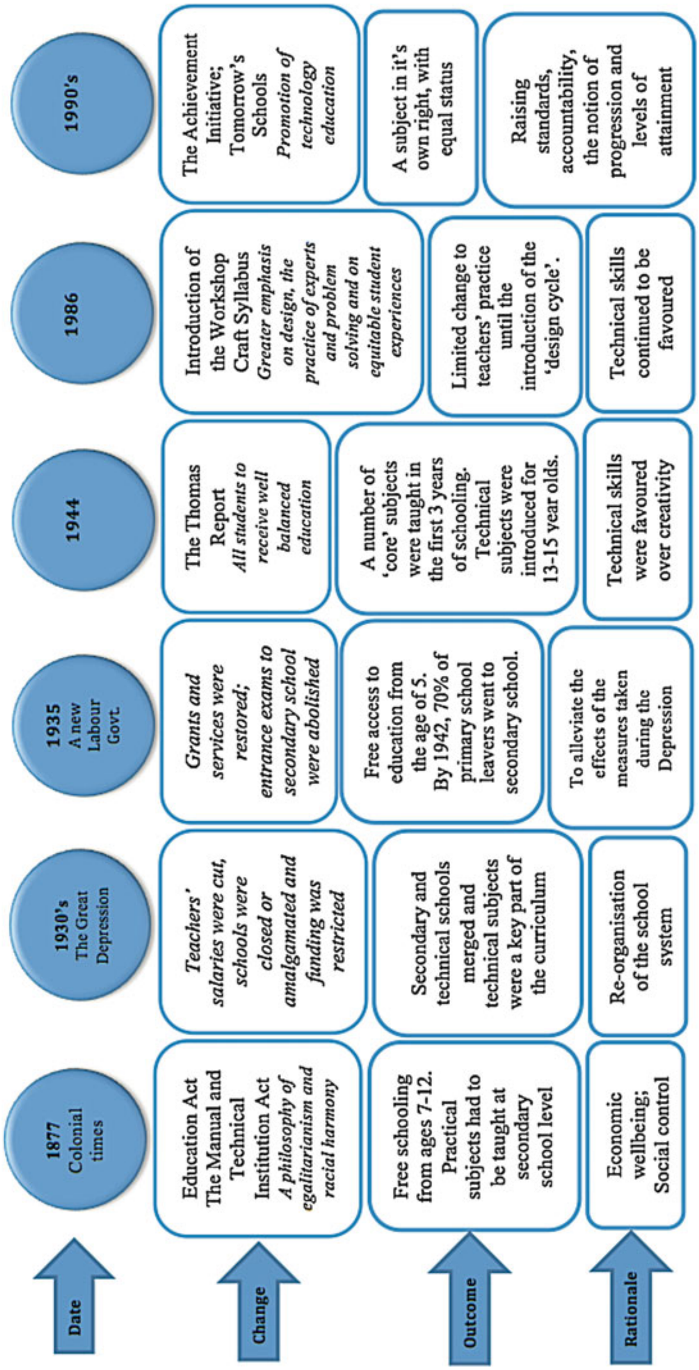


Fig. 2 The introduction of technical subjects into the New Zealand educational system

status with other learning areas, which offered a high level of intellectual rigor, and a practical capability for citizenship (V. Compton 2001).

The development of a policy framework for this new curriculum was contracted to the Centre for Science and Mathematics Education Research Centre [CSMER] at the University of Waikato by Ministry of Education. In order to fulfill the contract requirements, CSMER consulted widely and investigated best practice both nationally and internationally. The policy framework was required to be consistent with other government policies in education and to take account of the available resources in schools, current research informing teacher change and professional development, and where possible, to provide a number of implementation options that would best suit the diverse range of teachers participating in the programs (Jones 2003). A strength of this development was the extensive consultation that took place with professional technologists, teacher unions, practicing teachers, and professional organizations such as Workshop and Graphics Teachers and the New Zealand Association of Science Teachers. Jones (2003) describes this as an “eclectic mix” (p. 6) but one which attempted to gain broad ranging views to inform the development of this new curriculum.

Building on the resulting policy framework, CSMER was then contracted to develop the first draft technology curriculum. This was put out for discussion in 1993 and was trialed in schools in 1994 (Williams and Jones 2015). Again, an extensive consultation phase was undertaken and the feedback from interest groups allowed for a slightly more streamlined and focused outcome. The final curriculum which aimed to develop students’ technological literacy was published in 1995 and became one of eight compulsory core subjects in 1999. Technology education was described as:

> a planned process designed to develop students’ competence and confidence in understanding and using existing technologies and in creating solutions to technological problems. It contributes to the intellectual and practical development of students, as individuals and as informed members of a technological society (MoE 1995, p. 7).

The learning theories upon which this curriculum was based pointed to a curriculum that was to be pupil-centered, drawing on models of apprenticeship (Rogoff 1990), situated cognition (Brown et al. 1998) and learning through participation in communities of practice (Lave and Wenger 1991). Technology in the New Zealand curriculum was viewed as a human endeavor and the strengths and weaknesses of student performance were to be judged by the degree to which they could operationalize the three dimensions of the curriculum – technological knowledge and understanding, technological capability, and technology and society (Ministry of Education 1995).

This curriculum was to offer far more than the technical competency of the traditional technical subjects, it was also to develop a practical capability for citizenship (V. Compton 2001; Petrina 1992). This view linked directly with the Thomas Report of the postwar period (see Fig. 2) which advocated that patriotism and citizenship be fostered within education (Roth 1952). Education for citizenship was formally signaled in the New Zealand Curriculum Framework of 1993 when the secretary of education stated that "we need a workforce that is increasingly highly skilled and adaptable, and which has an international and multicultural perspective" (Ministry of Education 1993, p. 1). The interpretation of this through the learning areas of the curriculum presented no dominant view as such but rather common threads of creative problem solving, contributing to the future of society and the environment, and an awareness of the impact of global trends (Mutch 2005). Students were to be provided with the opportunity to study in a range of technological areas, and the focus of their work was to be positioned in a variety of relevant and authentic contexts (MoE 1995). Achievement objectives were to provide guidance for teacher planning and when considered together, were to give a structure to students' technological practice, and provide clearly defined levels of attainment and progression (see Fig. 2); they were to be "the vehicle that would enable students to develop their technological literacy" (V. Compton and France 2007, p. 2).

An emphasis on real-world contexts, the practice of experts, and the planning of coherent programs in technology education were central to the professional development that followed for teachers. "Authenticity" was a frequently used term to highlight the problems, needs, and opportunities that could form the basis of classroom programs, and a wide range of technological areas which were representative of the New Zealand context pointed the way for the diversity intended by the original policy statement. In the 1995 curriculum, these included materials technology, information and communication technology, electronics and control technology, biotechnology, structures and mechanisms, process and production technology, and food technology. Design was to be an integral part of students' technological capability and was to be integrated throughout the technology curriculum (Jones 2003).

It was recognized at this time that the professional development provided for both primary and secondary school teachers to support this new curriculum would be pivotal to the success of its implementation into New Zealand classrooms. The two programs that were developed including facilitator training and a resource package that were research informed, academic in nature, and presented over an extended time frame. These programs took into account past national and international research in teacher development, as well as technology education base line research carried out in New Zealand schools in 1995. This project referred to as the Learning in Technology Education project (LITE project) was funded by the Ministry of Education (Jones et al. 1995). Thirty facilitators were trained between 1995 and 1996, and according to the data collected over this period, "there was a high level of skill in both facilitation and programme development" (Jones 2003, p. 11) that was delivered to teachers during 1996 and 1997. Professional development programs were well funded, contracts were available in all regions in the country, and consisted in the initial phase, of up to 8 days' classroom release for participating teachers.

It was recognized early on that sustainable and enduring teacher change could take up to 2 years of in-depth and well-supported study and practice to generate a change in teaching practice (Moreland 1997). To rely wholly on what was provided by the Ministry of Education was considered unwise, and a professional association was established in 1995 to ensure continuity in the professional development of technology teachers. This became known as TENZ – Technology Education New Zealand, and its inaugural conference was held in Auckland in 1997 and has been held biennially since then. The current goals of TENZ aim to:

- Foster the development of Technology in the New Zealand curriculum
- Develop and maintain national and international links between those working in technology education and with the wider technological community
- Support professional, curriculum, and resource development in technology education
- Encourage research in technology education
- Organize a national technology education conference every 2 years (Ministry of Education 2010)

There was a level of autonomy in the way each professional development contract was delivered, which meant that "different regions experienced quite different professional development in technology and in some cases links to the 1995 technology curriculum were not a strong feature of the programme" (Jones and Compton 2009, p. 100). However, Ministry of Education contracts delivered nationally over the next few years attempted to gain greater consistency of delivery. Two programs of greatest significance were the Technology Education Assessment National Professional Development project and the Technology National Exemplar Project. The exemplar project was run across all learning areas and was met with considerable enthusiasm by the participating teachers and the facilitators who researched and negotiated models of development. A technology exemplar matrix to guide assessment was part of this project. This became a challenging time within the technology community with very diverse views being presented, and a lack of expertise and clarity from leadership groups as to the real direction and purpose of the models that were being developed. In the end, a huge resource that had drawn together all the energies and enthusiasm of a large group of researchers was sidelined and then discarded. It was a damaging phase within the new and fragile technology community and it took time to regroup and recover. However, the strength of shared knowledge and ongoing communication within the technology community emerged from this phase and the importance of supporting and growing the fledgling professional organization of TENZ strengthened. In 2004, the Ministry of Economic Development made available funding which was accessed to support technology education. This, as reported by Jones and Compton (2009), was used to set up the Growth and Innovation Frame – Technology Initiative, which became a highly valuable source of funding in technology education through to 2013. A number of professional development projects were established over this period, including the development of Techlink, an online portal for technology teachers and educators, the Beacon Practice project for teachers of secondary technology which included materials development, curriculum leader support research, and curriculum support, and the establishment of a National

Professional Development Manager (Ministry of Education 2008). The role of the manager had significant influence in strengthening the collaboration between preservice and in-service providers of technology education and between the regions and universities. Opportunities to meet regularly, to receive updates from the Ministry of Education, to share research projects and publications, and to collaborate in the development of support for teachers came about as a result of the GIF-Technology funding.

The 2007 New Zealand Technology Curriculum

With the introduction of the new school curriculum in 2007, there was a change of emphasis. The National Curriculum Stocktake that was carried out between 2001 and 2003 by the Wilf Malcolm Institute of Education Research at the University of Waikato reviewed all learning areas of the New Zealand curriculum. Along with other learning areas, this study invited feedback from teachers about their experiences in implementing the 1995 technology curriculum (Jones and Compton 2009). This was achieved through gathering survey data, running focus groups, and developing case studies from examples throughout the country. As a result, it became apparent that an uncertainty around what constituted "technological literacy" existed, with the technology community as a whole struggling to come to a common agreement (Ministry of Education 2002). Compton and Harwood (2004) reported that where classroom programs "focus on developing students' understanding of and about technology almost exclusively within the context of their own technological practice" (p. 160), the level of critical analysis required for informed decision-making lacked the breadth and depth anticipated by the 1995 curriculum. This concept is exemplified in the research of Elmose and Roth (2005), in which the notion of citizens' active participation in a society dominated by technological and scientific advances was explored. These advances were recognized as having the potential to present unforeseen and uncontrollable risks, for which populations were generally unprepared. The aim of the 2007 curriculum, therefore, was to develop programs that would foster "a broad technological literacy that would equip [students] to participate in society as informed citizens but also give them access to technology-related careers" (Ministry of Education 2007, p. 32). Furthermore, emphasis was placed on the practical nature of technology education, which aimed to include developing models, products, and systems, as well as appreciating technology as a field of human endeavor (MoE 2007). This is defined in the 2007 technology curriculum as follows:

> Technology is intervention by design: the use of practical and intellectual resources to develop products and systems (technological outcomes) that expand human possibilities by addressing needs and realising opportunities. Adaptation and innovation are at the heart of technological practice. Quality outcomes result from thinking and practices that are informed, critical, and creative. (Ministry of Education 2007, p. 32)

Technological practice remained a key part of this curriculum and is described by three subheadings or achievement objectives, namely, planning for practice, brief development, and outcome development and evaluation. It includes students studying the practice of others and gaining expert advice before planning and carrying out their own practice. There are two additional strands entitled Technological Knowledge, which includes technological modeling, technological products, and technological systems, and the Nature of Technology, which includes the characteristics of technology and the characteristics of technological outcomes. Compton et al. (2007) report that this latter strand offers an "opportunity for students to develop a philosophical understanding of technology, including how it is different from other domains of human activity" (p. 12).

These three overlapping strands work together to develop students' overall technological literacy and are described in the curriculum as the development of knowledge and skills relating to the principles and processes of technology, the ability to select appropriate materials and design solutions, and understanding technology as a human endeavor and a domain in its own right (Ministry of Education 2007).

The influence of Mitcham's philosophy of technology as artifacts, as activity, as knowledge, and as volition is clearly evident in Fig. 3, showing the technology education constructs within *The New Zealand Curriculum* (p. 25). Technology as activity is developed through the technological practice strand, technology as volition and as artifact is achieved through the nature of technology strand, and technology as knowledge, as indicated by its title, is explored through the technological knowledge strand.

The 2007 technology curriculum identifies five technological areas, including food technology, structural technology, control, biotechnology, and information and communication technology. The knowledge base, specific to each technological area within this curriculum, is recognized as vital to students' knowledge and skill development, and graphics and other forms of visual representation are acknowledged as important tools for both the exploration and communication of design ideas. The influence of culture, ethics, politics, and economics, as well as the impact of environmental issues of the day, is also acknowledged, and opportunities for these to be integrated and developed through students' technological practice are provided throughout the eight levels of attainment (Ministry of Education 2007).

A 3-year study from 2005 to 2008, known as the InSiTE project (Classroom Interaction in Science and Technology Education), was conducted at the University Waikato. This aimed to develop an understanding of the interactions between teachers, students and the ideas and tools that teachers use to support student learning (Ministry of Education 2008). Over this same period and particularly influential within the technology education community was the Ministry of Education Implementation Support Material which was delivered through the *Techlink* website. This outlined the ideas which underpinned the 2007 technology curriculum and included explanatory papers describing each of the achievement objectives, future program development, the link between technology and values, and technology and the key competencies as listed in the 2007 curriculum.

Technological practice	Nature of Technology	Technological Knowledge
Brief Development ***(Technology as Activity)*** (Level 1) Students will: Describe the outcome they are developing and identify the attributes it should have, taking account of the need or opportunity and the resources available.	**Characteristics of Technology** ***(Technology as Volition)*** (Level 1) Students will: Understand that technology is purposeful intervention through design	**Technological Modelling** ***(Technology as Knowledge)*** (Level 1) Students will: Understand that functional models are used to represent reality and test design concepts and that prototypes are used
Planning for Practice ***(Technology as Activity)*** (Level 1) Students will: Outline a general plan to support the development of an outcome, identifying appropriate steps and resources.	**Characteristics of Technological Outcomes** ***(Technology as Artefact)*** (Level 1) Students will: Understand that technological outcomes are products or systems developed by people and have a physical nature and a functional nature	**Technological Products** ***(Technology as Knowledge)*** (Level 1) Students will: Understand that technological products are made from materials that have performance properties.
Outcome Development and Evaluation ***(Technology as Activity)*** (Level 1) Students will: Investigate a context to communicate potential outcomes. Evaluate these against attributes; select and develop an outcome in keeping with the identified attributes.		**Technological Systems** ***(Technology as Knowledge)*** (Level 1) Students will: Understand that technological systems have inputs, controlled transformations, and outputs.

Fig. 3 Technology curriculum constructs in the New Zealand curriculum (Compton 2009, p. 25) with examples shown from Level 1 of the curriculum

The indicators of progression which were part of this package have been organized around each of the eight achievement objectives and developed for teachers working at all levels of the technology curriculum. Figure 4 gives an example of brief development, an activity-based achievement objective which shows how students should progress from Level 1 through to Level 7.

In addition to each achievement objective descriptor, the indicators of progression offer suggestions to teachers for planning learning experiences, and progressing students as per the level indicators. For example, the Level 3 indicators, generally recommended for Year 7 and 8 students (11–13 year olds), state students will be able to "describe the physical and functional nature of the outcome they are going to produce and explain how the outcome will have the ability to address the need or opportunity." Students should also be able to "describe attributes for the outcome and identify those which are key for the development and evaluation of an outcome" (Ministry of Education 2009, p. 3). This is a significantly higher level achievement goal from that of Level 1 in which students are expected to "communicate the outcome to be produced and identify attributes for an outcome" (p. 1), and Level 2 in which they should be able to also take account of the need or opportunity being

Brief Development: Indicators of progression Levels 1 – 7			
Level 1	Level 3	Level 5	Level 7
Students will: Describe the outcome they are developing and identify the attributes it should have, taking account of the need or opportunity and the resources available.	Students will: Describe the nature of an intended outcome, explaining how it addresses the need or opportunity. Describe the key attributes that enable development and evaluation of an outcome.	Students will: Justify the nature of an intended outcome in relation to the need or opportunity. Describe specifications that reflect key stakeholder feedback and that will inform the development of an outcome and its evaluation.	Students will: Justify the nature of an intended outcome in relation to the issue to be resolved and justify specifications in terms of key stakeholder feedback and wider community considerations.

Fig. 4 Progression of achievement objective indicators of progression (Ministry of Education 2010)

addressed and the resources that are available (Ministry of Education 2009). The teacher guidance that supports each achievement objective in this document provides a number of valuable teaching suggestions. Key elements of sound pedagogy and focused technological teaching goals are carefully woven through each one. For example, teacher guidance to support the Level 3 brief development achievement objective provides the following suggestions.

Level three teachers could:

- Provide the need or opportunity and develop the conceptual statement in negotiation with the students
- Guide students to describe the physical and functional nature of an outcome (e.g., what it looks like and what it can do) taking into account the need or opportunity, conceptual statements and resources available
- Guide students to identify the key attributes an appropriate outcome should have. Key attributes reflect those that are deemed essential for the successful function of the outcome.

The indicators of progression is an extensive document and has gone some way in bridging the gap between an absence of professional development for teachers of technology over the last 8 years, and the ongoing need to support teachers in planning programs that reflect the true essence of the technology curriculum. However, as recommended in the final report to the Ministry of Education on the 3-year technological literacy: Implications for teaching and learning research project (Compton et al. 2013), "robust facilitated professional development opportunities for teachers across all sectors" should now be offered (p. 3). The challenge for the next phase of development of this curriculum is how to build on the extensive achievements described in this chapter and effectively position technology education for its place within education in the future and ensure that it remains a key part of primary school curricular.

Conclusion and Future Directions

The evolution of the technology education curriculum in New Zealand is a tale that began in the early colonial period of New Zealand history, firstly with the introduction of the Manual and Technical Institution Act in 1900 and later on the Thomas Report of 1944 which prompted the introduction of a number of compulsory technical subjects for all 13–15 year olds (Jones 1997). The first New Zealand technology education curriculum emerged in 1995 with its emphasis on authentic design informed by the practice of experts, and finally the 2007 curriculum which, in response to a national curriculum stocktake, aimed "to develop a broad technological literacy that would better equip students to actively participate in society as informed citizens and also give them access to technology-related careers" (Ministry of Education 2007, p. 32).

The story of technology education in New Zealand concludes with the development and ongoing implementation of the new 2007 curriculum. It is a story which can rightfully celebrate many successes. It is research based, professional development provided for secondary teachers for the new curriculum has been well funded, and significant engagement by enthusiastic teachers and students in all sectors has been achieved. The community as a whole has been supported through TENZ, the professional organization for technology education, and this continues but with new challenges on the horizon. Jones et al. (2015) warn that "the subject remains susceptible to the vagaries of political whims and system disconnects" (p. 272) and this continues to be played out. Since 2008 the Ministry of Education has targeted numeracy and literacy as the major focus for professional development funding of teachers, and this has resulted in a loss of momentum in the consolidation and progress of technology education in the primary sector.

This has been complicated by an attempt to manage a congested curriculum and one that is dominated by literacy and numeracy. Learning areas other than mathematics and English are frequently taught under the heading of "topic," with several areas being combined in a way that, from anecdotal evidence observed by the author, dilutes the potential richness of areas such as technology education and results in integrated units of work that lack focus and real purpose. These units often consist of a piecing together of unrelated chunks from a number of learning areas. Compton et al. (2013) report that the components of the three strands of the technology curriculum working together have the potential to develop students' technological literacy, but this is dependent on teacher knowledge and an understanding of how each component can be developed and progressed through Levels 1–8.

A further complication has been a heightened interest in the physical learning spaces and pedagogical practices familiar to teachers in the primary sector for many years. These seem to have developed a life of their own and have driven what the author sees as a confused focus on *where* teaching and learning occurs rather than *what* is taught. For example, the reshaping of classroom architecture into "modern learning environments" and "innovative learning spaces" has occurred in many New Zealand schools, with open areas and small break-out rooms being constructed to cater for large numbers of students, but with negligible change to the way each learning area is being presented. Professional development which works alongside these changes is well overdue.

A flickering light on the horizon has been the launching of "Curious Minds" in 2014 by the Ministry of Business Innovation and Employment, the Ministry of Education, and the Office of the Prime Minister's Chief Science Advisor (Ministry of Business Innovation and Employment 2016). This is a 10-year project designed to take a strategic approach to the government's science investment by targeting public education. One of the goals of this project specifies the promotion of public engagement with science and technology. Two additional initiatives which will impact on the technology curriculum are the promotion of STEM education (Science, Technology, Engineering and Mathematics education) to secondary students, and the inclusion of digital technology as a new strand in the Technology curriculum (Ministry of Education 2016). A word of caution, however, from Alister Jones at the 2015 TENZ conference in which he expressed his disquiet at the way the "Curious Minds" project was playing out. He believes that, to date, there has been very little recognition of technology within this project, and the policies designed to capture public attention have not taken into account lessons learned from the past. TENZ therefore has a significant responsibility in this quickly changing environment, of asking hard questions of the Ministry of Education and continuing to promote this curriculum as the vibrant, forward thinking, and exciting subject that was anticipated 20 years ago (Jones et al. 2015).

References

Bronowski, J. (1973). *The ascent of man*. London: British Broadcasting Corporation.

Brown, J., Collins, A., & Duguid, P. (1998). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42.

Compton, V. (2001). *Developments in technology education in New Zealand 1993–1995: An analysis of the reflections of key participants*. Hamilton: University of Waikato.

Compton, V. (2009). Yep – We can do that: Technological response to the curriculum 'needs' arising. *Design and Technology Education: An International Journal, 14*(1), 21–36.

Compton, V., & France, B. (2007). Towards a new technological literacy: Curriculum development with a difference. *Curriculum Matters, 3*, 158–176.

Compton, V., & Harwood, C. D. (2004). Moving from the one-off: Supporting progression in technology. *Journal Issue, 1*, 23–30.

Compton, V., Dinning, N., & Keith, G. (2007). *Report to technology writing group: Summary of feedback and recommendations for change*. Retrieved from Wellington.

Compton, V. J., Compton, A., & Patterson, M. (2013). Technological literacy: Implications for teaching and learning: Final report to reference group. Retrieved from Auckland.

Egdell. (1966). A period of educational reform. In A. H. McLintock (Ed.), *Te Ara – the encyclopedia of New Zealand*. Retrieved from http://www.TeAra.govt.nz/en/1966/education-evolution-of-present-system/page-3. (An Encyclopaedia of New Zealand).

Elmose, S., & Roth, W.-M. (2005). *Allgemeinbildung*: Readiness for living in risk society. *Journal of Curriculum Studies, 37*(1), 11–34.

Hope, G. (2009). Beyond knowing how to make it work: The conceptual foundations of designing. *Design and Technology Education: An International Journal, 14*(1), 49–55.

Jones, A. (1997). Recent research in learning technological concepts and processes. *International Journal of Technology and Design Education, 7*, 83–96.

Jones, A. (2003). The development of a National Curriculum in Technology in New Zealand. *International Journal of Technology & Design Education, 13*, 83–99.
Jones, A., & Compton, A. (2009). Reviewing the field of technology education in New Zealand. In A. T. Jones & M. J. de Vries (Eds.), *International handbook of research and development* (pp. 93–104). Rotterdam: Sense.
Jones, A., Mather, V., & Carr, M. D. (1995). Issues in the practice of technology education. *Final report of the Learning in Technology Education Project*. Retrieved from.
Jones, A., Buntting, C., & de Vries, M. J. (2013). The developing field of technology education: A review to look forward. *International Journal of Technology and Design Education, 23*(4), 191–212.
Jones, A., Buntting, C., & Williams, P. J. (2015). Much remains to be done. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology* (pp. 271–274). Singapore: Springer.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.
Mawson, B. (2011). Emergent technological literacy: What do children bring to school? *International Journal of Technology and Design Education, 23*(4), 443–453.
Milne, L. (2002). *Technology education in the new entrant classroom.* Master Education, Waikato.
Ministry of Business Innovation and Employment. (2016, 16 June 2016). Curious minds. Retrieved from http://www.mbie.govt.nz/info-services/science-innovation/curious-minds
Ministry of Education. (1993). The New Zealand Curriculum Framework. Wellington, New Zealand: Learning Media.
Ministry of Education. (1995). Technology in the New Zealand Curriculum. Wellington, New Zealand: Learning Media.
Ministry of Education. (2002). Curriculum Stocktake report to the Minister of Education. Retrieved from Wellington.
Ministry of Education. (2007). History of curriculum development. Retrieved from http://nzcurriculum.tki.org.nz/Archives/Curriculum-project-archives/Developing-the-draft/History-of-curriculum-development
Ministry of Education. (2008). *Development of technology education in New Zealand school 1985–2008*. Wellington: Government Printer.
Ministry of Education. (2009). Indicators of progression. *Curriculum Support*. Retrieved from Techlink website: http://technology.tki.org.nz/Technology-in-the-NZC/What-does-learning-in-technology-look-like/Indicators-of-Progression
Ministry of Education. (2010). Techlink. Retrieved from http://www.techlink.org.nz/
Ministry of Education. (2016). Digital technology to become part of the New Zealand curriculum and Te Marautanga o Aotearoa. *Education News*. Retrieved from http://www.education.govt.nz/news/digital-technology-to-become-part-of-the-new-zealand-curriculum-and-te-marautanga-o-aotearoa/
Mitcham, C. (1996). *Thinking through technology*. Chicago: The University of Chicago Press.
Moiduser, D. (2009). Learning technological problem solving – A cognitive/epistemological perspective. In A. Jones & M. J. de Vries (Eds.), *International handbook of research and development* (pp. 391–406). Rotterdam: Sense.
Moreland, J. (1997). *Technology education teacher development: The importance of experiences in technological practice*. M.Ed thesis, University of Waikato.
Mutch, C. (2005). Developing global citizens: The rhetoric and the reality in the New Zealand curriculum. In C. White & R. Openshaw (Eds.), *Democracy at the crossroads. International perspectives on critical global citizenship education* (pp. 187–209). Lanham: Lexington Books.
Ortega y Gasset, J. (1941). *Towards a philosophy of history*. New York: W.W. Norton.
Petrina, S. (1992). Curriculum change in technology education: A theoretical perspective on personal relevance curriculum designs. *Journal of Technology Education, 3*(2), 37–47.
Rogoff, B. (1990). *Apprenticeship in thinking*. New York: Oxford University Press.
Roth, H. (1952). *George Hogben*. Wellington: Whitcome & Tombs Ltd.

de Vries, M. J. (2005). *Teaching about technology: An introduction to the philosophy of Technology for non-Philosophers* (Vol. 27). Dordrecht: Springer.
de Vries, M. J. (2012). Philosophy of technology. In P. J. Williams (Ed.), *Technology education for teachers* (pp. 15–34). Rotterdam: Sense.
Williams, P. J., & Jones, A. (2015). *From technical to technology education.* Paper presented at the XXI International Scientific-Practical Conference: "Technological Education for Innovation and Technological Development of the Economy", Moscow State Pedagogical University.

Middle Childhood Education: Engineering Concepts, Practices, and Trajectories

13

Cathy P. Lachapelle, Christine M. Cunningham, and Martha E. Davis

Abstract

This chapter discusses the important features of age-appropriate engineering education for school-age children. It lays out core concepts and practices for engaging children, articulating eight design parameters that include narrative context; goals, constraints, and requirements; engineering design processes and epistemic practices; exploring materials and methods; application of science and mathematics; analysis of data for planning and redesign; collaboration; and agency. It considers three bands: ages 7–8 (beginning readers), ages 9–10 (middle childhood), and ages 11–12 (preadolescents). This chapter extends the trajectory presented in chapter "Engineering Concepts, Practices, and Trajectories for Early Childhood Education" (Cunningham et al. In English LD, Moore TJ (eds) Early engineering learning. Springer, New York, in press). For each design parameter of engineering education, the chapter describes what engineering activity looks like for each age band, drawing on the authors' experience with curriculum design, evaluation, and observation and research in classrooms.

Keywords

Engineering education • Learning trajectories • Elementary school

Contents

C.P. Lachapelle (✉) • C.M. Cunningham • M.E. Davis
Museum of Science, Boston, MA, USA
e-mail: clachapelle@mos.org

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_23

Introduction

Technology as a precollege topic of study has become more widespread internationally in the last 25 years. Technology education evolved from study of the manual arts to a broader conceptualization of technology – its processes and products – and its impacts on people and the environment (Cajas 2001). More recently, technology education has shifted in many countries to include a greater focus on the practices of developing and designing technological processes and products. The United States, in particular, has emphasized familiarizing students with the discipline of engineering as a field devoted to the systematic development of technology in accord with scientific and ethical principles. The Next Generation Science Standards (NGSS Lead States 2013) advocates that precollege students in the United States learn engineering practices as well as science practices, following a number of federally sponsored reports advising that children should learn engineering (Committee on Integrated STEM Education et al. 2014; National Research Council [NRC] 2011, 2012).

The primary goal of engineering education, as an aspect of technology education, is not (necessarily) to prepare children for an engineering profession but to introduce them to the discipline and its major practices and concerns so children can learn to make informed decisions about technological development as adult citizens. To this end, all children should receive an education that prepares them to understand how and why technologies are developed. Engineering education should also support children's development of a systematic approach to technological problem solving that can serve them throughout their lives. A third goal is to spark the interest of children who may choose to pursue technological careers.

This chapter focuses on how to implement engineering education with children ages 7–12. This range covers children who are beginning readers through children on the cusp of adolescence. It discusses the changing developmental needs across the age span and how engineering curriculum and instruction can support children to develop their engineering skills over time.

The chapter draws on 13 years of experience by the authors in developing engineering curricula for children ages 3–14. From its inception, this work has drawn upon research literature to develop design principles and parameters that have guided the creation of curriculum units for both in-school and out-of-school settings. The curricula the authors have produced introduce children to technology and to fields of engineering and engage children in the practices of engineering at an age-appropriate level. *Engineering is Elementary* (EiE) is designed for use in elementary school classrooms and has been used by more than 12 million children in the United States over the past 10 years. The authors have also created two curricula for clubs and camps: *Engineering Adventures* (EA) for children ages 8–11 and *Engineering Everywhere* (EE) for children ages 11–14. Currently, the development of curricula for preschool and kindergarten children ages 3–6 is underway. Formative and summative evaluations and research projects have demonstrated how children in these age groups benefit from engineering education and the opportunity to design, construct, and improve technologies (Cunningham and Lachapelle 2011; Lachapelle et al. 2012).

Theoretical Framework

This chapter assumes that the goal of technology education is to increase learning and mastery of the disciplines of technology and that this should happen through contextualized engagement in the core content and authentic practices of that discipline at a developmentally appropriate level (Duschl 2008; Engle and Conant 2002; National Research Council [NRC] 2007; Sawyer 2006b). The key element of a social constructivist view of learning is that knowledge and understanding are actively constructed by the learner and also socially constructed and supported by the community within which learning takes place (Bransford et al. 2006; Palincsar 2005). The community frames and supports the development of learners as they interact with others and as learners come to recognize, abide by, and strive to excel given norms for acceptable and exemplary practice (Rogoff 2003; Roth and Lee 2007). Over time, with experience and guidance from others, learners develop mastery and independence (Collins 2006; Greeno 2006; Rogoff 2003). Within classrooms, both teachers and curricula support deep, flexible learning when they play the role of guide and coach (Hmelo-Silver et al. 2007; Kolodner et al. 2004).

Design Parameters

All curricula developed by the authors are developed using the framework of social constructivist learning theory. As we operationalized theory into practical guidelines for curriculum design, we developed a set of design principles to address design for diverse audiences (Cunningham and Lachapelle 2014), as well as design parameters to address the functions of curriculum and instruction (Lachapelle and Cunningham 2014).

This chapter describes eight design parameters for developmentally appropriate engineering curricula and pedagogy for children in the age bands 7–8, 9–10, and 11–12. Our concern is engineering education, which, as we stated in the Introduction, has recently been receiving more attention in conjunction with the broadening aims of technology education internationally. Table 1 provides an overview of the design parameters; more extended discussion of each parameter is found in the

Table 1 Curriculum design parameters overview[a]

Curriculum design parameter	Engineering curriculum and pedagogy should:
1. Narrative context	contextualize the engineering problem with a real-world story line that is relevant and interesting to children of different genders, races, ethnicities, and socioeconomic and linguistic backgrounds.
2. Goals, constraints, and requirements	explicitly specify a problem to be addressed as well as constraints and requirements on the solution in such a way that a variety of valid and creative solutions are possible.
3. Engineering design processes and epistemic practices	actively engage children in the processes and practices of engineering design while scaffolding their participation so they can develop mastery over time.
4. Exploring materials and methods	engage children in concrete activities that involve the manipulation of materials and the use of tools.
5. Application of science and mathematics	encourage the purposeful application of science and mathematics content and skills, in context, to the design of solutions to specified problems and needs.
6. Analysis of data for planning and redesign	afford children opportunities to collect data, evaluate their designs, use failure constructively, and reflect on what was learned so they can generate and test new design ideas and solutions.
7. Collaboration	support children to consider and build on each other's ideas and to negotiate shared solutions.
8. Agency	support children in developing confidence and strategies to solve ill-defined problems.

[a]Adapted from http://www.eie.org/engineering-elementary/trajectories-for-engineering-activities

remainder of the chapter. For a more in-depth description of the research base supporting each design parameter, see Lachapelle and Cunningham (2014).

Narrative Context

Children learn best when they are engaged in the content and practice of a discipline. Stories and narratives, both fiction and nonfiction, serve an important role in engineering education. An engaging story can serve as a "hook," drawing children in to see themselves in the role of engineer (Wilson 2002). A well-constructed narrative can help children to understand why learning about engineering matters. When children can understand the function of what they are doing as something relevant to their own lives and futures, they are more likely to become motivated and engaged (Buxton 2010; Klassen 2007). This is particularly true when the story focuses on helping others or the environment (Brotman and Moore 2008). Emotional engagement is a strong predictor of deep learning (Immordino-Yang 2015).

Setting engineering learning within a narrative context also supports children to understand the larger purposes and ethics of engineering practice. It shows children that engineering is not just invention – that engineers must attend to the needs of clients and the larger society as they design solutions (Brophy et al. 2008; NRC

Table 2 Trajectory for narrative context

Ages 7–8	Ages 9–10	Ages 11–12
The context can be presented through characters in a long picture book	The context can be presented through illustrated short chapter books	The context can be presented through longer texts, documentaries, and media reports; nonfiction is preferred
The teacher reads aloud and supports comprehension through questioning	Children can read independently with significant comprehension support	Youth can read independently with less support
The topic is familiar to children indirectly through texts and media	The topic can involve personal, social, industrial, or environmental problems	The topic can involve more current or complex societal or environmental problems
The teacher reads fiction and nonfiction books, provides video clips and exemplars, and supervises other experiences to expand children's knowledge base	In addition to resources and experiences used in earlier grades, children can now read and investigate independently in books and online	In addition to resources and experiences used in earlier grades, youth can now read and investigate independently in books and online

2011). In addition, an understanding of the larger context of the discipline of engineering improves children's ability to transfer what they have learned to new situations (Kolodner 2006).

A look at the EiE curricula illustrates a variety of ways that engineering can be situated within a narrative context. Different media are employed depending on the setting and grade level. For example, the in-school EiE curriculum uses illustrated storybooks. For the elementary out-of-school curricula, e-mail messages start each lesson. At the middle school level, documentary-style videos featuring practicing engineers are used, and for preschoolers puppets provide the narrative. In each curriculum, each unit has an engineering narrative tailored to its content. These narratives vary, so that all children – girls, boys, and children of different races, ethnicities, and socioeconomic and linguistic backgrounds – have the opportunity to find a story that appeals to them. For the youngest students, engineering stories are presented interactively through puppets, allowing children to role-play and engage their imaginations. New readers learn from storybooks, while older children appreciate true stories conveyed by people who serve as role models (Table 2).

Goals, Constraints, and Requirements

Engineering as a field is primarily concerned with meeting specified needs or wants within given constraints: usually, a client sets the goal and requirements (Brophy et al. 2008; Cunningham and Carlsen 2014). This presents opportunities to develop children's creativity, perspective taking, persistence, and problem-solving skills (Katehi et al. 2009).

Table 3 Trajectory for goals, constraints, and requirements

Ages 7–8	Ages 9–10	Ages 11–12
Children design a technology or model with one or two functions that are readily understood with instruction	Children design a technology or model that may have multiple functions or be part of a system; functions may require some instruction to understand	Youth design a technology or model that may be made up of multiple subsystems; functions may require instruction and investigation to understand
Up to four constraints and requirements require trade-offs	Up to five constraints and requirements may involve calculations and measurement in scoring	Up to six constraints and requirements may involve calculations and measurement in scoring
Balanced trade-offs ensure that many valid solutions are possible	Balanced trade-offs ensure that many valid solutions are possible	Balanced trade-offs ensure that many valid solutions are possible

Giving children a constrained, scaffolded design challenge increases the opportunities for learning as compared to the same challenge without constraints or scaffolds (Sawyer 2006a). It enables the teacher to focus on a small number of key learning objectives. It helps the children to all focus on the same learning objectives, measure their progress against the constraints and requirements, and learn from each other (Kolodner 2002; Sawyer 2006a). It is well established that unconstrained inquiry and design, sometimes called "discovery learning," is an inefficient and even ineffective way to promote specific learning goals, while well-scaffolded active learning opportunities can be highly effective (Hmelo-Silver et al. 2007; Kirschner et al. 2006).

Curriculum design can support learning by specifying problems that will challenge children at an age-appropriate level, yet still permit creativity in how to meet constraints and requirements. The challenge should be designed so that many valid solutions are possible. This can be accomplished by building trade-offs into the constraints or by providing a variety of materials and methods for use in the design. It's important to help children to focus on and balance goals, constraints, and requirements, through scaffolding with supportive materials and guided discussion.

Creativity can flourish in this environment, so long as children have support for making their own choices (Sawyer 2006a). The goal and challenge, however, must be meaningful for children to truly engage them in the deep thinking and effort needed for successful learning (Krajcik and Blumenfeld 2006) (Table 3).

Engineering Design Processes and Epistemic Practices

To learn the essentials of the content and practices of a discipline, children also need to engage in its epistemic practices (Kelly 2008; Duschl 2008). As engineers solve problems, they engage in engineering processes to scaffold their work. While there is no set "engineering design process," there is agreement that engineering involves a flexible, iterative process which may include cycles of defining the

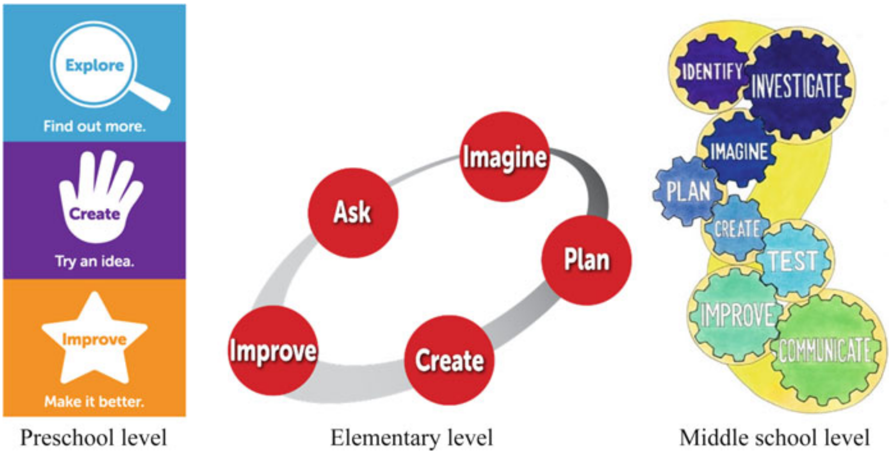


Fig. 1 Engineering design processes

scope of the process, background research, brainstorming, planning, the building and testing of prototypes and/or models, analysis and redesign, and communication of designs to clients (Cunningham and Carlsen 2014; International Technology Education Association 2007). It's important that both teachers and children understand that this process is both flexible and purposeful (Lewis 2005). Implementation of a rigid separation of steps in an engineering design process frustrates children and misrepresents the nature of engineering (Brophy et al. 2008; Hill and Anning 2001).

It takes time, experience, community support, and a careful matching of expectations to children's abilities over time for children to construct their own understanding and expertise (Gruber and Vonèche 1977; Vygotsky 1978). The practices and processes of engineering must be scaffolded so children of different abilities and experience can participate authentically and develop mastery over time. It is important to remember that the goal is not to produce professional engineers, rather to develop authentic, preprofessional understanding and mastery of the essential concepts and practices of engineering and technology.

Flexible and iterative use of an age-appropriate engineering design process with consistent presentation is important. For example, in the authors' curricula, preschoolers use a three-step process; children 7–10 are exposed to a five-step process; children 11–14 employ an eight-step process (see Fig. 1).

All children are given opportunities to iterate through steps of the process multiple times. In every case the steps of the process are explicitly named and discussed, so that children can learn to recognize and think metacognitively and purposively about their work. The use of a process with few steps does not mean that steps or practices are "skipped" – in cases with fewer steps, the same epistemic practices are supported, but they are subsumed under a smaller number of steps. This is envisioned as a gentle introduction to the complexities of engineering: first calling out the major landmarks, then slowly introducing additional detail, and naming

Table 4 Trajectory for engineering design processes and practices

Ages 7–8	Ages 9–10	Ages 11–12
The EDP has four or five steps	The EDP has five or six steps	The EDP has seven or eight steps
Children engage in problem scoping, brainstorming, drawing up plans, creating and testing prototypes, evaluating to make improvements, and communicating designs	Children engage in practices from earlier grades with more independence	Youth engage in practices from earlier grades with more independence
Teachers model for the class and ask open-ended, generative questions to encourage children to actively engage	Teachers model for the class and ask open-ended, generative questions to encourage children to actively engage, reflect, and draw conclusions	Teachers begin and end each activity with open-ended, generative questions to encourage youth to reflect and draw conclusions
Materials scaffold all processes through simple prompts	Materials scaffold all processes through extended prompts and some instruction	Materials provide higher-level scaffolding of all processes, with extended instruction and some prompts
Children communicate ideas, designs, and conclusions with drawings, basic writing, and class discussion	Children communicate ideas, designs, conclusions, and synthesis with drawings, extended writing, class discussion, and brief team presentations	Youth communicate ideas, designs, conclusions, synthesis, and arguments with drawings, extended writing, class discussion, and extended team and class presentations

practices that were subsumed under a single heading. Simultaneously, expectations for children of all ages to participate in the full variety of epistemic practices are built in, but with different levels of structure for children of differing abilities and experience. Thus, children have the opportunity to experience over time that engineering design processes are flexible to the abilities of the users and the needs of the problem (Table 4).

Exploring Materials and Methods

Working with physical materials and tools gives children practical, hands-on, concrete experience that can improve their fine motor skills and knowledge of the world. While computer simulations offer rich visualizations, only physical materials can give children the ability to evaluate their ideas against reality (Roth 2001). Such experience lays the foundation for later engagement with simulations and other abstractions. During elementary school, one primary goal of engineering education should be helping children construct knowledge about materials and their properties. Through hands-on manipulation, children can build understanding of materials and how they perform in different situations. Through reflection and guided discussions,

Table 5 Trajectory for exploring materials and methods

Ages 7–8	Ages 9–10	Ages 11–12
Children explore, describe, compare, and evaluate the properties of materials for use in a design solution with teacher support	Children explore, describe, compare, evaluate, and make arguments about the properties of materials for use in a design solution with teacher or written support	Youth explore, describe, compare, evaluate, and make arguments about the properties of materials for use in a design solution with support from written prompts
Children make use of a variety of methods and basic tools for construction, including specialized methods (e.g., folding paper to create a beam)	Children make use of a variety of methods and tools for construction, including specialized methods and tools (e.g., a goniometer or temperature gauge)	Youth make use of a variety of methods and tools for construction, including specialized methods and tools requiring maturity and/or adult supervision (e.g., a sharp blade)

children can begin to build understanding of which properties matter for a design challenge and also how the materials that are used shape and constrain the resulting technology.

Similarly, children develop methods of working with materials and using tools through exposure and practice. Through folding and rolling paper, for example, children can directly experience the properties of beams and columns in different material configurations. Learning to make accurate linear measurements is a developmental process beginning with comparison of items (longer, shorter), progressing to nonstandard measures (hands, arm widths), to the use of rulers and eventually other more accurate measures (Common Core State Standards Initiative 2012; Department for Education 2014; National Association for the Education of Young Children and National Council of Teachers of Mathematics 2010).

A variety of materials, tools, and methods that challenge children in age-appropriate ways are specified in our units. We expect that teachers will support children to engage with materials, focus on relevant properties, and develop arguments about their use. Children also need modeling and supervision to learn the appropriate use of tools and construction methods (Table 5).

Application of Science and Mathematics

In the real world, engineers rely heavily on their knowledge of science and mathematics. Children in classrooms should also begin to develop an understanding of the interrelationships of these disciplines. Furthermore, activities that meaningfully integrate mathematics, science, engineering, and technology have the potential to significantly benefit children's learning in all subjects (Katehi et al. 2009; Kolodner 2002; Lachapelle et al. 2011; Oh et al. 2016; Roth 2001; Zubrowski 2002). Integration of these domains demonstrates a context and utility for math and science. At the same time, the application of mathematics and science can improve children's engineering design skills (Lewis 2005). Measurement and data analysis can be

Table 6 Trajectory for application of science and mathematics

Ages 7–8	Ages 9–10	Ages 11–12
The most successful design solutions will take scientific considerations into account from age-appropriate science content	A successful design solution will take scientific considerations into account from age-appropriate science content	A successful design solution will take scientific considerations into account from age-appropriate science content
Children use standard measures, calculate scores, and collect and record data	Children take measurements, calculate variables and scores, collect and record data, and construct charts and tables at an age-appropriate level	Youth take measurements, calculate variables and scores, collect and record data, and construct charts and tables at an age-appropriate level

used to evaluate and make decisions about how to improve an engineering design (Barron et al. 1998). An understanding of science can be put to use in creating effective design solutions (Kolodner 2002).

Designing curriculum that effectively integrates science and mathematics takes careful planning and testing. The design challenge needs to be developmentally appropriate in all subjects. The teacher needs to understand how the content and skills of mathematics and science apply to the challenge, so she or he can help students to recognize and reflect upon their use of math and science (Table 6).

Analysis of Data for Planning and Redesign

A technology is never "final"; as people further improve their designs, they introduce new features and materials, or new knowledge drives a cycle of design and redesign. In engineering, children have the opportunity to be rewarded for risk-taking, persistence, and openness to learning from failure (Diefes-Dux 2014). Learning is stronger when teachers support children in reflecting on what they've learned. Iteration is also necessary for children to be truly successful with an age-appropriate design challenge (Brophy et al. 2008; Katehi et al. 2009). A teacher or curriculum that skips the process of analysis, evaluation, reflection, and redesign shortchanges the learning process, reducing engineering design to simple "messing around." Curricular materials must be designed to engage and support children as they collect and evaluate data. Activities and teacher questions should draw out children's reasoning. In the classroom, teachers help children understand that most engineered technologies did not work as expected the first time – engineers learn from failure. Part of engineering is systematically analyzing what can be improved. Failure presents an opportunity to encourage children to reflect. Children must be supported to draw inferences and use reasoned argument to make design decisions (Table 7).

Table 7 Trajectory for analysis of data for planning and redesign

Ages 7–8	Ages 9–10	Ages 11–12
Children test materials and methods of construction for specific qualities	Children analyze data collected from specified controlled experimentation with materials and methods to inform design planning	With teacher support, youth decide how to conduct tests of materials and methods and evaluate results which may vary across groups or repetitions
With teacher support, children construct graphs and charts and discuss and compare results across the class to draw lessons about "fair tests" and planning a design solution	With teacher and written support, children construct graphs and charts and discuss and compare results across the class to draw lessons about reliability, variability, and planning a design solution	With written support, youth construct graphs and charts, discuss and compare results, and draw conclusions for planning a design solution; with teacher support they discuss reliability and variability as a class
Children judge the success of a design solution using a specified testing procedure to make qualitative judgments and quantitative measures	Children judge the success of a design solution using a specified controlled testing procedure using quantitative measures and qualitative rubrics	Youth judge the success of a design solution using a specified controlled testing procedure and/or by devising their own testing procedures using quantitative measures and qualitative rubrics
Children analyze and describe which parts of their technology failed during testing and offer suggestions for modifications they will make in redesign	Children analyze data from testing of design solutions to understand points of failure and improve upon them in redesign	Youth analyze data from testing of design solutions to understand points of failure and improve upon them in redesign

Collaboration

Technological design is naturally a collaborative activity. Engineers work in teams on complex problems. Therefore, supporting children to learn to collaborate with their peers is fundamental to engineering. As with engineers, children working collaboratively produce designs of better quality than they would if working alone (Solomon and Hall 1996). Learning to collaborate through engineering has wider benefits as well. Collaboration increases creativity and the quality of innovation (Sawyer 2006a). It increases social skills, which undergo dramatic development in childhood (Copple and Bredekamp 2009). It fosters increased motivation and engagement, particularly for girls and racial minorities (Burke 2007). It gives children the chance to develop their skills in communication, argument, and negotiation.

Children need adult support, however, to learn to collaborate effectively. Teachers can support children's development of collaborative skills by structuring groups carefully, guiding children to interact effectively, intervening with support when communications break down, and helping children to reflect on their group

Table 8 Trajectory for collaboration

Ages 7–8	Ages 9–10	Ages 11–12
Children collaborate in pairs or groups of three on a shared design solution	Children collaborate in groups of three to four on a shared design solution	Children collaborate in groups of three to five on a shared design solution
The teacher discusses and models appropriate interactions	The teacher discusses and models appropriate interactions	The teacher discusses appropriate interactions and offers suggestions for how youth can manage their group work
The teacher provides support to consider each other's ideas and negotiate shared solutions	The teacher and written materials provide support and prompts to consider each other's ideas and negotiate shared solutions	Written materials convey the expectation that the group will come to consensus on how to conduct group work and what to do

functioning and their own contributions (Wendell et al. 2014). Age-appropriate opportunities for children to share ideas and work together throughout the engineering process are built into materials (Table 8).

Agency

The essence of engineering education is learning to solve ill-defined problems. Children need to have the confidence to approach a difficult problem and investigate it deeply if they are to be able to persist and solve it. A key factor in developing children's confidence and persistence with difficult problems is allowing children the agency to decide upon their own approach and to make and overcome mistakes (Blumenfeld et al. 2006). Granting children some agency has other benefits as well. It increases creativity as well as motivation and engagement (Sawyer 2006a).

Curriculum design should permit children room to take charge of their own learning at a developmentally appropriate level. Children need to be challenged, but not overwhelmed. In the classroom, teachers need to allow children time and space to try their ideas and work on their own or with peers. Both curriculum materials and educators should emphasize that multiple approaches and solutions are possible and encourage children to contribute their own ideas about the problem and possible solutions. Children should finish an engineering challenge recognizing that they are capable of engineering novel solutions to simple problems (Table 9).

Conclusion and Future Directions

As engineering is included in K-12 classrooms, it is important to consider both what are the critical elements of engineering that students should build facility with and also how these manifest themselves in age-appropriate ways. In the United States,

Table 9 Trajectory for agency

Ages 7–8	Ages 9–10	Ages 11–12
The teacher models for children and prompts them to come up with their own questions and ideas, as well as to make observations and draw their own conclusions	The teacher models for children and prompts them to come up with their own questions, ideas, and hypotheses, as well as to make observations, decide how to test materials, and draw their own conclusions	The teacher encourages youth to come up with their own questions, ideas, and hypotheses, as well as to make observations, decide how to test materials, design experiments and tests, and draw their own conclusions
Children work together to make decisions and plans as a team and to create, test, and improve their ideas	Children work together to make decisions and plans and to create, test, evaluate, and improve their ideas	Youth work together to make decisions and plans, to decide how to test materials and methods and how to evaluate their solutions, and to create, test, evaluate, and improve their ideas
Written materials support children to reflect and make connections through open-ended prompts for short answers and basic observations	Written materials support children to reflect and make connections through open-ended prompts for extended reasoning and detailed observations	Written materials support youth to reflect and make connections through open-ended prompts for extended reasoning and detailed observations

the National Academy of Engineering (NAE) has taken a leadership role with respect to thinking about K-12 technology and engineering education, assembling committees of engineers and educators to delve into pertinent issues. Their initial report highlighted the need to create a more technologically literate society (Pearson and Young 2002). As the field evolved, the focus morphed from technology to engineering. One early report explored messages that might effectively communicate to a range of audiences including teachers, students, and the general public the “role, importance and career potential of engineering” (NAE 2008, p. 2). This study recommended the use of four messages that they found resonate with diverse audiences:

- Engineers make a world of difference.
- Engineers are creative problem solvers.
- Engineers help shape the future.
- Engineering is essential to our health, happiness, and safety.

EiE and many other projects have used these in their work. By 2009 K-12 engineering education was gaining traction in the United States, and another NAE committee and report examined efforts that were occurring across the country to teach engineering in elementary and secondary schools (Katehi et al. 2009). It considered curricula, professional development, and assessments, reviewing a number of programs. EiE is one of the featured curricula. As increasing numbers of state standards began to include engineering, the question was posed about whether the development of K-12 content standards for engineering was feasible. An NAE panel explored this issue, argued against creating a separate set of standards, and instead recommended leveraging current state and national standards (NAE 2010). The most recent NAE engineering education report (Honey et al. 2014) examined the issue of STEM integration, probing what that would look like at the K-12 level and what research was available to contribute to this topic. EiE was invited to present its work and approach as one possible model. With engineering standards now a part of the NGSS, current NAE efforts are focused on creating resources for teachers to support classroom implementation.

Almost every NAE report calls for more research about engineering education. By articulating a set of eight curriculum design parameters for K-12 engineering and offering a learning trajectory for these concepts and practices from ages 7–12, this chapter provides a resource that can help structure curricular activities and professional development. Because engineering at these levels is still relatively new, a goal of this work is further refining these ideas as additional research studies are completed that can further inform them.

References

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. *Journal of the Learning Sciences, 7*, 271–311.

Blumenfeld, P. C., Kempler, T. M., & Krajcik, J. S. (2006). Motivation and cognitive engagement in learning environments. In *The Cambridge handbook of the learning sciences* (pp. 475–488). New York: Cambridge University Press.

Bransford, J. D., Barron, B., Pea, R. D., Meltzoff, A., Kuhl, P., Bell, P., et al. (2006). Foundations and opportunities for an interdisciplinary science of learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 19–34). New York: Cambridge University Press.

Brophy, S. P., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education, 97*(3), 369–387.

Brotman, J. S., & Moore, F. M. (2008). Girls and science: A review of four themes in the science education literature. *Journal of Research in Science Teaching, 45*(9), 971–1002.

Burke, R. J. (2007). Women and minorities in STEM: A primer. In R. J. Burke & M. C. Mattis (Eds.), *Women and minorities in science, technology, engineering and mathematics: Upping the numbers* (pp. 3–27). Northampton: Edward Elgar Publishing.

Buxton, C. A. (2010). Social problem solving through science: An approach to critical, place-based, science teaching and learning. *Equity & Excellence in Education, 43*(1), 120–135.

Cajas, F. (2001). The science/technology interaction: Implications for science literacy. *Journal of Research in Science Teaching, 38*(7), 715–729.

Collins, A. (2006). Cognitive apprenticeship. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences*. New York: Cambridge University Press.

Committee on Integrated STEM Education, National Academy of Engineering, & National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: National Academies Press.

Common Core State Standards Initiative. (2012). Common core state standards for mathematics. Common Core State Standards Initiative.

Copple, C., & Bredekamp, S. (Eds.). (2009). *Developmentally appropriate practice in early childhood programs serving children from birth through age 8*. Washington, DC: NAEYC.
Cunningham, C. M., & Carlsen, W. S. (2014). Precollege engineering education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education*. Mahwah: Lawrence Erlbaum Associates.
Cunningham, C. M., & Lachapelle, C. P. (2011). *Research and evaluation results for the engineering is elementary project: An executive summary of the first six years*. Boston: Museum of Science.
Cunningham, C. M., & Lachapelle, C. P. (2014). Designing engineering experiences to engage all students. In S. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 117–140). Lafayette: Purdue University Press.
Cunningham, C. M., Lachapelle, C. P., & Davis, M. E. (in press). Engineering concepts, practices, and trajectories for early childhood education. In L. D. English & T. J. Moore (Eds.), *Early engineering learning*. New York: Springer.
Department for Education (2014). Statutory framework for the early years foundation stage. Department for Education. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/335504/EYFS_framework_from_1_September_2014__with_clarification_note.pdf.
Diefes-Dux, H. A. (2014). In-service teacher professional development in engineering education: Early years. In S. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 233–258). Lafayette: Purdue University Press.
Duschl, R. A. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*(1), 268–291.
Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a Community of Learners classroom. *Cognition and Instruction, 20*, 399–483.
Greeno, J. G. (2006). Learning in activity. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 79–96). New York: Cambridge University Press.
Gruber, H. E., & Vonèche, J. J. (Eds.). (1977). *The essential Piaget*. London: Routledge & Kegan Paul.
Hill, A. M., & Anning, A. (2001). Primary teachers' and students' understanding of school situated design in Canada and England. *Research in Science Education, 31*(1), 117–135.
Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107.
Honey, M., & Pearson, G. (2014). In H. Schweingruber (Ed.), *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: National Academies Press.
Immordino-Yang, M. H. (2015). *Emotions, learning, and the brain: Exploring the educational implications of affective neuroscience* (Vol. 1). New York: W. W. Norton & Co.
International Technology Education Association. (2007). *Standards for technological literacy: Content for the study of technology*. Reston: ITEA.
Katehi, L., Pearson, G., & Feder, M. A. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press.
Kelly, G.J. (2008). Inquiry, activity, and epistemic practice. In R. Duschl & R. Grandy (Eds.). *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 99–117; 288–291). Rotterdam: Sense Publishers.
Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.
Klassen, S. (2007). The application of historical narrative in science learning: The Atlantic cable story. Science & Education, *16*(3–5), 335–352.
Kolodner, J. L. (2002). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education, 39*(3), 119–170.

Kolodner, J. L. (2006). Case-based reasoning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 225–242). Cambridge: Cambridge University Press.
Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., & Ryan, M. (2004). Promoting deep science learning through case-based reasoning: Rituals and practices in learning by design™ classrooms. In N. M. Seel & S. Dijkstra (Eds.), *Curriculum, plans, and processes in instructional design: International perspectives* (pp. 89–89). Mahwah: Lawrence Erlbaum Associates.
Krajcik, J. S., & Blumenfeld, P. C. (2006). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 317–334). New York: Cambridge University Press.
Lachapelle, C. P., & Cunningham, C. M. (2014). Engineering in elementary schools. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 61–88). Lafayette: Purdue University Press.
Lachapelle, C. P., Cunningham, C. M., Jocz, J., Kay, A. E., Phadnis, P., Wertheimer, J., & Arteaga, R. (2011). *Engineering is elementary: An evaluation of years 4 through 6 field testing*. Boston: Museum of Science.
Lachapelle, C. P., Phadnis, P., Jocz, J., & Cunningham, C. M. (2012). The impact of engineering curriculum units on students' interest in engineering and science. Presented at the NARST Annual International Conference, Indianapolis.
Lewis, T. (2005). Coming to terms with engineering design as content. *Journal of Technology Education, 16*(2), 37.
National Academy of Engineering [NAE]. Committee on Public Understanding of Engineering Messages. (2008). *Changing the conversation: Messages for improving public understanding of engineering*. Washington, DC: National Academies Press.
National Academy of Engineering [NAE]. Committee on Standards for K-12 Engineering Education. (2010). *Standards for K-12 engineering education*. Washington, DC: National Academies Press.
National Association for the Education of Young Children, & National Council of Teachers of Mathematics. (2010). Early childhood mathematics: Promoting good beginnings. NAEYC. Retrieved from http://www.naeyc.org/files/naeyc/file/positions/psmath.pdf.
National Research Council [NRC]. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.
National Research Council [NRC]. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=13158.
National Research Council [NRC]. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.
NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press. Retrieved from http://www.nextgenscience.org/.
Oh, Y., Lachapelle, C. P., Shams, M. F., Hertel, J. D., & Cunningham, C. M. (2016). Evaluating the efficacy of engineering is elementary for student learning of engineering and science concepts. Presented at the AERA Annual Meeting, Philadelphia.
Palincsar, A. S. (2005). 12 social constructivist perspectives on teaching and learning. In H. Daniels (Ed.), *An introduction to Vygotsky* (p. 285). New York: Routledge.
Pearson, G., & Young, A. T. (Eds.). (2002). *Technically speaking: Why all Americans need to know more about technology*. Washington, DC: National Academies Press.
Rogoff, B. (2003). *The cultural nature of human development*. Oxford: Oxford University Press.
Roth, W.-M. (2001). Learning science through technological design. *Journal of Research in Science Teaching, 38*(7), 768–790.
Roth, W.-M., & Lee, Y.-J. (2007). "Vygotsky's neglected legacy": Cultural-historical activity theory. *Review of Educational Research, 77*(2), 186–232.
Sawyer, R. K. (2006a). Educating for innovation. *Thinking Skills and Creativity, 1*(1), 41–48.

Sawyer, R. K. (2006b). Introduction: The new science of learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 1–16). Cambridge: Cambridge University Press.

Solomon, J., & Hall, S. (1996). An inquiry into progression in primary technology: A role for teaching. *International Journal of Technology and Design Education, 6*(3), 263–282.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wendell, K., Kendall, A., Portsmore, M., Wright, C. G., Jarvin, L., & Rogers, C. (2014). Embedding elementary school science instruction in engineering design problem solving. In S. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 143–162). Lafayette: Purdue University Press.

Wilson, E. O. (2002). The power of story. *American Educator, 26*(1), 8–11.

Zubrowski, B. (2002). Integrating science into design technology projects: Using a standard model in the design process. *Journal of Technology Education, 13*(2), 48–67.

The Nature of Interdisciplinary STEM Education

14

Michael K. Daugherty and Vinson Carter

Abstract

Interdisciplinary STEM education is the pedagogical approach by which students learn the interconnectedness of the disciplines of science, technology, engineering, and mathematics. Interdisciplinary STEM education also provides a platform to introduce problem-based learning, cooperative learning, expand problem-solving capabilities, and introduce students to the use of engineering design. Several research studies suggest that when students are introduced (early) to the STEM disciplines through integrated and problem-centered learning activities, they are more likely to remain engaged throughout formal education and are more likely to enter one or more of these fields as a career.

Keywords

STEM Education • Integration • Interdisciplinary learning • Problem and project-based learning • Performance-based assessment • Integrated STEM curriculum

Contents

M.K. Daugherty (✉) • V. Carter
Department of Curriculum and Instruction, University of Arkansas, Fayetteville, AR, USA
e-mail: mkd03@uark.edu; vcarter@uark.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_12

Introduction

Early efforts to organize the technology education curriculum resulted in borrowing content from adjoining and related disciplines and integrating that content in a single course of study. For example, early drafting courses borrowed heavily from conceptual information typically delivered in mathematics or geometry courses. The desire for students to learn in an integrated fashion can be found in the United States dating back to the founding of the nation. Indeed, the first State of the Union address offered by President George Washington called upon educational leaders in the young nation to establish schools that focused on the promotion of literature, arts, and sciences (The American Presidency Project 2016).

Perhaps due to the lack of a concrete, defining body of knowledge other than an attempt to mirror the practices of industry, technology education has a long history of drawing content from related disciplines like engineering, science, the arts, mathematics, and others. During the nineteenth and early twentieth Centuries in the US, the field of technology education was referred to as manual training, manual arts, and then industrial arts and the rationale for much of the content of those areas was its necessity for national industrial success. The same is true in many other countries. In the latter half of the twentieth Century the field in the USA transitioned to what is now known as technology and engineering education and the curriculum began to draw heavily from science, technology, engineering, and mathematics (International Technology and Engineering Educators Association (ITEEA) 2007).

Vars (1991), noted that an integrated school curriculum is an attempt to help students make sense out of the multitude of fragmented and departmentalized bits of knowledge offered in most schools. Technology education has the potential to be the discipline that would reduce curricular fragmentation through the integration of content from other disciplines. This integration is a clear departure for some of the more traditional program offerings (Daugherty 2005). This curricular integration could involve multidisciplinary or thematic integration, interdisciplinary teams, and intradisciplinary integration (Drake and Burns 2004). Thematic integration involves faculty selecting a common theme that cuts across several disciplines and then delivering instruction related to that theme in different fields of study. Meanwhile, interdisciplinary teaching involves a team of teachers from different disciplines who are encouraged to correlate at least some of their teaching. In an intradisciplinary curriculum, one teacher may take on the responsibility for instruction in several subjects during an extended period of study within a single subject area (Drake and Burns 2004). Even though most in the field of technology education would refer to the curriculum as interdisciplinary, it is likely better defined as intradisciplinary.

As the world entered the twenty-first Century, it became more technologically complex. At the same time, researchers made new discoveries related to learning, and it became evident that forming connections between the disparate components of the school curriculum was essential (Drake and Burns 2004). The integration of the STEM disciplines was perceived to have the potential to aid students in their ability to transfer learning from one discrete field to another as was necessary to solve the problems at hand (Berry et al. 2004). In an integrated setting, students can solve new problems and often draw conclusions based upon previously learned principles drawn from fields like science, technology, engineering, and mathematics (Roberts 2012). Havice (2009) noted that implementing teaching strategies, such as problem-based learning through a STEM curriculum, may also reinvigorate students' desires to understand the world around them and engage them further in classroom instruction.

Roberts (2012) suggested that integrated STEM programs are based on some common characteristics. First, they are integrated utilizing a curriculum centered on principles from science, technology and engineering, and mathematics, where students learn to apply information to creatively seek solutions to given engineering design problems. Second, integrated STEM education is inquiry-based and centered on solving engaging design problems that require the application of information from science, mathematics, and engineering fields. Distinct from the traditional science or mathematics classrooms, which are typically lecture-based or teacher directed, integrated STEM classrooms in technology education require students to work together to solve problems while utilizing questioning techniques, research, and experimentation (Roberts 2012). Finally, integrated STEM incorporates instruction in the "soft skills" needed for business and industry like collaboration, partner dependence, journaling, and design thinking (Partnership for 21st Century Skills 2003).

Unfortunately, the STEM acronym has also been politicized and is often attached to initiatives that have little to do with integrated, inquiry-based, and problem-centered learning. In some cases, the STEM title is used to attract attention and perhaps funding. Bybee (2010) noted that numerous conflicting definitions of integrated STEM may be damaging the effort put forth in high-quality programs that increase participation in the STEM disciplines and suggested that it is important that the STEM education community resolve the definition of the STEM acronym. While many researchers have suggested that STEM education be implemented using an integrated approach to better serve students (Atkinson and Mayo 2010; Mahoney 2010; Sanders 2009a; Satchwell and Loepp 2002), STEM is often attached to curricula and programs that primarily focus on a single discipline and curriculum projects that are obviously not integrated. Meanwhile, numerous research studies conducted in the technology education field have found that an interdisciplinary or integrated curriculum provides students with a meaningful classroom experiences that augment learning (Bybee et al. 1991; Furner and Kumar 2007; LaPorte and Sanders 1993; Loepp 1999; Sanders 2009; Satchwell and Loepp 2002).

Interdisciplinary STEM

Honey et al.'s (2014) report on STEM Integration in K-12 Education defined STEM integration as "working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines" (p. 52). STEM education has received increasing attention over the past decade with calls both for greater emphasis on these fields and for improvements in the quality of instruction. In response, numerous new curriculum projects, instructional materials, and teaching approaches have emerged, however leaders in technology education continue to call for more emphasis on the connections between and among the subjects of STEM (Sanders 2009). Advocates for greater integration of the STEM subjects argue that teaching STEM in a more connected way, especially in the context of real-world problems, can make the STEM subjects more relevant to students (Honey et al. 2014). Solutions to problems in society are rarely solved using the knowledge, tools, and skills from one discipline. Often, the unique content, techniques, and contributions from each of the STEM disciplines is used to tackle even the messiest problems that humans encounter. Ideally, interdisciplinary STEM learning mimics authentic real-world problem solving.

Interdisciplinary educational efforts have long been implemented to mirror this concept in the classroom. However, the structure of public schools systems, especially at the secondary level, may stifle collaboration and integration of subject matter. Mahoney (2010) suggests in his study of students' attitudes toward STEM learning that the development of national content standards which advocate for content integration, call educators to action to provide students with opportunities for interdisciplinary learning to "enhance student learning and STEM preparation" (p. 24). This concept was reconfirmed with the releases of the Common Core State Standards for English Language Arts and Mathematics in 2010 (CCSS 2016) and the Next Generation Science Standards in 2013 (NGSS Lead States 2013), all of which provided specific references for the integration of content and interdisciplinary learning and began to elevate the stature of engineering design as a curricular construct.

Additionally, multiple efforts to integrate disciplinary content outside of the STEM disciplines have been seen in recent years. Daugherty (2013) suggested that the integration of the arts into STEM education may be important for the promotion and development of creativity and innovation. Furthermore, Wilson-Lopez and Gregory (2015) described the symbiotic relationship between engineering and literacy in elementary school, and how the engineering design process can be an important tool for engaging students in reading and writing instruction.

Delivering Interdisciplinary STEM Content Through Engineering Design

The engineering design method of inquiry is regarded by some to be the cornerstone of integrated STEM education (Basham and Marino 2013; Berland 2013; Brophy et al. 2008; Stohlmann et al. 2012) and is a tool for fostering creativity, innovation, and inventiveness among student participants. Engineering design can be regarded as the core problem solving process of technology education and is increasingly known as a foundational methodology for all integrated STEM curricula. According to Standards for Technological Literacy:

> It is as fundamental to technology as inquiry is to science and reading is to language arts. To become literate in the [engineering] design process requires acquiring the cognitive and procedural knowledge needed to create a design, in addition to familiarity with the process by which a design will be carried out to make a product or system. (ITEEA 2000, p. 90)

Individuals working in the STEM fields have a number of well-defined methods they use to arrive at logical solutions to the problems they encounter, all of which share common traits (ITEEA 2000). First, designers and innovators set out to meet certain design criteria or solve a given problem. Second, designers must work under constraints such as money, materials, time, and human resources. Finally, a set of logical procedures or steps are used to work toward a reasonable solution to the given problem (ITEEA 2000; Wells 2016). In STEM education, these procedures or steps may be called the engineering design process, the design loop, or a design method. The engineering design process demands critical thinking, the consideration of core concepts from the STEM disciplines, the application of technical knowledge, and creativity. There are numerous models found in the literature (Wells 2016) that attempt to describe the engineering design process. Some of the most widely accepted models illustrate the engineering design process as a loop, circle, or spiral of procedures that, if loosely followed lead to a successful conclusion (ITEEA 2000). These engineering design model attempts to represent the process as an iterative method that includes processes like: Clearly defining the problem, generating multiple potential ideas/solutions, building models and prototypes and testing them, and communicating the results of the effort.

Engineering design can be reasonably defined as a series of steps that engineering teams use to guide them as they solve problems. Thus, engineering design has become an integral component of pedagogy in integrated STEM education. The engineering design process is cyclical, meaning that engineers or problem solvers repeat a series of steps as many times as needed to reach an acceptable conclusion, making improvements along the way. Although there is no single accepted engineering design process, it typically consists of steps or procedures like: (1) conduct research and gather information, (2) conduct rough ideation, (3) propose multiple potential solutions, (4) create a representative model, (5) create a prototype, (6) test the solution; and, (7) communicate the results. Koen (2003) notes that the engineering design process provides a plausible aid or direction in the solution of a problem, but is often an ill-structured method of ideation.

In the simplest terms, the engineering design process (see Fig. 1 below) can be considered to be an algorithm, or a set of steps to follow in an attempt to solve a given problem. The engineering design process, mathematical equations, and computer programs are types of algorithms. The scientific community uses scientific inquiry in a similar fashion. Meanwhile, all sorts of technicians use analogous techniques or steps to diagnose and repair equipment and machinery. For example, a technician repairing an automobile often seeks to identify the fault in the vehicular system by first making certain that vehicle has fuel, spark, air, and compression – the four ingredients necessary for internal combustion engines to operate (Tracy 2015). In a more formal sense, these learning algorithms are referred to as heuristics that

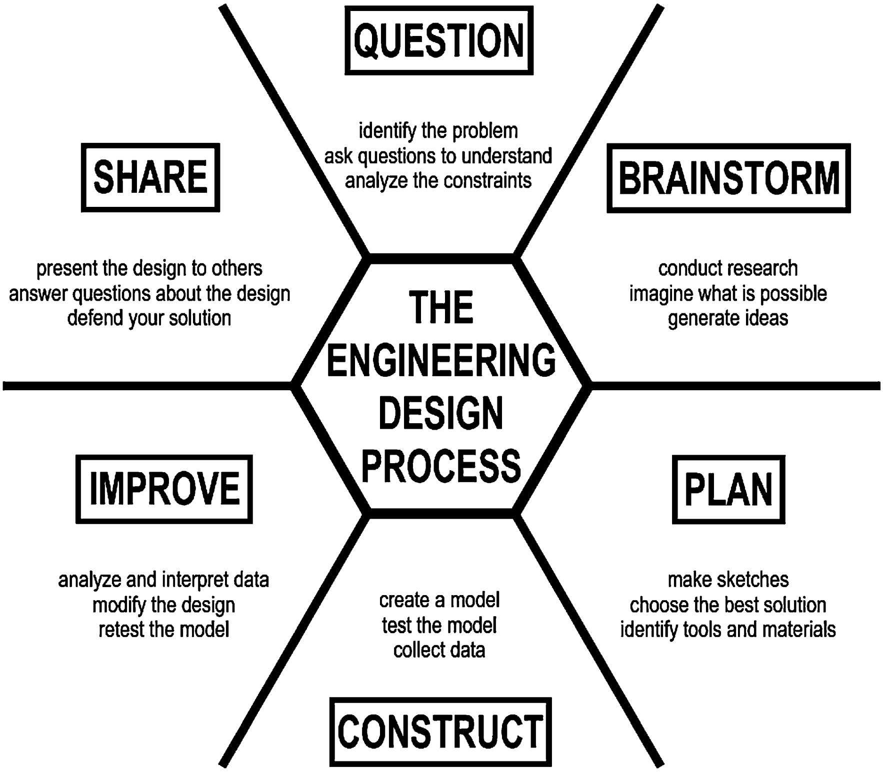


Fig. 1 Example of the engineering design process developed through a collaboration between the University of Arkansas and Springdale Public Schools

support the logical thinking skills and deductive reasoning methods needed to solve STEM problems. A heuristic is a mental shortcut that gives some directions or hints for successfully completing a task or for solving a problem. Engineers and technicians frequently use synonyms for heuristics like intuition, rule of craft, guiding thread, or rule of thumb (Koen 2003). These synonyms vary from country to country. For example, in France the intuition used to solve a technical problem could be referred to as le pif (the nose), in Germany, Faustregel (the fist), in Russia, by the fingers, or in Japan, measuring with the eye (Koen).

While engineering design does not guarantee success, it does provide the problem solver with some practical tools useful for deductive reasoning and for arriving at reasonable solutions to ill-structured problems (Petroski 1992). Pahl and Beitz (2015) noted that engineers use engineering design as a method for applying scientific and engineering knowledge to the solution of technical problems, and then optimize those solutions within the parameters and constraints presented by the original problem. Problems become concrete tasks through the deductive reasoning presented through the implementation of engineering design (Pahl & Beitz). Although solving engineering, or STEM problems calls for sound grounding in mathematics, physics, chemistry, mechanics, and other disciplines; initiative, resolution, tenacity, teamwork, and other psychological skills that are indispensable to the problem solver or designer (Pahl & Beitz). Engineering design emphasizes both the tangible and intangible, as well as the iterative nature of STEM problem solving. This process also provides an invaluable tool for teachers attempting to deliver agreed upon standards for learning.

The Integrated STEM Curriculum

With the popularity and increased emphasis of STEM and project or problem-based learning (PBL) instruction in schools, a plethora of commercially available curricula became available for educators early in the twenty-first Century.

There are a variety of curricular opinions for educators seeking an appropriate STEM curriculum. While off-the-shelf curricula provide educators with readily available materials, these materials sometimes lack the local buy-in that will be critical if lasting change is to be created. Subsequently, many STEM educators and technology education teachers develop their own project-based, engineering design driven, performance-based assessment STEM curriculum. These curricula are based on authentic STEM problems drawn from the local community and connected with the learners. Most STEM educators utilize the backwards curriculum design process popularized by Wiggins and McTighe (2005). This curriculum planning process provides a structure to guide curriculum, assessment, instruction, and to meet learning standards. Backwards curriculum design is focused on teaching and assessing for understanding and learning transfer, and starting the planning process with the desired outcome as a guide (Wiggins and McTighe 2005).

The Role of the STEM Teacher

The role of the STEM teacher is similar to the teacher in any project or problem-based learning (PBL) environment. The characteristics of a PBL classroom include the teacher as a facilitator of learning, the students are responsible for self-directed and regulated learning, and learning is comprised of ill-structured learning challenges (Savery 2006). Savery contends that one of the most difficult challenges for teachers in a PBL learning environment is the transition into the role of a facilitator.

A chief concern in STEM education is the preparation of educators with both content knowledge and the ability to integrate STEM education learning into the K-12 classroom (Stohlmann et al. 2012). Honey, et al. contended that the:

> The expertise of educators, whether in classrooms or in after-/out-of-school settings, is a key factor – some would say the key factor – in determining whether the integration of STEM can be done well. At the most basic level, educator expertise combines knowledge of the subject matter with an understanding of effective approaches for teaching it to students with diverse learning styles. Such approaches include not only teaching strategies but also the

skill with which educators plan lessons and work collaboratively to support student learning (Honey et al. 2014, p. 115).

Stohlmann et al. (2012) identified a model for teaching integrated STEM education. Their model consists of four major components including opportunities for collaboration and professional development, teaching with focus on integrated lesson planning and effective classroom practices, efficacy and a commitment to STEM education, and access to materials and resources needed to implement instruction. The increased emphasis on STEM education and the ambiguity of how it should be taught provide an opportunity for the technology education profession. The technology education profession can stake the claim for teaching engineering at the K–12 level, align with the engineering profession, and reform its instructional practices to reaffirm its place in the core curriculum (Strimel and Grubbs 2016).

The Promise of Early Intervention

A number of research reports indicate that children's ambitions and confidence in science and other STEM areas are largely formed by the time they are 10–14 years old and diverge little after this age (Murphy 2011; Archer et al. 2012, 2013; DeJarnette 2012). Because interest in STEM subjects and STEM careers is largely formed by the time children reach the upper elementary or middle school level, it is vital that children be engaged in rich STEM learning experiences in early elementary grades, long before the point at which they enroll in courses leading to eventual career paths during high school and college. Unfortunately, most STEM initiatives and projects, especially in the USA, are launched at the secondary school level – long after the majority of students have made the decision that they do not like science, or that they are not good at math. Many of these students avoid the STEM disciplines for the rest of their lives and programs designed to engage them are too little, too late (Daugherty et al. 2014).

The combined effects of educational reforms and accountability demands arising from recent technological and economic changes are requiring schools to accomplish something they have never been required to accomplish previously – substantially ensure that all students achieve at a relatively high level academically (Corcoran and Silander 2009). Meeting that challenge has required educational leaders to reexamine the curriculum, the instructional delivery system, and the level at which core subjects are taught. Unfortunately, if STEM was emphasized at all, most schools started STEM instruction at the secondary school level (Means et al. 2008). In 2008, Means, et al. found that there were 315 public schools in the United States that referred to themselves as STEM schools and 86% of those schools served students in grades 9–12 while only 3% served students in grades 1–5. Anthony Murphy, Executive Director of the National Center for Elementary STEM Education, noted that we need to begin STEM education in elementary school and possibly even younger (2011). Murphy goes on to note that very young children are natural scientists, engineers, and problem-solvers. They try to make sense of the world by touching, tasting, building, dismantling, creating, discovering, and exploring. Yet, research documents that by the time students reach 4th grade, 30% have lost interest in science. By 8th grade, almost 50% have lost interest or deemed it irrelevant to their future. This means that millions of students are tuning out or lack the confidence needed to pursue a future in STEM fields.

When Pantoya et al. (2015) asked over 300 3–7 year olds “What do engineers do?” during a research project designed to develop engineering identities, the most common response was: “I don’t know.” The 2nd most common response was: “They drive a train.” These responses reflect a fundamental lack of understanding of engineering. Other research points out that by the 4th grade, students who have limited exposure to early STEM education lack key mathematics and science skills and background knowledge (Successful STEM Education 2013; National Research Council 2011; Honey et al. 2014). As noted above, by the 4th grade there is a decline in STEM interest and this decline has been linked to a lack of consistent focus in science and math content, as well as a lack of instructional methods that shape young children’s curiosity to explore the world around them (Kang and Lundeberg 2010); and a lack of focus on scientific literacy (Gibbons 2003). Pantoya et al. (2015) argue that “early experiences are critical to developing a students’ engineering identity” (p. 61).

After examining a variety of elementary STEM programs across the nation, Dejarnette (2012) noted that students who complete STEM programs in high school have a greater likelihood of continuing in a STEM concentration for college/careers and the same would occur between the elementary school and the middle school if STEM programs were expanded during the early grades. To increase the number of students interested in STEM at the middle school and high school, these concepts should be presented during the elementary grades. In secondary education, effective teachers with content knowledge in STEM play a key role in student achievement. Almost all of these secondary STEM teachers have a degree in one of the STEM disciplines, but elementary teachers are generalists and typically major in education. It should not surprise anyone to learn that elementary teachers are somewhat apprehensive about teaching STEM – in large part because, they were not prepared to teach some of the disciplines represented in STEM effectively. If they lack confidence, they are likely to avoid teaching STEM.

Elementary STEM education that includes vast opportunities for students to engage in project-based learning, the engineering design process, integrated content from adjoining disciplines, and performance-based assessment must become a defining goal of technology education (Daugherty et al. 2014). Such programs will not only inspire heightened levels of curiosity, creativity, and innovation among participating students, but will also ensure that the next generation will have a markedly greater understanding of the core concepts of science, technology, engineering, and mathematics.

Conclusion and Future Directions

STEM education has gained widespread attention from educators, politicians, state and federal agencies, and the media. This attention is often connected to the assumption that children are retreating from the STEM fields, which may lead to decreases in national and international competitiveness. Subsequently, there have been calls for transformation, new standards have been developed, governmental agencies have issued reports, and many leaders have called for an increased treatment of STEM education in schools.

Meanwhile, technology education, with a long history of integrating content from related disciplines, seems an ideal program to cement STEM into the school setting. In 2000, Standards for Technological Literacy was published in the USA and this document made the case that technology education should play a role in students' learning STEM. Moreover, Standards for Technological Literacy, as well as standards from the fields of science and mathematics, called for increased attention to an integrated curriculum and less emphasis of disciplinary fragmentation and departmentalization. As the world entered the twenty-first Century and became more technologically complex, researchers developed evolved theories related to learning, and it became evident that forming connections between the STEM disciplines in school was essential.

Other researchers began to note that in addition to the integration of content from the STEM disciplines, such programs should utilize instructional strategies focused on authentic problem solving and creativity, as well as inquiry-based engineering design problems and performance assessment. These advocates called for STEM education to be delivered in a more connected way, especially in the context of real-world problems, making integrated STEM subjects more relevant to students – fostering creativity, innovation, and inventiveness among student participants.

Other researchers noted that such STEM programs should be launched much earlier in the educational process. A number of research reports indicated that children's ambitions and confidence in STEM was largely cemented by the time they were 10–14 years old and that it was vital that children be engaged in rich STEM learning experiences in early elementary grades, long prior to making eventual career decisions.

The nature of interdisciplinary STEM education is in flux, however opportunities await those educators seeking to develop and implement interdisciplinary educational programs that center upon core content from the STEM disciplines. Particularly those educators who desire to deliver such programs through engaging and authentic, project-based learning mechanisms at an early age.

References

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B., (2012). Science aspirations and family habitus: How families shape children's engagement and identification with science. *American Educational Research Journal, 49*(5), 881–908.

Archer, L., Osborne, J., Dewitt, J., Dillon, J., Wong, B., & Willis, B. (2013). *ASPIRES: Young people's science and career aspirations, age 10–14*. London: King's College London. Retrieved from: http://www.kcl.ac.uk/sspp/departments/education/research/aspires/ASPIRES-final-report-December-2013.pdf.

Atkinson, R., & Mayo, M. (2010). Refueling the U.S. innovation economy: Fresh approaches to science, technology, engineering and mathematics (STEM) education (December 9, 2010). The Information Technology & Innovation Foundation.

Basham, J. D., & Marino, M. T. (2013). Understanding STEM education and supporting students through universal design for learning. *Teaching Exceptional Children, 45*(4), 8–15.

Berland, L. K. (2013). Designing for STEM education. *Journal of Pre-College Engineering Education Research, 3*(1), 22–31.

Berry, R., Reed, P., Ritz, J., Lin, C., Hsiung, S., & Frazier, W. (2004). STEM initiatives: Stimulating students to improve science and mathematics achievement. *The Technology Teacher, 64*(4), 23–29.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education, 97*, 369–387.

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher, 70*, 30–35.

Bybee, R. W., Powell, J. C., Ellis, J. D., Giese, J. R., Parisi, L., & Singleton, L. (1991). Integrating the history and nature of science and technology in science and social studies curriculum. *Science Education, 75*, 143–155.

Common core state standards for English Language Arts. [Internet]. National Governors Association Center for Best Practices & the Council of Chief State School. 2016 [cited 28 June 2016]. Available from: http://www.corestandards.org/assets/CCSSI_ELA%20Standards.pdf

Common core state standards for mathematics. [Internet]. National Governors Association Center for Best Practices & the Council of Chief State School. 2016 [cited 28 June 2016]. Available from: http://www.corestandards.org/wp-content/uploads/Math_Standards1.pdf

Corcoran, T., & Silander, M. (2009). Instruction in high schools: The evidence and the challenge. *The Future of Children, 19*(1), 157–183.

Daugherty, M. K. (2005). A changing role for technology teacher education. *Journal of Industrial Teacher Education, 42*(1), 41–58.

Daugherty, M. K. (2013). The prospect of an "A" in STEM education. *Journal of STEM Education, 14*(2), 10–15.

Daugherty, M. K., Carter, V., & Swagerty, L. (2014). Elementary STEM education: The future for technology and engineering education? *The Journal of STEM Teacher Education, 49*(1), 45–56.

DeJarnette, N. (2012). America's children: Providing early exposure to STEM (science, technology, engineering and math) initiatives. *Education, 133*(1), 77–84.

Drake, S. M., & Burns, R. C. (2004). *Meeting standards through integrated curriculum*. Alexandria: ASCD/Author.

Furner, J. M., & Kumar, D. D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science & Technology, 3*(3), 185–189.

George Washington: First annual message to Congress on the State of the Union [Internet]. Presidency.ucsb.edu. 2016 [cited 28 June 2016]. Available from: http://www.presidency.ucsb.edu/ws/?pid=29431

Gibbons, P. (2003). Mediating language learning; Teacher interactions with ESL students in a content-based classroom. *TESOL Quarterly, 37*(2), 247–273.

Havice, W. (2009). The power and promise of a STEM education: Thriving in a complex technological world. In ITEEA (Ed.), *The overlooked STEM imperatives: Technology and engineering* (pp. 10–17). ITEEA: Reston.

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: National Academies Press.

International Technology and Engineering Educators Association (ITEA/ITEEA). (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed.). Reston: Author.

Kang, H., & Lundeberg, M. A. (2010). Participation in science practices while working in a multimedia case-based environment. *Journal of Research in Science Teaching, 47*(9), 1116–1136.

Koen, B. V. (2003). *Discussion of the method: Conducting the engineer's approach to problem solving*. New York: Oxford University Press.

LaPorte, J., & Sanders, M. (1993). Integrating technology, science, and mathematics in the middle school. *The Technology Teacher, 52*(6), 17–21.

Learning for the 21st century: A report and mile [Internet]. Partnership for 21st Century Skills. 2016 [cited 28 June 2016]. 2003. Available from: http://www.p21.org/storage/documents/P21_Report.pdf

Loepp, F. L. (1999). Models of curriculum integration. *Journal of Technology Studies, 25*(2), 21–25.

Mahoney, M. (2010). Students' attitudes toward STEM: Development of an instrument for high school STEM-based programs. *Journal of Technology Studies, 36*(1), 24–34.

Means, B., Confrey, J., House, A., & Bhanot, R. (2008). *STEM high schools: Specialized science, technology, engineering, and mathematics secondary schools in the United States*. Menlo Park: SRI International.

Murphy, T. (2011). *STEM education – It's elementary. St. Catherine University, National Center for STEM elementary education*. St. Paul: St. Catherine University Press.

National Research Council (US). Committee on Highly Successful Schools or Programs for K-12 STEM Education. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states by states*. Washington, DC: The National Academies Press.

Nurturing STEM skills in young learners, preK-3. [Internet]. Successful STEM Education. 2016 [cited 28 June 2016]. 2013. Available from: http://successfulstemeducation.org/sites/successfulstemeducation.org/files/STEM%20Smart%20Brief-Early%20Childhood%20Learning.pdf

Pahl, G., & Beitz, W. (2015). *Engineering design: A systematic approach* (2nd ed.). Darmstadt: Springer.

Pantoya, M., Aguirre-Munoz, Z., & Hunt, E. Developing an engineering identity in early childhood [Internet]. American Journal of Engineering Education. 2016 [cited 28 June 2016]. 2015. Available from: http://files.eric.ed.gov/fulltext/EJ1083229.pdf

Petroski, H. (1992). *To engineer is human: The role of failure in successful design*. New York: Vintage Books.

Roberts, A. A justification for STEM education. [Internet]. Iteea.org. 2016 [cited 28 June 2016]. 2012. Available from: https://www.iteea.org/File.aspx?id=86478&v=5409fe8e

Sanders, M. (2009a). Integrative STEM education: Primer. *The Technology Teacher, 68*(4), 20–26.

Sanders, M. (2009b). Technology teacher education in the United States. In *Essential topics for technology educators: 58th yearbook of the Council of Technology Teacher Education*. New York: Glencoe McGraw-Hill.

Satchwell, R., & Loepp, F. L. (2002). Designing and implementing an integrated mathematics, science, and technology curriculum for the middle school. *Journal of Industrial Teacher Education, 39*(3). Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v39n3/satchwell.html

Savery, J. Overview of problem-based learning: Definitions and distinctions. [Internet]. Docs.lib.purdue.edu. 2016 [cited 28 June 2016]. 2006. Available from: http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1002&context=ijpbl

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research, 2*(1), 28–34.

Strimel, G., & Grubbs, M. (2016). Positioning technology and engineering education as a key force in STEM education. *Journal of Technology Education, 27*(2), 21–36.

Tracy, D. Here's how to diagnose an engine that won't start. [Internet]. Jalopnik.com. 2016 [cited 28 June 2016]. 2015. Available from: http://jalopnik.com/heres-how-you-diagnose-an-engine-that-wont-start-1717491831

Vars, G. Integrated curriculum in historical perspective. [Internet]. Middle Grades Curriculum. 2016 [cited 28 June 2016]. 1991. Available from: http://middlegradescurriculum.yolasite.com/resources/Int.%20Curr.%20VARS.pdf

Wells, J. G. (2016). Pirposal model of integrative STEM education: Conceptual and pedagogical framework for classroom implementation. *Technology and Engineering Teacher, 75*(6), 12–19.

Wiggins, G., & McTighe, J. (2005). *Understanding by design*. Alexandria: Association for Supervision and Curriculum Development.

Wilson-Lopez, A., & Gregory, S. (2015). Integrating literacy and engineering instruction for young learners. *The Reading Teacher, 69*(1), 25–33.

Engineering and Technology Concepts: Key Ideas That Students Should Understand 15

Michael Hacker

Abstract

Competencies people need to be well educated will vary in response to societal waves of change. As STEM education grows in popularity worldwide, interest is increasing in using this paradigm to break down the traditional conception of the four component subjects as individual "silos" of science, technology, engineering, and mathematics. In the United States, Engineering and Technology education (ETE) is seen as a route through which the four disciplines can be integrated. In Europe, 30 countries promote and support STEM collaboration.

The evolution of ETE from its craft-oriented and industrial roots has resulted in a demand for new curriculum – driven not only by contemporary workforce and employability demands but by other values-driven aspirations that educators, parents, and policy makers hold for students.

Since the 1980s, conceptual learning has been defined by curricular learning standards and associated performance expectations (often quite numerous) that, when attained, are presumed to provide disciplinary competence. In this chapter, the author suggests that revisiting a small set of transferable ETE thematic ideas in different contexts can complement learning of standards-based domain-specific concepts and skills. Doing so would make instruction more manageable and enable students to assimilate a more holistic understanding of engineering and technology.

The chapter draws upon research studies that established a consensus of expert opinion about the most important ETE competencies high school students should attain within five thematic categories that consistently appear in the literature: (a) design, (b) modeling, (c) systems, (d) resources, and (e) human values.

Two case studies are offered as examples. The first exemplifies how a cutting-edge technology company looks to hire new employees with a broad mix of skills. The second describes a new ETE curriculum model that integrates

M. Hacker (✉)
Hofstra University Center for STEM Research, Hempstead, NY, USA
e-mail: Michael.hacker@hofstra.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_15

important concepts within authentic social contexts and supports the fundamental purposes of education.

Keywords
Concepts • Conceptual learning • Contexts • Engineering education • Technology education

Contents

Introduction

There is growing recognition that school-based ETE experiences can be pedagogically valuable for all students – not only in providing an effective way to contextualize and reinforce STEM skills but also in mobilizing engineering thinking as a way for young people to approach problems of all kinds (Brophy and Evangelou 2007; Forlenza 2010).

A literature review indicates that transferable concepts in engineering and technology education relate to five broad categories of knowledge, including design, modeling, systems, resources, and human values (Katehi et al. 2009; Custer et al. 2010; NRC 2010; Rossouw et al. 2010; NGSS 2012; NCES 2014; Hacker and Barak 2017).

A Comparison of Perceptions Delphi study (Hacker 2014) identified 38 competencies within those five ETE categories that are most important for students to understand, based on a consensus of opinions of expert university-based Academic Engineering Educators (AEEs) and high school Classroom Technology Teachers (CTTs) (see Table 2, p. 7).

However, conceptual learning must be embedded in contexts that are important and authentic to students for them to be truly engaged in the learning process. Moreover, instructional interventions must not lose sight of the fundamental purposes of education to remain focused on meeting individual and societal needs.

Conceptual Learning

Many books and papers have been written to explain the essence of a concept (Bealer 1998; Smith 1989; Peacocke 1992; Rey 1995; Earl 2006). Concepts can be thought of as ideas, abilities (the concept TREE implies the ability to distinguish a tree from a bush), or referents and senses (Frege 1892) where a *referent* is the proper name of an object and the *sense* is what the name expresses. A concise definition is that a concept is "a general idea about a thing or group of things, derived from specific instances or occurrences" (vocabulary.com 2016).

According to Merrill et al. (1992), "a concept is a set of specific objects, symbols, or events which are grouped together on the basis of shared characteristics and which can be referenced by a particular name or symbol." (p. 6). Naming a concept makes the concept understandable and useful and is critical to discussing it.

Margolis and Laurence (2011) define concepts as the constituents of thought. Fodor (1998) considered concepts so fundamental to cognition that he declared that "the heart of a cognitive science is its theory of concepts" (p. vii). Dogar (2015) suggests that "a concept is a generalization from experience" (p. 3). Webster's Dictionary defines a concept as "an idea, especially a generalized idea of a class of objects; a general notion" (Webster and McKechnie 1979, p. 376).

Conceptual Understanding

Conceptual understanding occurs when broad concepts are revisited in different contexts and deepens through inductive reasoning. Thus, conceptual understanding depends upon people having the ability to generalize from their experiences and argues for the need to *teach for transfer*. According to Earl (2006), conceptual understanding and cognition are related in that:

> Our understanding and interaction with the world involves concepts and our grasp of them. Our understanding that a given thing is a member of a given category is at least partly in virtue of our grasp of concepts, and so are our acts of categorizing. (p. 1)

Teaching for Conceptual Understanding

Erickson (2008) stated that "Concepts are the foundational organizers for curriculum design. They serve as a bridge between topics and generalizations. A conceptually organized curriculum helps solve the problem of the overloaded curriculum" (p. 23).

Bransford et al. (2000) maintain that to develop competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application (p. 16).

Donovan and Bransford (2005) concluded that “concepts must be placed in a conceptual framework to be well understood and take on meaning in the knowledge-rich contexts in which they are applied.” To deepen conceptual understanding and facilitate learning transfer, students should encounter the same concept in a variety of contexts (de Vries 2010; Bransford et al. 2000).

The development of conceptual understanding includes placing content knowledge and skills within universal themes and engaging students in active learning (Erickson 2008 as cited by Edwards and Edwards 2013). Conceptual learning, therefore, implies an understanding of broad, overarching ideas in context, rather than the learning of discrete bits of content. Parker (2013) asserted that:

> There are two key parts to concept formation. Students begin by studying multiple examples of the concept to be learned, and the teacher helps them see the similarities across the examples. When the similarities are established in students’ minds, they form the concept. But the teacher needs to find examples that students of a particular age can grasp, and simplify the critical characteristics as needed.

Teaching for deep conceptual understanding in engineering and technology education therefore invites teachers and students to (a) place big ideas into thematic categories such as design, systems, modeling, resources, and human values, (b) identify how big ideas manifest themselves in a variety of apparent and familiar contexts, and (c) revisit these big ideas in contexts that may be more complex and less familiar.

Content Standards and Performance Expectations

Rather than focusing on teaching for deep conceptual understanding, professionals in education have instead developed and relied upon sets of discipline-based content standards, performance indicators, and high-stake assessments mapped to these standards and performance indicators. Frequently, the standards are atomistic in nature.

Content standards are “descriptions of the knowledge and skills students should acquire in a particular subject area” (NRC 2008), and standards have been developed within most school disciplines. These have largely been developed by highly regarded educators representing communities of interest (discipline-based practitioners). The excellent reputations of these highly experienced experts lend great credibility to their development efforts, but we are often impelled by standards into addressing competencies that even highly educated people outside the community of practitioner-developers might question as being necessary for *all* students to attain as part of their fundamental education. Questionable examples from the Common Core Standards for Mathematics (NGA 2010) include the following performance expectations:

HSN-CN.A.3: Use conjugates to find moduli and quotients of complex numbers.
HSF.LE.B.5: For exponential models, express as a logarithm the solution to $ab^{ct} = d$ where a, c, and d are numbers and the base b is 2, 10, or e.
HSA.APR.C.4: Prove polynomial identities and use them to describe numerical relationships. *For example, the polynomial identity* $(x^2 + y^2)^2 = (x^2 - y^2)^2 + (2xy)^2$ *can be used to generate Pythagorean triples.*

A National Academy of Education (NAoE) Policy White Paper titled *Standards, Assessments, and Accountability* opines that "the political solution of adding in everyone's favorite content area topic created overly-full, encyclopedic standards in some states, or vague, general statements in others" (NAoE 2009, p. 3). The NAoE indicated that findings from cognitive science research make it at least *theoretically* (emphasis added) possible to focus instruction on depth of understanding, but the report cautioned that extrapolating from small-scale, intensive studies to full-system reform was an unprecedented task.

The emphasis on standards (and the high-stake assessments based upon them) has led to what has become a hugely profitable private-sector enterprise of developing standardized tests at all levels of the education continuum. In the US state of Texas alone, Pearson Corporation will have been paid $428 million for the current 5-year assessment development contract (Weiss 2015).

The Engineering and Technology Education Conceptual Knowledge Base

There are inconsistencies and confusion about the term "technology concepts." According to Kipperman (2009):

> There is wide consensus about the necessity of teaching technology concepts, yet technology concepts are not consistently defined in the literature and there is still much confusion in the technology education community with regard to what are technology concepts and how to teach technology concepts. Often the nature of technology concepts as big ideas is missing or gets lost in the teaching of craft skills and design and make activities. (p. 279)

The International Technology Education Association (ITEA), now renamed the International Technology and Engineering Educators Association (ITEEA), attempted to identify core ETE concepts in developing the **Standards for Technological Literacy** (STL) to identify what students should know and be able to do to be technologically literate (ITEA 2000).

The publication of STL was a major step forward in identifying educational outcomes needed for life in a technological world (ITEA 2000). However, hundreds of benchmarks have been written in STL and in national and state STEM frameworks, and standards generally have been criticized as vague, repetitive, and poorly coordinated (NRC 2008).

An alternative to developing standards-based curriculum is to invite curriculum developers and decision-makers to think less atomistically (i.e., less in terms of specific standards-based performance indicators) and more holistically (i.e., more in terms of thematic big ideas) about what is important for all students to learn as part of their fundamental education.

From Standards to Thematic Ideas

As content standards have been developed in many disciplines to include myriad student performance objectives, there has also been a move toward identifying overarching and thematic understandings in STEM disciplines to emphasize transferable "big ideas."

In 1963, the Commission on Engineering Education and the US National Science Foundation initiated the **Engineering Concepts Curriculum Project**. The *Man-Made World* was a book that resulted from that project and as a seminal work identified several powerful and transferable engineering concepts, among them modeling, feedback, and stability (ECCP 1971).

The US **National Academy of Engineering** identified 16 categories of engineering concepts, skills, and dispositions for K-12 education. These included Design, STEM Connections, Engineering and Society, Constraints, Communication, Systems, Systems Thinking, Modeling, Optimization, Analysis, Collaboration and Teamwork, Creativity, Knowledge of Specific Technologies, Nature of Engineering, Prototyping, and Experimentation (NRC 2010).

The National Assessment of Educational Progress (NAEP) Technology and Engineering Literacy Assessment consists of technological content areas and technological practices among which are design and systems, information and communication technology, and technology and society.

In a study titled *Formulating a Concept Base for Secondary Level. Engineering: A Review and Synthesis*, Custer et al. (2010) identified 13 major engineering concepts (among them design, systems, and modeling) that were drawn from a variety of sources and by focus groups of engineering experts (Sanders et al. 2012).

In the British *Association for Science Education* report titled *Principles and Big Ideas of Science Education*, international science education experts identified "overarching concepts that cut across domains of scientific ideas." These include systems and modeling (p. 18; p. 23) and ethical, social, economic, and political implications (p. 25). Notably, the report cautions that "further breakdown into a range of narrower ideas is, of course, possible but risks losing the connections between the smaller ideas that enable them to merge into a coherent big idea." (p. 18).

In an international research study titled *Concepts and Contexts in Engineering and Technology Education* (CCETE) (Rossouw et al. 2010), five overarching areas of conceptual understanding were identified in engineering and technology: design, modeling, systems, resources, and human values. See Table 1.

Table 1 Themes and sub-concepts

Themes	Sub-concepts
Design	Optimization and trade-offs, criteria and constraints, iteration
Modeling	Representational, explanatory, predictive
Systems	Systems/subsystems, input-process-output, feedback and control
Resources	Materials, energy, information, time, tools, humans, capital
Human values	Sustainability, technological assessment, creativity/innovation, ethical decisions

The *Comparison of Perceptions* study (Hacker 2014; Hacker and Barak 2017) furthered the work accomplished by the CCETE study by adding more specificity about the most important ETE concepts and skills within the five overarching thematic categories. The study determined where consensus existed (using two consensus factors: interquartile range, IQR, and frequency distribution) among two groups of experts, both concerned with educating students about engineering and technology – university-based academic engineering educators (AEEs, $n = 18$) and high school classroom technology teachers (CTTs, $n = 16$). Using modified Delphi research methodology, the 34 expert and highly experienced educators were surveyed about their perceptions of the most important underlying ETE concepts and skills within the five ETE thematic categories. The study identified a set of 38 domain-specific competencies (12 related to design; six related to modeling; six related to systems; seven related to resources; and seven related to human values) that all high school students in the USA should learn as part of their fundamental education. These competencies were rated and ranked by importance. Whole-group consensus on the importance of survey items is shown in Table 2.

In four of the 38 survey items in the Comparison of Perceptions study, significant differences in the perception of importance (at the $\alpha = 0.05$ level) were found between academic engineering educators and classroom technology teachers. These are shown in Table 3.

Is There Still a Place for Disciplinary Concepts and Skills?

The argument that standards and key ideas should be limited in number and contextualized within holistic overarching ideas does not contravene the need for students to learn salient disciplinary concepts and skills. In the following case study, *Palantir*, a forward-looking state-of-the-art engineering company, sees domain knowledge as necessary, but clearly not sufficient.

Case Study 1: Palantir Corporation Palantir (www.palantir.com) is a company with an engineering culture that "builds products that make people better at their most important work – the kind of work you read about on the front page of the newspaper, not just the technology section" (Palantir 2016a).

Table 2 Comparison of perceptions study items reflecting strongest whole group consensus about important ETE concepts and skills relating to Design (D), Modeling (M), Systems (S); Resources (R); and Human Values (HV)

Item	Survey item wording	IQR	*freq.*
R7	Identify and discuss environmental, health, and safety issues involved in implementing an engineering project	0.79	100
M1	Use representational modeling (e.g., a sketch, drawing, or a simulation) to convey the essence of a design	0.82	100
D6	Explain why a particular engineering design decision was made, using verbal and/or visual means (e.g., writing, drawing, making 3D models, using computer simulations)	0.91	94.1
HV6	Show evidence of considering human factors (ergonomics, safety, matching designs to human and environmental needs) when proposing design solutions	0.91	94.1
R4	Safely and correctly use tools and machines to produce a desired product or system	1.00	95.3
D1	Iteratively design and construct a model or full-scale product, system, process, or environment that meets given constraints and performance criteria	1.09	82.3
R3	Evaluate technological and scientific information for accuracy and authenticity of sources	1.15	87.8
D9	Engage in a group problem-solving activity to creatively generate several alternative design solutions and document the iterative process that resulted in the final design	1.34	85.3
R6	Identify and discuss privacy issues involved in using information resources	1.31	88.3
S1	Label and explain a diagram of a familiar technological system (e.g., a home heating system) that specifies inputs, processes, outputs, feedback, and control components	1.26	88.2
S2	Identify and explain the function of the interacting subsystems that comprise a more complex system	1.27	82.4
D2	Solve engineering design problems by identifying and applying appropriate science concepts	1.23	88.2
D3	Solve engineering design problems by identifying and applying appropriate mathematics concepts	1.3	82.3
M2	Develop a fair test (changing only one factor at a time) and use it to analyze the strengths and limitations of a physical or virtual model of a design	1.29	80.0

Note: For a more in-depth statistical analysis of the study results, see Hacker and Barak 2017

> Engineers build things that solve problems. You don't have to be a computer scientist or have any particular degree to be an engineer. You just have to speak up when things aren't right, evaluate ideas on their merits, and build things that fix what's broken. At Palantir, we're all engineers, and we're focused on solving the hardest problems we can find (Palantir 2016b)

Palantir interviews prospective employees. The interviews include technical questions about data structures, algorithms, and software engineering. For Palantir,

Table 3 Significant differences in median item ratings between AEEs and CTTs based on the Mann-Whitney U Test

Item	Survey wording of item	AEEs (n = 18) medians	CTTs (n = 16) medians	Mann-Whitney U value	D.f.	p-value exact sig. (2-tailed)
D2	Solve engineering design problems by identifying and applying appropriate science concepts	6.35	5.80	81.00	33	.012
D11	Provide examples of how psychological factors (e.g., bias, overconfidence, human error) can impact the engineering design process	5.27	4.69	91.00	33	.049
S5	Explain the difference between an open-loop control system and a closed-loop control system and give an example of each	5.17	5.85	88.50	33	.040
S6	Develop and conduct empirical tests and analyze system and analyze test data to determine how well actual system results compare with measurable performance criteria	6.21	5.36	89.00	33	.046

domain knowledge is very much the coin of the realm. One interview focuses on systems design.

> At Palantir, many of our teams give a systems design interview along with an algorithms interview and a couple of coding interviews. We don't expect anyone to be an expert in all three disciplines. We're looking for generalists with depth – people who are good at most things, and great at some. If systems design isn't your strength, that's okay, but you should at least be able to talk and reason competently about a complex system. (Palantir 2016c)

Undoubtedly there is still a place for teaching and learning disciplinary skills and concepts at Palantir; but Palantir and many contemporary companies have a strong social conscience and expect their employees to contribute to making the world a better place. Palantir's mission is about "protecting privacy and civil liberties; we put our values to work in the service of making the world a better place, every day." To that end, the company is creating slavery-free supply chains, addressing small-plot farmer food security, improving global health, fighting disease outbreaks, and providing humanitarian relief in the wake of natural disasters (Palantir 2016d).

Palantir looks for employees who understand the problem they are asked to solve, break it down into manageable subproblems, try different approaches, model solutions, and ask questions (Palantir 2016e).

But consider that the competencies Palantir seeks are related to design, systems, modeling, resources, and human values (not surprisingly, those that were identified in the CCETE and Comparison of Perceptions studies). These overarching themes are transferable to many different contexts; and it is *context* that enables learners to make sense of their learning – to see how knowledge and skill can be applied in ways that make the world a better place.

Remembering the Fundamental Purposes of Education

Historically, formal education was propagated by institutions as a way of spreading and preserving their traditions (Nagdy and Roser 2016). The goal of education in the Greek city-states was to prepare the child for adult activities as a citizen. According to Plato, the education of mind, body, and aesthetic sense was so that the boys "may learn to be more gentle, harmonious, and rhythmical, and so more fitted for speech and action" (Guisepi 2007). But evidently, not all pedagogy was gentle and harmonious. According to Guisepi (2007), on an ancient Egyptian clay tablet discovered by archaeologists, a child had written: "Thou didst beat me and knowledge entered my head."

Dewey (1897) saw schools not only as a place to gain content knowledge but also as a place to learn how to live. After 1910, vocational education was added, as a mechanism to train the technicians and skilled workers needed by the expanding industrial sector (Church and Sedlak 1976).

What we can too easily forget when focused on specific subject matter is how the enterprise of teaching and learning should, at the end of the day, be fundamentally driven by (and support) the overall purposes of education.

Alfie (1966) was a film that was popular in the mid-1960s starring British actor Michael Caine. The main character, Alfie, was a Cockney chauffer who was a womanizer and a narcissist. After his misadventures, at the film's end, he reflects on his life in the song "What's it all about, Alfie?" (Bacharach and David 1966).

What's it all about Alfie?
Is it just for the moment we live?
What's it all about.
When you sort it out, Alfie?

What would be revolutionary (well, perhaps not revolutionary but certainly provocative and conceivably threatening to groups protecting vested interests) would be to search for curricular significance by returning to the fundamental purposes of education – what Alfie's education should have been all about. We educators help learners:

Cultivate mind, body, and spirit.
Respect and practice honesty and civility.
Earn a living.
Augur toward tolerance and social equity.
Question prejudices.
Derive optimal fulfillment from life's experiences.
Make the world a better place.

Education for today's learners should not lose sight of these fundamental purposes – and it is these purposes that provide the strongest rationale for education.

Educational Change as a Response to Societal Change

What is deemed to be important for people to learn changes over time and evolves in relation to societal waves of change. During the period of exponential growth in the industrial/manufacturing economy in the nineteenth century, Johann Heinrich Pestalozzi developed a whole-child approach to education involving development of three aspects of a person, head, heart, and hands (Lindgren 2013), and established an institute in Yverdon, Switzerland, which melded vocational and general education.

John D. Runkle, when president of the Massachusetts Institute of Technology (from 1870–1878), integrated Pestalozzi's ideas with those advocated by the Imperial Technical School in St. Petersburg, Russia. Runkle became a proponent of incorporating tool instruction into engineering education and his ideas were further developed by Calvin Woodward who is largely credited with being the "father of manual training" (Bennet and Bawden 1910). During the Great Depression, manual training enjoyed widespread popularity and political support as it prepared future workers for their jobs (Metcalf 2007).

The new skill set necessary for a knowledge and service economy has been conceptualized by the US National Research Council into three domains: **cognitive** (cognitive processes and strategies; knowledge; creativity), **intrapersonal** (intellectual openness; work ethic; self-evaluation), and **interpersonal** (teamwork and collaboration; leadership) (Pellegrino and Hilton 2012). Lawrence Katz, a labor economist at Harvard, asserts:

> The economic return to pure technical skills has flattened, and the highest return now goes to those who combine soft skills – excellence at communicating and working with people – with technical skills, but you need both, in my view, to maximize your potential. (Kristoff 2015)

Learning Important Concepts Through Context-Based Learning

If our students are to be competitive in the workplace and successful in becoming fully functioning individuals, schools will have to emphasize cognitive, intrapersonal, and interpersonal competencies. Of critical importance is that the ways in which student tasks are designed must facilitate the development of these competencies. The temptation for curriculum decision-makers to avoid is to become enamored of curricula focused on atomistic learning standards rather than on overarching, thematic ideas that are revisited in contexts suited to the interests of the learners.

As opposed to starting the curriculum design process with "enduring understandings" (Wiggins et al. 1998), in engineering and technology education, curriculum designers might consider starting with **contexts** that are perceived by students as relevant and compelling and embed thematic ideas and related performance expectations within them. Choosing contexts wisely can serve not only to teach contemporary domain-specific skills but can also refocus learning to reflect the fundamental purposes of education (make the world a better place, earn a living, respect honesty and civility, etc.).

Context-based learning (assuming instructional contexts are chosen to be important and relevant to learners) can promote high student engagement. Our goal as instructional leaders is to design learning environments that enable students to feel so engaged that they are in a state of "flow."

Flow Theory

Once learners are engaged and inspired by contextual learning and are totally absorbed in an activity, learning becomes intrinsically rewarding. Psychologist Mihaly Csikszentmihalyi calls this being in a state of "flow." According to Csikszentmihalyi (2004):

> The best moments in our lives are not the passive, receptive, relaxing times. The best moments usually occur if a person's body or mind is stretched to its limits in **a voluntary effort** to accomplish something difficult and worthwhile. Flow is being completely involved in an activity for its own sake. People are at their optimal level of happiness when they are in an engaged state of "flow."

When a person is in a state of flow (Csikszentmihalyi 1990):

- Time flies.
- There is complete involvement in the task. The person is focused and concentrated.
- The person knows that the activity is doable. Skills are adequate to the task.
- Motivation is intrinsic – whatever produces flow becomes its own reward.
- The activity becomes an end in itself.

We have all found ourselves in a state of flow doing what we love to do: writing, playing music, skiing, dancing, exercising, reading, painting, building things, solving math problems, and doing research. George Leonard, a former editor of Look Magazine, wrote a book titled *Education and Ecstasy* (Leonard 1968). His premise was that learning could be so enhanced that students would find it to be *ecstatic* – as ecstatic as a 16-year-old learning how to drive!

A great reward for us as educators is to see joyful learning that results from our creation of ecstatic learning environments in which our students are in a state of flow

– where they have control over their own learning and where learning is so meaningful that they are inspired to plumb further depths on their own.

So, paraphrasing the words to Alfie, we might ask, “What’s it all about for us, as educators, as engineering and technology educators?” Most would agree that it’s about learning that is purposeful, engaging, meaningful, authentic, personally and societally relevant, and joyful. We collectively have the capacity to make learning ecstatic for our students.

Case Study 2: Engineering for All – A Curriculum Focused on Authentic Social Contexts *Engineering for All* (EfA) (Hofstra 2016) is a US National Science Foundation-funded project (Grant # DRL-1316601) that introduces middle school students to engineering, not only as a career path but for its potential as a social good. EfA meets the needs of today’s students who are civic minded, team oriented, and want to make a difference in the world (Gleason 2008). The Project represents a new paradigm for ETE in that learning is situated in contexts that relate to *authentic social issues* – those that are felt by students to be important and relevant. EfA “big ideas” are contextualized in two important social contexts: Food and Water.

The EfA design activities oriented toward solving problems that are globally significant have the potential to *engender a state of flow* in students and to motivate them to probe deeply into areas of just-in-time learning needed to address the design problem from a more informed perspective (Burghardt and Hacker 2004). EfA learning activities have been explicitly designed to relate to the fundamental purposes of education, particularly to help students see that they can indeed make the world a better place.

Two engineering design-based 6-week curriculum units have been developed, classroom tested nationally, evaluated, and revised. The units address urban food scarcity (designing hydroponic vertical farming systems) and water contamination (designing filtering systems to provide potable water to populations in need). A video introduction is at: https://www.youtube.com/watch?v=OQkowF2g53Q&feature=youtu.be. EfA’s expectation is that students will develop predispositions to forge a sustainable future and learn that engineering is a route to engage in socially significant work (Figs. 1, 2, and 3).

The instructional intent of EfA is to illustrate how instruction in engineering and technology education can address important ETE ideas and still reflect the fundamental purposes of education. The curriculum units address a limited and manageable number of big ideas and revisit these ideas within both the Food and Water units. The major EfA Project drivers are to:

- Promote the potential of engineering as a social good
- Illustrate how several overarching themes (i.e., design, modeling, systems, resources, and human values) are central to engineering and technological development
- Use hands-on engineering activities in authentic contexts to convey STEM ideas and practices

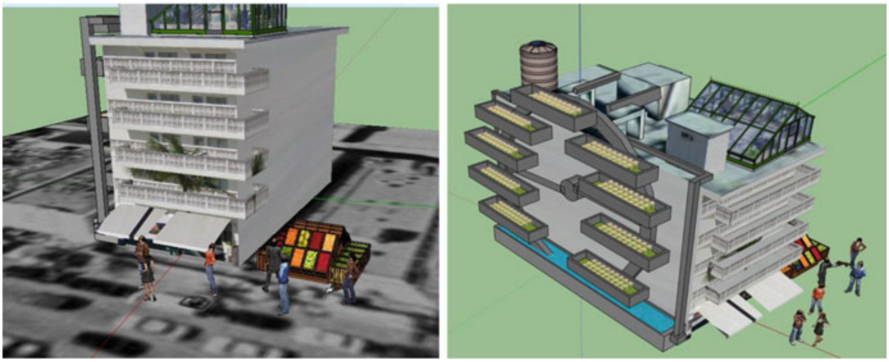


Fig. 1 Two middle school student vertical farm designs (Images courtesy of Stephen Haner)

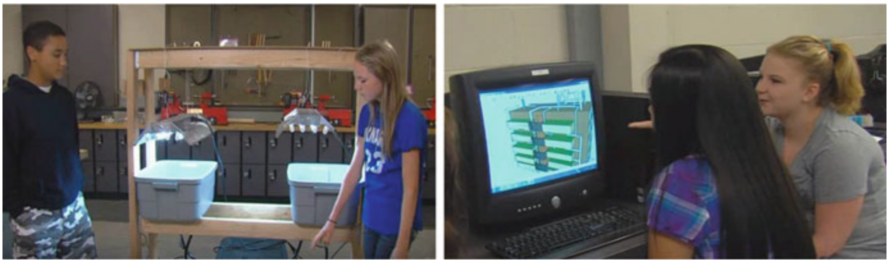


Fig. 2 Students designing hydroponic and vertical farming systems (Images courtesy of Stephen Haner)

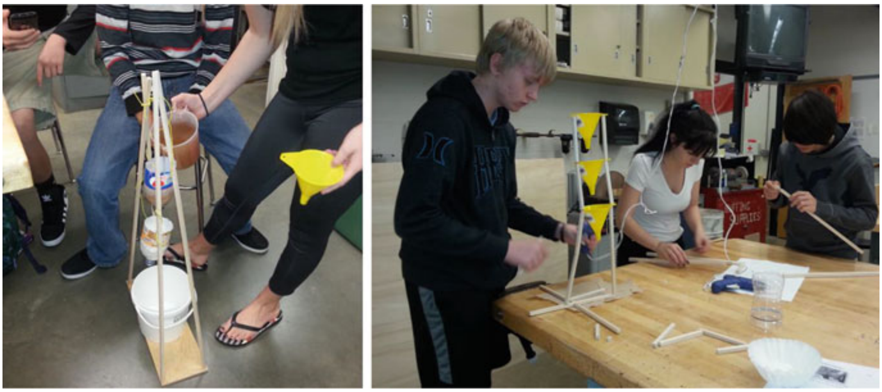


Fig. 3 Water unit students designing filtering systems (Images courtesy of Sandy Cavanaugh)

- Use informed engineering design as the core pedagogical methodology (see http://www.hofstra.edu/pdf/academics/colleges/SEAS/ctl/ctl_informeddesign_001.pdf)

Teachers reported that they were surprised at how unaware their students were about the social issues discussed. Teachers also learned about these issues. Following are some teacher comments about EfA:

- Students care about problems that can affect their lives and want to do something proactive about it.
- The social values aspect of it was something that jumped off the page. I had students wanting to go to other countries and help with the water crisis problem.
- Students were very surprised by the extent of the global water crisis and the negative effect on children.
- Students were surprised that the areas they live in could be considered a food desert.
- Students began discussing community gardens and pop-up farmer's markets as a way to bring in fresh fruit and vegetables to the area.
- All the themes were in there. Some big ideas were covered very well. Modeling was huge, so was systems.

EfA students commented that:

- We learn how to help people.
- We learn how to make water filters for people who don't have them.
- We are so careless with our water.
- This is what we came up with. This is what kids our age can do. It was a proud moment.

Summary and Conclusions

As disciplinary content standards have been developed to include hundreds of atomistic student performance objectives, the challenge to curriculum designers of embedding these in meaningful student experiences has become apparent. Several recent projects have tried to reduce the number of student performance expectations and to situate "big ideas" within a thematic conceptual framework.

To be well understood, concepts should be placed in contexts that are engaging and relevant to learners, and "big ideas" are best internalized when revisited in several different contexts. Deep conceptual understanding depends upon people having the ability to generalize from their experiences – and this argues for the need to *teach for transfer*.

A thematic approach focused on identifying a manageable number of important concepts and skills related to five ETE domains, design, systems, modeling, resources, and human values, can focus instruction on recurring and overarching transferable "big ideas" and facilitate a more holistic understanding of engineering and technology.

When we design instructional interventions for today's learners, we should not lose sight of the fundamental purposes of education – those that define what education should be all about.

Choosing contexts wisely can serve to refocus learning to reflect the fundamental purposes of education and facilitate learning of contemporary domain-specific skills in settings that are so inspiring to students that they are in a state of "flow" when learning.

Two case studies have been offered as examples. The first exemplifies how a cutting-edge technology company (Palantir) looks for new hires with a mix of cognitive, intrapersonal, and interpersonal skills. The second describes a new middle school curriculum model, *Engineering for All*, that integrates thematic concepts within social contexts that are authentic and engaging to today's learners.

References

Alfie. (1966). Dir. Lewis Gilbert. Paramount Pictures: Film.

Bacharach, B. & David, H. (1966). Alfie. Produced by George Martin.

Bealer, G. (1998). A theory of concepts and concept possession. *Philosophical Issues, 9*, 241–301.

Bennett, C. A. & Bawden W. T. (Eds.) (1910). *Manual Training Magazine* (Vol. 11). Peoria. The Manual Arts Press.

Bransford, J. D., Brown, A., & Cocking, R. (2000). *How people learn: Brain, mind, experience and school*. Washington, DC: National Academy of Sciences and the National Research Council.

Brophy, S., & Evangelou, D. (2007). *Precursors to engineering thinking project*. Washington, DC: American Society of Engineering Education.

Burghardt, M. D., & Hacker, M. (2004). Informed design: A contemporary approach to design pedagogy as the core process in technology. *The Technology Teacher, 64*, 6. International Technology Education Association. Reston, VA.

Church, R. L. & Sedlak, M. W. (1976). *Education in the United States: An interpretive history* (pp. 288–313). New York: Free Press. isbn:0-02-90490-7.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York: Harper and Row.

Csikszentmihalyi, M. (2004). *Flow: The secret to happiness*. TED Talk. Retrieved July 1, 2015, from https://www.ted.com/talks/mihaly_csikszentmihalyi_on_flow?language=en.

Custer, R. L., Daugherty, J. L., & Meyer, J. P. (2010). Formulating a concept base for secondary level engineering: A review and synthesis. *Journal of Technology Education, 22*(1), 4–21.

de Vries, M. (2010). A concept-context framework for engineering and technology education. In M. Barak & M. Hacker (Eds.), *Fostering human development through engineering and technology education*. Amsterdam: Sense Publisher.

Dewey, J. (1897, January 16). My pedagogic creed. *The School Journal, 54*(3), 77–80.

Dogar, S. (2015, May 15). *Education your child, they must live in a time different from you*. (PowerPoint slides). Retrieved May 29, 2016, from http://www.slideshare.net/samiadogar/cls-lect-3.

Donovan, M. S., & Bransford, J. D. (2005). Introduction. In M. S. Donovan & J. D. Bransford (Eds.), *How students learn: History, mathematics, and science in the classroom* (pp. 1–28). Washington, DC: The National Academies Press.

Earl, D. (2006). Concepts and properties. A defense of the view that concepts and properties are one and the same sort of entity. *Metaphysica, 7*(1), 67–85.

Edwards, J. & Edwards, J. (2013). *Getting the big idea: Concept-based teaching and learning*. UNC World View. Retrieved May 8, 2016, from http://worldview.unc.edu/files/2013/07/Getting-the-Big-Idea-PPT.pdf.

Engineering Concepts Curriculum Project. (1971). *The man-made world*. Polytechnic Institute of Brooklyn: McGraw-Hill Book Company.

Erickson, H. L. (2008). *Stirring the head, heart and soul: Redefining curriculum and instruction* (3rd ed.). Thousand Oaks: Corwin Press.

Fodor, J. A. (1998). *Concepts: Where cognitive science went wrong*. Oxford: Clarendon Press.

Forlenza, Vincent. (2010). *Mutual reinforcement*. Interview by William Tavani. Resolve: An Online Magazine (Vol. 1). Lehigh University. http://www3.lehigh.edu/engineering/resolve7/q-and-a.html.

Frege, G. (1892). Über Sinn und Bedeutung in Zeitschrift für Philosophie und philosophische Kritik 100: 25–50. Translation: On Sense and Reference in Geach and Black; 1980. Also see https://en.wikipedia.org/wiki/Sense_and_reference.

Gleason, Paula. (2008, Winter). Meeting the needs of millennial students. *In touch newsletter*. 16(1). Student Services. CSULB; Retrieved May 1, 2014, from http://web.csulb.edu/divisions/students2/intouch/archives/2007-08/vol16_no1/01.htm.

Guisepi, R. (Ed). (2007, March 16). *The History of Education. International World History Project*. Retrieved May 26, 2016, from http://history-world.org/history_of_education.htm.

Hacker, M. (2014). *Key engineering and technology concepts and skills for the general education of all high school students in the United States: A comparison of perceptions of academic engineering educators and high school classroom technology teachers*. Doctoral Dissertation. Beersheva: Ben-Gurion University of the Negev.

Hacker, M. & Barak, M. (2017, Spring). Important engineering and technology concepts and skills for all high school students in the United States: Comparing perceptions of engineering educators and high school teachers. *Journal of Technology Education*. In Press.

Harlen, W. (2010). *Association for Science Education*. Hatrfield, Harts, UK: Ashrod Colour Press Ltd.

Hofstra University Center for STEM Research. (2016). EfA Project Abstract. Retrieved May 29, 2016, from http://www.hofstra.edu/academics/colleges/seas/CTL/efa/index.html.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston: ITEEA.

Jones, A. (1997). Recent research in learning technological concepts and processes. *International Journal of Technology and Design Education, 7*, 1–2.

Jones, A., & de Vries, M. (Eds.). (2009). *International Handbook of Research and Development in Technology Education*. Rotterdam: Sense Publishers.

Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009). *Engineering in K-12 education*: Understanding the status and improving the prospects. Committee on K-12 Engineering Education; National Academy of Engineering and National Research Council. Washington, DC. http://www.nap.edu/catalog/12635/engineering-in-k-12-education-understanding-the-status-and-improving#description.

Kearney, C. 2015. *Efforts to Increase Students' Interest in Pursuing Mathematics, Science and Technology Studies and Careers*. National Measures taken by 30 Countries – 2015 Report, European Schoolnet, Brussels; January, 2016. Retrieved October 6, 2016, from http://files.eun.org/scientix/Observatory/ComparativeAnalysis2015/Kearney-2016-NationalMeasures-30-countries-2015-Executive-Summary.pdf.

Kipperman, D. (2009). Teaching through technology concepts: Strengthening the position of technology education in the curriculum. *Proceedings of the 22nd pupils attitudes toward technology (PATT) conference, international conference on design and technology education research, Delft,* 279–283.

Kristoff, N. (2015, April 16). Starving for wisdom. *The New York Times*. The Opinion Pages. Retrieved May 1, 2016, from http://nyti.ms/1CQEv4s.

Leonard, G. B. (1968). *Education and ecstasy*. New York: Delacorte Press.
Lindgren, C. E. (2013, September). *The evolution of the educational paradigm*. World Academy Forum on Global Higher Education. World Academy of Art and Science. Retrieved May 28, 2016, from http://www.worldacademy.org/files/UCB/The_Evolution_of_the_Educational_Paradigm by_C. E.Lindgren.pdf.
Margolis, E. & Laurence, S. (2011). Concepts. *Stanford encyclopedia of philosophy*. Stanford University: Stanford Center for the Study of Language and Information.
Merrill, M. D., Tennyson, R. D., & Posey, L. O. (1992). *Teaching concepts: An instructional design guide* (2nd ed.). Englewood Cliffs: Educational Technology Publications, Inc.
Metcalf, B. (2007). *Craft education: Looking back, looking forward*. Distinguished Lecture given at the at the NCECA 41st Annual Conference, Louisville.
Nagdy M. & Roser, M. (2016) *Primary education and schools*. Published online at OurWorldInData.org. Retrieved May 26, 2016, from https://ourworldindata.org/primary-education-and-schools.
National Academy of Education. (2009). In L. Shepard, J. Hannaway, & E. Baker (Eds.), *Standards, assessments, and acountability. Education policy white paper*. Washington, DC: National Academy of Education.
National Assessment Governing Board. (2016, May 17). *The Nation's Report Card: Technology and engineering literacy*. Detroit: Michigan Science Center.
National Center for Education Statistics. (2014). *More about the NAEP technology and engineering literacy (TEL) assessment*. NAEP Publications. Retrieved March 1, 2014, from https://nces.ed.gov/nationsreportcard/tel/moreabout.aspx.
National Governors Association. (2010). *Center for best practices*. Council of Chief State School Officers. Washington, DC: Common Core State Standards for Mathematics.
National Governors Association Center for Best Practices. (2007). *Innovation America: Building a Science, Technology, Engineering and Math Agenda*. Washington, DC: National Governors Association. http://www.nga.org/Files/pdf/0702INNOVATIONStem.pdf.
National Research Council. (2008). *Common Standards for K-12 education? Considering the evidence.* A Workshop Series. Alexandra Beatty, Rapporteur. Center for Education, Division of Behavioral and Social Science and Education. Washington, DC: The National Academies Press.
National Research Council. (2010). *Standards for K-12 engineering education? Committee on standards for K-12 engineering education*. Washington, DC: National Academies Press.
National Research Council. (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Committee on New Science Education Standards, Board on Science Education, Division of Behavioral and Social Sciences and Education*. Washington, DC: The National Academies Press.
NGSS Lead States. (2012). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.
Palantir. (2016a). *Scale. Speed. Agility.* Retrieved May 24, 2016, from https://www.palantir.com.
Palantir. (2016b). *An engineering culture*. Retrieved May 24, 2016, from https://www.palantir.com/engineering-culture.
Palantir. (2016c). *How to ace a systems design interview.* Retrieved May 24, 2016, from https://www.palantir.com/2011/10/how-to-ace-a-systems-design-interview.
Palantir. (2016d). Why are we needed? Retrieved May 24, 2016, from https://www.palantir.com/philanthropy-engineering.
Palantir. (2016e). *Getting hired*. Retrieved May 24, 2016, from https://www.palantir.com/getting-hired.
Parker, W. (2013, April 15). *Concept formation*. Teachinghistory.org. Retrieved May 26, 2016, from http://teachinghistory.org/teaching-materials/teaching-guides/25184.
Peacocke, C. (1992). *A study of concepts*. Cambridge: M.I.T. Press.

Pellegrino, J. W., & Hilton, M. L. (Eds.). (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. Washington, DC: The National Academies Press.

Rey, G. (1995). Concepts. In S. Guttenplan (Ed.), *A companion to the philosophy of mind* (pp. 185–193). Oxford: Blackwell Publishers.

Rossouw, A., Hacker, M., & de Vries, M. J. (2010). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–423. doi:10.1007/s10798-010-9129-1.

Sanders, M., Sherman, T., & Watson, P. (2012, March 17). *Engineering concepts taught and teaching methods employed by technology education teachers*. Paper presented at the ITEEA Conference. Long Beach.

Smith, E. E. (1989). Three distinctions about concepts and categorization. *Mind and Language, 4*(1, 2), 57–61.

Vest, Charles. (2009, Fall). Putting the "E" in STEM Education. *The Bridge, 39*(3). Washington, DC: National Academy of Engineering.

Vocabulary.com. 2016, *Concept*. Retrieved May 7, 2016, from https://www.vocabulary.com/dictionary/concept.

Webster, N. & McKechnie, J. L. (1979). *Webster's new universal unabridged diction* (2nd ed., p. 376). New York: Dorset and Babar.

Weiss, J. (2015, May). Pearson loses Texas contract for standardized exams. *Dallas News*.

Wiggins, G. P., McTighe, J., Kiernan, L. J., & Frost, F. (1998). *Understanding by design*. Alexandria, VA: Association for Supervision and Curriculum Development.

16 Technical Vocational Education: From Dualistic to Pluralistic Thinking

Nina Kilbrink

Abstract

Discussions of technical and vocational education often concern various dichotomies that need to be bridged in learning. In this chapter, the dichotomizations between theory and practice, school and workplaces, and the what and how aspects of learning are addressed, and the chapter reports on and discusses some suggestions in research on bridging or handling such dichotomies in technical vocational education. Often, a holistic view and an integration of dichotomies are advocated. Bridging the gap involves complex processes, but being aware of the processes can be one step in the direction of integration. Another step, as argued in this chapter, is to abandon dualistic thinking and instead embrace pluralism, since research shows that there are often complex contexts involved that are not divisible into two different parts but rather into many different aspects. The complex processes of learning content in different contexts in vocational education constitute the students' whole education. In order to understand these processes, it may be meaningful to divide phenomena into different units for analytical reasons, in order to understand how the parts integrate into the whole.

Keywords

Dualisms • Technical Education • Theory and Practice • Transfer • Vocational Education

Contents

N. Kilbrink (✉)
Department of Educational Studies, Karlstad University, Karlstad, Sweden
e-mail: nina.kilbrink@kau.se

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_22

Introduction

In relation to technical and vocational education, discussions are often dichotomized in terms of theory and practice, school and workplaces, verbalized knowledge and manual work, head and body, reading and doing, what and how, etc. (cf. Asplund and Kilbrink 2016; Berglund 2009; Kilbrink 2013a; Lindberg 2003b). Almost as often, these dichotomizations are criticized in research, and it is argued that such concepts and phenomena need to be integrated in relation to student learning and the understanding of student learning (cf. Bengtsson 2010; Berglund 2009; Kilbrink 2013a). Unfortunately, there is no easy answer to how this integration can come about and how to bridge the dichotomies in relation to learning in technical vocational education. However, different suggestions have been proposed in research. This chapter will report on and discuss some of these suggestions in relation to the dichotomization of (1) theory and practice, (2) school and workplaces, and (3) the what and how aspects of learning.

Learning in Technical Vocational Education

Learning in technical vocational education involves learning processes where theory and practice need to be integrated and related to learning in several learning arenas (e.g., classrooms and workshops at school and different kinds of workplaces) and to different kinds of learning content, from basic knowledge to learning to learn (Kilbrink 2013a; Kilbrink et al. 2014b). In order to keep up with the (technical) development in society and occupations, students need to continuously learn after graduating as well (Poortman et al. 2011; Schaap et al. 2009). Learning to learn is seen as a crucial competence of vocational programs (Poortman et al. 2011; Schaap et al. 2009; Tynjälä 2009). However, there is a risk that the students are expected to take responsibility for learning for the future when the focus is solely on learning to learn. Bransford and Schwartz (1999) argue that schools also need to take responsibility for the learning content in education.

New competences such as holistic thinking and the ability to solve complex problems are needed (Angervall and Thång 2003). Middleton (2002), on the other hand, argues that it is not possible to find generalizable complex problems to teach at school. Also, educational programs cannot cover all content necessary for students' future lives, which makes transfer very important, and students need to acquire "the ability to transfer – to use what they have learned to solve new problems successfully or to learn quickly in new situations" (Tuomi-Gröhn and Engeström 2003, p 1). Hence, students need to learn a knowledge base at school on which they can build upon in new situations (cf. Bransford and Schwartz 1999; Kilbrink 2013a; Lindberg

2003b). Furthermore, in a society where technical development is rapid, students in vocational education need to learn how to learn and to adapt and how to use and reconsider – to transfer – knowledge in new situations. They also need to learn in different situations and learning arenas and transfer the learning into new arenas, problems, and situations. In order to facilitate transfer, in-depth learning is needed where theory and practice are integrated (Bransford 2000; Kilbrink 2008, 2013a).

The dichotomy of theory and practice, however, is discussed and criticized in relation to the learning of technology. In relation to vocational education, a dimension of learning space is added to this discussion, since the learning takes place in different learning arenas. In many school systems, vocational education is conducted both at schools and at workplaces. Therefore, learning in different arenas and the transfer of learning within and between those arenas become a complex question (Kilbrink 2013a). Transfer can also relate to the form and content of learning, which means that the how and the what aspects of the learning process are involved. Therefore, it is important to discuss how to bridge the gap between theory and practice to reach holistic learning, school and workplaces to create unity in students' education, and what and how aspects of learning in order to understand the complexity of different learning processes in technical vocational education.

Theory and Practice

Handicraft, practical experience, and physical work are emphasized as central to learning in both vocational subject areas and technical content. These specific aspects of learning are often referred to as practical (cf. Berglund 2009; Bjurulf 2008; Björkholm 2015; Björklund 2008; Kilbrink 2013a). However, to remember and be able to use and build on previous knowledge in new situations (transfer), learning needs to be deep, and theory and practice need to be integrated (cf. Bransford 2000; Eraut 2004; Kilbrink 2008; Tynjälä 2009). Tynjälä (2009) claims that it is important that theories are considered in relation to practical experiences and vice versa, and Bengtsson (2010) argues for their mutual dependence.

Theory and practice can have different meanings in different situations and contexts. The division between theory and practice has been discussed and also criticized in several studies, and this discussion often refers all the way back to ancient Greece and the Aristoteles, where *theoria* referred to contemplation and *praxis* to actions (cf. Bjurulf 2008; Björkholm 2015; Liedman 2002; Tsagalidis 2008). Researchers claim that the division of theory and practice is complex, when you start reflecting on it (cf. Bjurulf 2008; Liedman 2002; Kilbrink 2013a).

In a study on vocational education in the building and construction area, Berglund (2009) has compiled common dichotomized perceptions of the concepts of theory and practice, which can be seen in Table 1:

These conceptions are used in different contexts in relation to vocational education. However, Berglund (2009), like other researchers, argues for a more integrated view on the concepts (cf. Kilbrink 2013a) or a discussion on how to bridge the gap between them (cf. Schwendimann et al. 2015; Tempelman and Pilot 2011).

Table 1 Conceptions about the dichotomy of theory and practice (Berglund 2009, p 23)

	Theory	Practice
Content	Verbalized knowledge Science Abstract thinking (ideas)	Manual, physical work Application of science Empirical world/real life
Tools	Text/models	Body/hands Physical tools
Humans	Theoretical Intelligent	Practical Unintelligent
Arena	School	Workplace
Hierarchy	Superior	Subordinate

A model on how learners learn through practical experiences from novice to expert was presented by Dreyfus and Dreyfus (1986). They state that novice learning is related to facts and general roles rather than more context-related demands, but the more practical experiences and the more skilled the learner gets, the learning becomes more intuitive and holistic. Since technical vocational learning is related to practical experiences, this model is relevant (compare also Björklund 2008). However, Bengtsson (2010) criticizes this model for lacking focus on the *knowledge about* the practical experiences; he highlights the importance of the theoretical knowledge underpinning the practical *knowledge in something* in technical vocational education as well. Another critique that Bengtsson emphasizes is the unilateral focus on the individual in the model, and he highlights the importance of also taking cultural, historical, and social aspects into consideration in learning.

This leads to another way of handling theory and practice, meaning viewing them as different aspects of the same phenomenon (Bengtsson 2010). Bengtsson uses theory for *knowledge about* something and practice for *knowledge in something* and sees them as intertwined aspects of importance in relation to learning a vocation. Bengtsson discusses this way of approaching the concepts in relation to teacher education, but I argue that it is relevant to technology education and vocational education as well. In this approach, theory and practice are two aspects of the same phenomenon. It is therefore important that theory as knowledge in something and practice as knowledge about something concern the same object of learning (cf. Kilbrink 2013a).

In some cases, it can be justified to divide theory and practice for analytical reasons (cf. Svensson 2011). In Bjurulf and Kilbrink's (2008) study, the analytic focus was on the nature of the tasks as theoretical or practical in order to understand how different tasks were handled in technology education. Bjurulf and Kilbrink made an empirical study of how theoretical and practical tasks are handled in technology education in order to deepen the knowledge of how they are actually integrated in education, or not. In the study, theoretical tasks referred to tasks mainly involving thinking or intellectual work, such as reading, writing, reflecting, or discussing. Practical tasks referred to tasks mainly involving manual work or a concrete doing, such as constructing or building. The result showed that theory and practice seldom were handled as integrated in the tasks. Sometimes theoretical and practical tasks concerned different learning objects (e.g., the practical task concerned the construction of an artefact and the theoretical task concerned the history of the artefact), and sometimes theory and practical tasks were handled in succession (e.g., in different school subjects, where the concrete building tasks were handled in technology, and the understanding of the task was handled in, e.g., physics). In the study, it was clear that theoretical and practical tasks were seldom integrated in technology education, and the few examples in the empirical material when there was an integration of theoretical and practical tasks, it was the students themselves who brought the integration about.

Although research indicates the importance of interweaving theory and practice, it is not clear what should be interwoven, since there can be different interpretations of what theory and practice are. In order to understand how those who learn and work in technical vocational education conceive of theory and practice, a study in Swedish upper secondary school was carried out, where teachers, workplace supervisors, and students were asked about their experiences of theory and practice (Kilbrink 2013b). The results revealed experiences of theory and practice in relation to different learning arenas, theory and practice as different parts of the body, practice as an application of theory, and theory as understanding practice and vice versa. The results mainly pointed to a traditional dualistic view, focusing on space (school/workplace), body (head/body), and time (i.e., what comes first (learning)/ what comes next (application of learning)). But also, there were results indicating a view where theory and practice were more interwoven in the discussion and concerned more complex content. The result also indicated that interweaving the aspects of space, body, and time is needed in order to reach a holistic learning where theory and practice are intertwined (Kilbrink 2013a, b). In Berglund's (2009) table above, there are also different aspects that relate to content, tools, humans, arena, and hierarchy, which indicate a complex process of integrating theory and practice in vocational education, not only relating to a dualistic way of seeing the concepts but rather to a more pluralistic and multidimensional way.

School and Workplaces

In relation to vocational education, conducted both at school and in different workplaces (dual system), the theory/practice divide is often linked to different kinds of learning arenas. In dual system vocational education, the students move between different learning arenas and are supposed to learn continuously in the different settings throughout the programs (cf. Kilbrink 2013a). Consequently, transfer of learning is necessary. Learning in vocational education addresses concrete professional tasks in different learning arenas, which makes it different from learning in academic settings (Baartman and de Bruijn 2011) in addition to the practical experiences and physical work mentioned above. Many researchers highlight how school and workplace learning can complement each other and contribute to students learning in different ways in vocational education. There are also suggestions that some things can be learned better in one arena and some in another (cf. Aarkrog 2005; Al-Ali and Middleton 2004; Berner 2010; Baartman et al. in press; Illeris

2009; Tynjälä 2009). Kilbrink (2013a) also emphasizes that the different learning arenas can contribute to student learning both concerning form (the how aspect of learning) and content (the what aspect of learning).

Previous research on vocational education, however, highlights that there is often a gap between school and workplace learning and that the learning at school and at the different vocational workplaces are not connected (e.g., Aarkrog 2005; Akkerman and Bakker 2012; Schaap et al. 2012; Tanggaard 2007). Hence, learning in different learning arenas in vocational education can both be experienced as contributing to student learning and as problematic when the learning at school is not connected to the learning at the workplace and vice versa. In vocational education research, there is a discussion on how to bridge this gap in order to achieve holistic learning and to create coherent vocational programs (cf. Illeris 2009; Tynjälä 2009). Often the students themselves have to connect the learning at school with the learning in different workplaces. Research on the transfer of learning and how learning in different learning arenas build on previous learning has been conducted in different research traditions and perspectives on vocational education (cf. Eraut 2004; Kilbrink 2013a; Tuomi-Gröhn and Engeström 2003). Tuomi-Gröhn and Engeström (2003) describe different ways of understanding transfer in research. The focus in transfer research can either mainly relate to the *task*, the *individual*, or the *context*. However, such understandings are not mutually exclusive. The modes of understanding task-oriented transfer are content related dealing with transferring knowledge from solving one task into solving another task. The modes of understanding individual-oriented tasks have a greater focus on the individual process than on the task and center on how the individuals use principles of previous experiences to solve new problems trying to use what has been learned in school to solve problems outside of school. Individuals can adapt their skills to new situations themselves. The modes of understanding context-oriented transfer are based on participation in social and material contexts. Process patterns in the different contexts are in focus rather than individual knowledge. Knowledge is continuously created in context and not transferred from one context to another in such ways of understanding transfer. Sociocultural perspectives on transfer and theories on boundary crossing relate more to the context (Beach 1999; Tuomi-Gröhn and Engeström 2003), while, for example, Marton (2006) and Bransford and Schwartz (1999) refer more to the task and to the individual understanding of transfer.

One way of bridging the gap between school and workplace learning in vocational education relating to the context is to discuss different kinds of boundary objects to strengthen the connection between different learning arenas. This has been done in transfer research on boundary crossing, emphasizing the aspects of learning at the boundary, the value of dissimilarities, and the contribution of the ongoing two-sided interaction between different arenas or vocations in vocational education as promoting student learning (cf. Akkerman and Bakker 2012; Berner 2010). Communication and ICT are examples of tools for learning at the boundary highlighted in different studies (cf. Baartman et al. 2013; Schwendimann et al. 2015). The technical development creates new possibilities for learning on the boundary between school and workplaces in dual vocational education.

Schwendimann et al. (2015) studied, for example, how different digital technologies can contribute to student learning in vocational education conducted in dual systems, where both school and workplaces contribute to students' education. They examined how mobile technology and different apps can support the students' reflection on their learning in the different learning arenas in car mechanics programs.

However, in the transfer research focusing on boundary crossing, there is still a dichotomization between school and workplace learning in vocational education. Using the lifeworld perspective, Bengtsson (2010) instead argues for seeing every part of personal lives as regional lifeworlds, where all parts of the persons' life influence how different situations in the different parts are experienced. Hence, there is interplay between all experiences in the whole lifeworld in every regional lifeworld. Also the view of transfer as preparation for future learning (PFL) emphasizes that all previous experiences influence how new situations are experienced (Bransford and Schwartz 1999; Kilbrink 2013a). Studies on vocational education also emphasize that there are more than those two learning arenas and contexts involved in student learning during their training. Experiences from home and spare time (cf. Kilbrink 2013a) as well as branch specific competitions and tests (cf. in progress; Öhman 2015) can influence student learning in vocational programs. Therefore, also the dichotomization between school and workplaces in vocational education needs to be seen as more pluralistic, where experiences from several learning arenas are important to student learning. Kilbrink (2013a) argues that teachers and workplace supervisors have an important role in helping the students connect what they learn in different learning arenas in their vocational programs. Other studies also emphasize the importance of giving the students time to reflect on their learning, together with teachers at school (cf. Akkerman and Bakker 2011, 2012; Schaap et al. 2012; Schwendimann et al. 2015).

Transfer in technical vocational education can involve different kinds of content and different types of arenas in- and outside school (Kilbrink and Bjurulf 2013). It can be about translating written material into actions (e.g., following drawings and instructions) and vice versa (e.g., document actions). It can be about practicing on one kind of material at school and transferring it to other materials in different workplaces or finding problems to solve in workplaces and reflect on them at school. Transfer needs to focus on the content of the tasks without losing the focus on social, cultural, and historical aspects in the process of learning (cf. Kilbrink 2013a). This means that transfer cannot be discussed as related to either the tasks/the content being transferred (the what aspect of learning) or the process including social aspects (the how aspect of learning) but to all these aspects.

What and How Aspects of Learning

Learning processes concern the aspects of what and how, relating to the learning content and ways of going about learning (Marton and Booth 1997). However, the what and the how aspects of learning are often dichotomized and separated in research and discussions about learning in relation to different learning contexts (Emanuelsson and Sahlström 2008; Melander and Sahlström 2008) and also in relation to technical and vocational education. However, in order to understand the whole process of learning, such aspects need to be discussed in relation to one another.

There are few studies focusing on learning processes in relation to technical objects of learning in vocational education, and it is of importance to redress the lack of research in this area. Since the specificness of technical and vocational objects of learning, where handicraft, practical experiences, as well as interweaving theoretical and practical aspects of the object of learning are central, there is a great need to conduct more studies in this area of vocational education (cf. Asplund and Kilbrink 2016; Kilbrink 2013a; von Schantz Lundgren et al. 2013). In a study, Asplund and Kilbrink (2016) focused specifically on a technical vocational object of learning (welding) to identify what can be learned and how the learning is oriented to interaction with this specific learning object. In the study, it was made clear that by focusing on the different aspects – the what and the how – as analytical units, it was possible to reach a deeper understanding of the learning process as a whole. Furthermore, it was obvious that there was a mutual relationship between the aspects of the actual teaching/learning situation in the interaction between the vocational teacher and the student. The study shows that interaction influences what is possible to learn in the learning situation and vice versa.

However, it is complex to define an object of learning (Dahlin 2007; Kilbrink et al. 2014a; von Schantz Lundgren et al. 2013). For example, it is not obvious how much of the context that needs to be taken into consideration in relation to the object of learning, so the relation between learning content and context is something that needs to be considered when defining an object of learning in technical vocational education.

Furthermore, it was highlighted that when learning a specific content at school, it can be helpful for the students to relate to learning in other arenas and experiences made outside of school and reflect on them together with a teacher (cf. Akkerman and Bakker 2011, 2012; Kilbrink et al. 2014a; Kilbrink 2013a; Schaap et al. 2012; Schwendimann et al. 2015). In the vocational learning process, the different learning arenas contribute to student learning both in terms of the what aspect of learning and the how-aspect of learning – from basic knowledge and specific objects of learning to larger context and processes of learning to learn. Different kinds of learning – both concerning content and contexts – are important ingredients in students learning for an unpredictable future, and a mixture between program-specific content, holistic learning, and learning to learn could prepare students for their future lives (cf. Kilbrink et al. 2014b). Transfer between different learning arenas needs to focus on the content of the tasks without losing the focus on social, cultural, and historical aspects in the process of learning (cf. Kilbrink 2013a). This means that transfer too can *only* be discussed in relation to all aspects involved, that is, tasks/content to be transferred (the what aspect of learning) and the process, including social aspects (the how aspect of learning).

Hence, also in relation to what and how, it is important to take a more pluralistic rather than dualistic approach and also consider the aspect of place (where) in relation to technical vocational education (cf. Kilbrink 2013b).

Conclusion and Future Directions

In this chapter, the issue of how three dichotomies relating to teaching and learning in technical vocational education can be bridged has been discussed, namely, theory and practice, school and workplace learning, and the what and the how aspects of learning. Theoretical and empirical research has problematized and found different solutions to bridging the alleged gaps that can be problematic in teaching and learning in vocational education with a technical content, but there is still no easy answer to how to do it in educational settings. Bridging such dichotomies involves complex processes, and an awareness of the processes can be one step in the direction of integration. Another step, argued for in this chapter, could be to abandon dualistic thinking and instead embrace pluralism, since research shows that there are often more complex contexts involved, which are not divisible in just two different parts – but rather into many different aspects, which is an argument for pluralistic thinking about learning in technical vocational education.

Complex learning processes, concerning different content in different arenas, constitute the students' training as a whole in vocational education. In order to understand those processes, it can sometimes be meaningful to divide phenomena into different units for analytical reasons, in order to understand how the parts integrate as the whole.

Too often, it seems that students are left to integrate the different parts on their own. Instead teachers can help students in their learning by creating learning situations where theory (knowledge in) and practice (knowledge about) concern the same object of learning; they can help students connect learning in different arenas and be clear about what the students need to learn in the interaction about different learning objects.

In order to create opportunities to make learning go beyond the actual learning situation, theory and practice need to be integrated, and thus aspects relating to learning processes in different learning arenas could be connected. More research with a holistic approach, integrating several different aspects of learning in technical vocational education, is needed to further clarify complex learning processes.

References

Aarkrog, V. (2005). Learning in the workplace and the significance of school-based education: A study of learning in a Danish vocational education and training programme. *International Journal of Lifelong Education, 24*(2), 137–147.

Al-Ali, S., & Middleton, H. (2004). Technology transfer: The interaction of vocational education and industry, the college of technological studies, Kuwait. *Australian Vocational Education Review, 11*(2), 19–28.

Akkerman, S., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research, 81*(2), 132–169.

Akkerman, S., & Bakker, A. (2012). Crossing boundaries between school and work during apprenticeships. *Vocations and Learning, 5*(2), 153–173.

Angervall, P., & Thång, P. (2003). Learning in working life: From theory to practice. I T. Tuomi-Gröhn, & Y. Engeström, Between school and work: New perspectives on transfer and boundary-crossing (ss. 257-270). Oxford: Pergamon

Asplund, S-B, & Kilbrink, N. (2016). Learning how (and how not) to weld: Vocational learning in technical vocational education (Accepted for publication in Scandinavian Journal of Educational Research).

Baartman, L. K., & de Bruijn, E. (2011). Integrating knowledge, skills and attitudes: Conceptualising learning processes towards vocational competence. *Educational Research Review, 6*(2), 125–134.

Baartman, L., Gravemeijer, K., & de Bruijn, E. (2013). Nurses' and technicians' communication and learning at the boundary. In H. Middleton & L. Baartman (Eds.), *Transfer, transitions and transformations of learning* (pp. 49–68). Rotterdam: Sense Publishers.

Baartman, L., Kilbrink, N., & de Bruijn, E. (in press). *Students' processes of transfer between school and workplaces in vocational education.*

Beach, K. (1999). Consequential transitions: A sociocultural expedition beyond transfer in education. *Review of research in education, 24*(1), 101–139.

Bengtsson, J. (2010). Teorier om yrkesutbildning och deras praktiska konsekvenser för lärare. In M. Hugo & M. Segolsson (Eds.), *Lärande och bildning i en globariserad värld* (pp. 83–98). Lund: Studentlitteratur.

Berglund, I. (2009). *Byggarbetsplatsen som skola – eller skolan som byggarbetsplats?: En studie av byggnadsarbetarens yrkesutbildning*. (Institutionen för didaktik och pedagogiskt arbete, No. 4). Dissertation, Stockholm: Stockholm University.

Berner, B. (2010). Crossing boundaries and maintaining differences between school and industry: Forms of boundary-work in Swedish vocational education. *Journal of Education and Work, 23*(1), 27–42.

Bjurulf, V. (2008). *Teknikämnets gestaltningar: En studie av lärares arbete med skolämnet teknik* (Karlstad University Studies, no. 2008:29). Dissertation, Karlstad: Karlstad University.

Bjurulf, V., & Kilbrink, N. (2008). The importance of interweaving theoretical and practical tasks in technology education. I H. Middleton, & M. Pavlova (Red.), *Exploring technology education: Solutions to issues in a globalised world* (Vol 1, ss. 27–34). Brisbane: Griffith Institute for Educational Research.

Björkholm, E. (2015). *Konstruktioner som fungerar: En studie av teknikkunnande i de tidiga skolåren*. Dissertation, Stockholm University, Stockholm.

Björklund, L. (2008). *Från novis till expert: Förtrogenhetskunskap i kognitiv och didaktisk belysning* (Linköping studies in science and technology education, No. 17). Dissertation, Linköping University, Linköping.

Bransford, J. D. (2000). *How people learn*. Washington, DC: National Academy Press.

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. *Review of Research in Education, 24*, 61–100.

Dahlin, B. (2007). Enriching the theoretical horizons of phenomenography, variation theory, and learning studies. *Scandinavian Journal of Educational Research, 51*(4), 327–346.

Dreyfus, H. L., & Dreyfus, S. E. (1986). *Mind over machine: The power of human intuition and expertise in the era of the computer.* New York, NY: Free Press.

Emanuelsson, J., & Sahlström, F. (2008). The price of participation. Teacher control versus student participation in classroom interaction. *Scandinavian Journal of Educational Research, 52*(2), 205–223.

Eraut, M. (2004). Transfer of knowledge between education and workplace settings. In I. H. Rainbird, A. Fuller, & A. Munro (Eds.), *Workplace learning in context* (pp. 201–221). London: Routledge.

Illeris, K. (2009). Transfer of learning in the learning society: How can the barriers between different learning spaces be surmounted, and how can the gap between learning inside and outside schools be bridged? *International Journal of Lifelong Education, 28*(2), 137–148.

Kilbrink, N. (2008). *Legorobotar i skolan: Elevers uppfattningar av lärandeobjekt och problemlösningsstrategier* (Karlstad University Studies, No. 2008:7). Licentiate thesis, Karlstad University, Karlstad.

Kilbrink, N., & Bjurulf, V. (2013). Transfer of knowledge in technical vocational education: A narrative study in Swedish upper secondary school. *International Journal of Technology and Design Education, 23*(3), 519–535.

Kilbrink, N. (2013a). *Lära för framtiden: Transfer i teknisk yrkesutbildning* (Karlstad University studies, No. 2013:4). Dissertation, Karlstad University, Karlstad.

Kilbrink, N. (2013b). Transfer of learning through integration of theory and practice in technical vocational education. In H. Middleton & L. Baartman (Eds.), *Transfer, transitions and transformations of learning* (pp. 69–84). Rotterdam: Sense Publishers.

Kilbrink, N., Bjurulf, V., Blomberg, I., Heidkamp, A., & Hollsten, A.-C. (2014a). Learning a specific content in technology education: Learning study as collaborative method in Swedish preschool class using hands-on material. *International Journal of Technology and Design Education, 4*(3), 241–259.

Kilbrink, N., Bjurulf, V., Olin-Scheller, C., & Tengberg, M. (2014b). Experiences of educational content in Swedish technical vocational education: Examples from the energy and industry programmes. *International Journal of Training Research, 12*(2), 122–131.

Liedman, S. (2002). *Ett oändligt äventyr: Om människans kunskaper*. Stockholm: Albert Bonniers Förlag.

Lindberg, V. (2003a). Vocational knowing and the content in vocational education. *International Journal of Training Research, 1*(2), 40–61.

Lindberg, V. (2003b). *Yrkesutbildning i omvandling: En studie av lärandepraktiker och kunskapstransformationer* (Studies in educational sciences, No. 2003:64). Dissertation, Stockholm University, Stockholm.

Marton, F., & Booth, S. (1997). *Learning and awareness*. Mahwah, NJ: Erlbaum.

Marton, F. (2006). Sameness and difference in transfer. *Journal of the Learning Sciences, 15*(4), 499–535.

Melander, H., & Sahlström, F. (2008). In tow of the blue whale. Learning as interactional changes in topical orientation. *Journal of Pragmatics, 41*(8), 151–166.

Middleton, H. (2002). Complex problem solving in a workplace setting. *International Journal of Educational Research, 37*(1), 67–84.

Öhman, A. (2015). *Cykler och loopar i Salongen: En studie av återkoppling i frisörklassrummet* (Karlstad University Studies, No. 2015:11). Licentiate thesis, Karlstad University, Karlstad.

Poortman, C. L., Illers, K., & Nieuwenhuis, L. (2011). Apprenticeship: From learning theory to practice. *Journal of Vocational Education and Training, 63*(3), 267–287.

Schaap, H., de Bruijn, E., van der Schaaf, M. F., and Kirschner, P. A. (2009). Students' personal professional theories in competence-based vocational education: The construction of personal knowledge through internalisation and socialisation. *Journal of Vocational Education and Training, 61*(4), 481–494. doi: 10.1080/13636820903230999.

Schaap, H., Baartman, L., & de Bruijn, E. (2012). Students' learning processes during school-based learning and workplace learning in vocational education: A review. *Vocations and Learning, 5* (2), 99–117.

von Schantz Lundgren, I., Lundgren, M., & Svensson, V. (2013). Learning study i gymnasial yrkesutbildning: En fallstudie från ett hantverksprogram [Learning study in secondary vocational education: A case study from a craft program]. *Nordic Journal of Vocational Education and Training, 3*(4), 1–16.

Schwendimann, B., Cattaneo, A., Dehler Zufferey, J., Gurtner, J., Bétrancourt, M., & Dillenbourg, P. (2015). The 'Erfahrraum': A pedagogical model for designing educational

technologies in dual vocational systems. *Journal of Vocational Education and Training, 67*(3), 367–396.
Svensson, M. (2011). *Att urskilja tekniska system: Didaktiska dimensioner i grundskolan* (Linköping studies in science and technology education, No. 2011:33). Dissertation, Linköping University, Linköping.
Tanggaard, L. (2007). Learning at trade vocational school and learning at work: Boundary crossing in apprentices'everyday life. *Journal of Education and Work, 20*(5), 453–466.
Tempelman, E., & Pilot, A. (2011). Strengthening the link between theory and practice in teaching design engineering: An empirical study on a new approach. *International Journal of Technology and Design Education, 21*(3), 261–275.
Tsagalidis, H. (2008). *Därför fick jag bara godkänt...bedömning i karaktärsämnen på HR-programmet*. (Doktorsavhandlingar från Pedagogiska institutionen, No. 149). Dissertation, Stockholm University, Stockholm.
Tsagalidis, H. (2016). Bedömning i Skol-SM-matlagningstävling (in review).
Tuomi-Gröhn, T., & Engeström, Y. (2003). *Between school and work: New perspectives on transfer and boundary-crossing*. Oxford: Pergamon.
Tynjälä, P. (2009). Connectivity and transformation in work-related learning: Theoretical foundations. In M. Stenström & P. Tynjälä (Eds.), *Towards integration of work and learning* (pp. 11–37). Dordrecht: Springer.

17 Exploring the Relationship Between Technology Education and Educational Sloyd

Jonas Hallström

Abstract

The aim of this chapter is to investigate the relationship between Technology education and Educational sloyd (*slöjd*) in Sweden from the early 1960s until today. It is concluded that the technology subject domain during this period has modernized and become broader and broader, including a systems component. Educational sloyd, on the other hand, partly contains modern, technology-related components but also partly remains a subject emphasizing knowledge and skills rooted in a rural society including elements such as manual handicraft, tool management, aesthetic skills, as well as personal development. The most notable difference between the two subjects lies in their philosophical foundations. Technology education is about various aspects of the human-made world. Its main interest is technology itself; what it is, how it evolves, and how we as humans conceive, design, use, and manage technology. Educational sloyd, on the other hand, is mainly about human development, human capabilities of creating, crafting, working, and developing. However, the curriculum overlap between the two subjects is strikingly similar, and a major part of sloyd can therefore also be seen as a part of the field of Technology education today.

Keywords

Educational sloyd and Technology education • Hughes, T.P. • National board of education • Sweden, Sloyd education. *See* Educational sloyd and Technology education • Swedish national curriculum • Technological knowledge

J. Hallström (✉)
Technology and Science Education Research (TESER), Department of Social and Welfare Studies, Linköping University, Norrköping, Sweden
e-mail: jonas.hallstrom@liu.se

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_13

Contents

Introduction

> Technology is messy and complex. It is difficult to define and to understand. In its variety, it is full of contradictions, laden with human folly, saved by occasional benign deeds, and rich with unintended consequences [. . .]. (Hughes 2004, pp. 1–2)

What historian of technology Thomas P. Hughes so succinctly expresses in this quote is a challenge to every technology educator and Technology education researcher, because we are dealing with a subject domain – technology – which is at the same time complex, amorphous, and difficult to grasp. This complexity has historical roots but is also in the nature of technology. Technology education has thus taken a multitude of forms around the world, being influenced by and forming connections to science, mathematics, social science, as well as crafts. One of the latter subjects is the Swedish *slöjd*, Educational sloyd in the English translation (The English translations of *slöjd* that are most commonly used in the international literature are sloyd, Educational sloyd, or Sloyd education, but on occasion also craft (education), which was invented in the late nineteenth century by Finnish school reformer Uno Cygnaeus and was spread to Sweden and around the world by Swedish sloyd enthusiast Otto Salomon (Hartman et al. 1995).

In his study of the legacy of Educational sloyd, Whittaker (2014) calls Finnish sloyd founder Cygnaeus the "father of technology education" and points to an "ideational continuum from the 1860s out of Finland through Sweden" and globally to this day. Although acknowledging that Technology education "involves an amalgam of ideas from mathematics, the sciences, arts, crafts [. . .]," he also claims that it is – or should be – "aiming at a holistic view of craft. Termed 'craft-plus' it constitutes a much larger view of 'Hands, Head and Heart'" (Whittaker 2014, pp. vii, 122–123, 135). From Whittaker's point of view, Technology education today seems to be an extension of, and perhaps modernization of, Educational sloyd – "craft-plus."

Educational sloyd was arguably an important precursor to, or evolved in close parallel to, Technology education in many countries across the globe (Jones et al. 2013). Sloyd is also partly a distinctly technical subject, including elements of handicraft and craftsmanship to this day (e.g., Virtanen et al. 2015). Furthermore, Technology education and Educational sloyd share many structural characteristics. In many primary and secondary schools in Sweden, there is often only one person teaching either subject, or both of them. In the latter case, the teaching takes place in the same classroom and with the same equipment (Hasselskog 2010; Samuelsson et al. 2015; *Teknikämnet i träda. Teknikföretagens och CETIS rapport om teknikundervisningen i grundskolan* 2012).

Sloyd is thus one of the most important subjects that Technology education relates to in various ways in different countries, but many questions remain unanswered in regard to exactly how this relation can be described. The aim of this chapter is to investigate the relationship between Technology education and Educational sloyd (*slöjd*) in compulsory education in Sweden, from the early 1960s until today. In Sweden, Technology education and Educational sloyd exist as separate subjects in the school curriculum and have done so for decades. This historical coexistence in the curriculum has led to fairly well-developed and well-researched knowledge domains in both Technology and Sloyd education in Sweden (see, e.g., Borg 2001; Hallström et al. 2014; Klasander 2010; Sjögren 1997).

The empirical material studied in this chapter is, first of all, primary material in the form of Swedish national curriculum documents. Secondly, there is Swedish and international secondary material such as articles, doctoral theses, and books in the fields of Technology education and Educational sloyd. The primary focus when studying both the primary and secondary material is the specified curriculum, that is, the curriculum as found in national curriculum documents and standards (cf. Banks and McCormick 2006). A hermeneutic method was therefore employed in the analysis of this material, that is, single texts were related to the whole body of texts, the genres, and the educational and historical context in a reciprocal, reinterpretive way (Postholm 2006; Ödman 2007).

Background: From Educational Sloyd to Technology Education

Kananoja (1994) argues that Educational sloyd was the most influential forerunner to modern technology subjects or cross-curricular areas in Sweden, Finland, Denmark, and to a lesser degree Norway. The sloyd tradition was influential as a precursor even in the USA, the UK, Russia, the Netherlands, Germany, Italy, France, Argentina, Cuba, Chile, Peru, and Brazil (Hartman et al. 1995; Kananoja 1994; Whittaker 2014). The role of sloyd should not be overemphasized, however, not even in Sweden. There Educational sloyd constitutes a significant precursor to the modern, obligatory subject of technology in compulsory school that was introduced in 1980, but its direct predecessor was a vocational subject and there were also other influences from the subjects of science and civics (Hallström 2009; Hultén 2013).

The originator of Swedish sloyd, Salomon, and many of his followers, saw it as a comprehensive subject in the German tradition of *Bildung* (cf. Gustavsson 1996; Liedman 2001); it was therefore arguably an early twentieth-century version of what was later to be termed "technological literacy." According to Lewis and Zuga (2005), proponents of the subject industrial arts in the USA in the 1920s similarly saw it as comprehensive, inspired as they were by Cygnaeus, Salomon, Della Vos, Dewey, and others (Lewis and Zuga 2005). A more vocational and industrial approach subsequently became influential in the few countries that hosted some form of general Technology education in the decades to come, for instance, Educational sloyd, Swedish voluntary technology, craft and design in England and Wales, and industrial arts in the USA (de Vries 1994; Elgström and Riis 1990; Herschbach 1996; Layton 1994; Zuga 1997).

After the mid-twentieth century, however, many countries left the craft or industrial arts stage and moved on to more modern subjects such as technology, design and technology, or the like. For example, Technology education in Swedish compulsory education was introduced in 1980; in England and Wales, design and technology was established in 1990; and in New Zealand they introduced technology in 1992 (de Vries and Mottier 2006; Jones and Moreland 2002). The knowledge domain of Technology education was indeed broad and varied if we look at Northern Europe as well as countries such as the USA, France, South Africa, New Zealand, and Australia, but the advent of modern Technology education generally coincided with a trend toward the incorporation of elements of technological literacy in many countries (e.g., Dakers 2006; Jenkins 1997). Today, there are many influences including STEM, science, design and craft, as well as industrial and vocational training. The heritage of sloyd and other craft subjects thus still plays an important role in some countries (Jones et al. 2013).

In the Nordic countries, craft-oriented subjects remain particularly influential, which very likely has to do with the more direct cultural heritage of Educational sloyd. Finland retains its Sloyd education in its comprehensive schools to this day, even though since 2004, there has been a cross-curricular area named “human beings and technology” which should permeate sloyd and many other subjects. From the fall of 2016, sloyd as “technical work” and “textile craft” has been integrated into the curriculum for grades one to seven, but are still optional for grades seven to nine (Niiranen 2016; Rasinen et al. 2009; Virtanen et al. 2015). In Norway, there is the relatively new cross-curricular area *Teknologi og design*, which has been inspired by design and technology in England but has also acquired its own distinct Norwegian identity in compulsory education (*grunnskole*). This cross-curricular area should be implemented in relation to various subjects (Bungum 2006a, b). Denmark combines technology and science education in primary education (grades one to six of its *folkeskole*), but there is also the sloyd-like design, wood−/metalwork, and home economics in grades four to seven (“Subjects & Curriculum,” 2015).

Technology Education and Educational Sloyd: A Swedish Comparison

Technology was initially introduced as a school subject in the 1960s in the new Swedish compulsory school (*grundskola*), which provided primary and lower secondary education (ages 7–16). In the 1962 national curriculum, it was the subject technological orientation (*teknisk orientering*), which largely prepared the pupils for working in industry and trade. In the 1969 curriculum, a subject named technology, which was optional for lower secondary level (ages 13–16), was introduced. In Sweden this introduction started the shift toward more comprehensive Technology education – technological literacy. In this curriculum, there was also specific technical content in the civic subject home region instruction (*hembygdskunskap*) for lower primary (ages 7–10) (Hallström 2013; Hultén 2013). Compulsory Educational sloyd existed alongside technology during the 1960s and 1970s and was divided between wood/metal sloyd and textile sloyd. Apart from handicraft, there was also an emphasis on creative and aesthetic skills and moral values such as carefulness, orderliness, and thrift. The 1969 curriculum emphasized free, creative art more, and 1970s' Sloyd education thus became freer – and more unstructured – according to Borg (1995).

In the mid-1970s, there were initiatives to introduce technology as a mandatory, comprehensive subject for all Swedish pupils in the lower secondary school, which was very early by international standards (de Vries 2006; Layton 1994). The National Board of Education (*Skolöverstyrelsen*), which carried out this momentous introduction of a new subject, saw sloyd teachers as important actors in this work and consequently invited some representatives to participate in preparing for the new subject. The arguments for this were, first of all, that technology would provide a theoretical foundation for sloyd, and a combined subject would therefore have pedagogical benefits since they were both practical subjects dealing with everyday concerns. Representatives of technology teachers, however, argued that technology should rather be seen as part of science, something which was embraced by many politicians, educationists, and other societal actors of the day (Elgström and Riis 1990; Lövheim 2010). Technology therefore finally ended up as part of science in the 1980 national curriculum. This curriculum was very progressive in the sense that the sciences and technology were not really seen as subjects but divided into themes. Technology was mainly under the theme "human activities" (*Människans verksamhet*), and the subject was consequently introduced without a clear definition of its curricular content (*Läroplan för grundskolan, Lgr 80, Allmän del.* 1980; Riis 2013).

Sloyd education was retained as a distinct subject and was divided into three main strands: creative arts, production and consumption, and environment and culture. The most important reason for including the subject in the curriculum was for the pupils to be able to learn manual labor and the manual processing of various materials, notably textiles, wood, and metal. The significance of the cultural heritage of sloyd for producing new artifacts was also emphasized as subject content (Borg 1995, 2001; *Läroplan för grundskolan, Lgr 80, Allmän del.* 1980).

The final arrangement in the 1980 national curriculum came to have far-reaching consequences for the Swedish compulsory school. Two different teacher categories – science and sloyd teachers, who had previously had very little to do with each other because of their different subject domains – all of a sudden struggled to define the boundaries of the new obligatory subject of technology (Andersson 1988). This can be seen even today as most compulsory school technology teachers either have a combination of technology–sloyd or technology–science, and the actual teaching of technology turns out quite differently depending on whether the technology teacher is also a sloyd teacher or a science teacher (Bjurulf 2008).

In the 1994 national curriculum (Lpo 94), the technological *Bildung*/literacy argument was revived. Already in the fourth paragraph of the technology curriculum, one can read about the importance of pupils acquiring a "basic competence in technology" (*Grundskolan. Kursplaner, betygskriterier* 1996, p. 91). This was later developed in the revision of 2000:

> Technical knowledge is increasingly becoming a prerequisite for mastering and using the technology surrounding us. Citizens in a modern society need basic competence in technology, and this competence must, in addition, be continuously expanded and adapted. This competence covers not only knowledge about the role of technological development from an historical perspective, but some experience in reflecting over and solving technical problems in practical terms. In addition, it is necessary to be able to analyze and evaluate the interaction between people, technology and the conditions under which we will exist in the future. ("Swedish Technology Curriculum, Lpo 94," 2000, p. 1)

It is obvious here that technological literacy is not regarded as something static, but that the pupils need to be able to update their technological knowledge as society and technology evolve.

Technological knowledge was here portrayed as different from its scientific equivalent, and a huge amount of effort was being expended in the epistemologically motivated separation from science. This separation was also a result of a movement away from progressivism and toward a clear separation between subjects in the 1994 curriculum (Carlgren 2013). The parliamentary report preceding the new technology curriculum of 1994 stressed the notion of "an independent area of knowledge with a considerable element of practical experience and craftsmanship" (quoted in Hallström et al. 2014, p. 134).

Despite this emphasis on practical work and craftsmanship, there was no sign of a closer relationship to sloyd, however. Educational sloyd continued as a subject of its own, building on the historical sloyd tradition although being somewhat modernized. Under the heading "Aim of the subject and its role in education," the purpose and role of the subject *slöjd* (crafts, in English translation) were laid out:

> The subject of Crafts helps the pupils' all-round development by training their creative, manual and communicative abilities. Crafts involve a combination of manual and intellectual work that develops creativity, curiosity, taking responsibility, independence and the ability to solve problems. A typical process starts from an idea and results in a finished product. Working with textiles, wood and metal aims at strengthening pupils' confidence in their own ability and developing their knowledge to provide preparation for managing tasks in daily life.[. . .]
>
> The subject aims at creating an awareness of aesthetic values and developing an understanding of how choices over material, processing and construction influence a product's function and durability. The subject also aims at providing a knowledge of environmental and safety issues, and creating an awareness of the importance of resource management. The subject lays a foundation for innovation and creativity. By developing familiarity with earlier and contemporary crafts traditions, the subject provides insights into everyday history and gender equality issues.[. . .]. (*Compulsory School Syllabuses 2000* 2009, p. 79)

The more modernized items were environment, resource management, and gender equality issues.

Borg investigated the essence of sloyd from the pupils' and teachers' perspectives in her 2001 dissertation. She concluded by constructing a model of Educational sloyd with the following components: the practical, the theoretical, the aesthetic, and the social. The *practical component* had to do with manual construction and production, but also artful creativeness and a *theoretical component* in the form of reflection and understanding. The *aesthetic component* consisted of art, aesthetics, and communication through manual work and reflection. The *social component* dealt with the development of pupils' identities and their access to a common community and cultural heritage (Borg 2001). This resonated well both with sloyd in the then current curriculum of 1994/2000 and the ideas of the early sloyd pioneers Cygnaeus and Salomon (*Compulsory School Syllabuses 2000* 2009; Whittaker 2014).

In the latest and still running Swedish national curriculum, Technology education is now even more modernized, at the same time as there is somewhat of a re-vocationalization (cf. Hallström 2011) in the sense that the technological capabilities needed in a future career are emphasized more than in the previous curriculum. The technology curriculum begins with the following rationale and aim:

> Technological solutions have always been important for man and for the development of society. The driving forces behind the evolution of technology have often been a desire to solve problems and meet human needs. In our time, more exacting demands are imposed on technological expertise in daily and working life, and many of today's societal and political decisions embody elements of technology. To understand the role of technology for the individual, society and the environment, the technology that surrounds us needs to be transparent and understandable.
>
> Aim
>
> Teaching in technology should aim at helping the pupils to develop their technical expertise and technical awareness so that they can orient themselves and act in a technologically intensive world. Teaching should help pupils to develop their interest in technology and their ability to deal with technical challenges in a conscious and innovative way. (*Curriculum for the compulsory school, preschool class and the recreation centre 2011* 2011, p. 254)

This curriculum was written in the context of an "intensive" technological landscape, and the most important aim of the subject was thus to ensure the pupils could act in and handle this technological, human-built world (*Curriculum for the compulsory school, preschool class and the recreation centre 2011* 2011).

Sweden retains a distinct technology subject while also keeping a parallel Sloyd education subject. Sloyd education in Sweden today retains much of the historical heritage of Educational sloyd while also bringing in more modern features. However, sloyd is arguably still very much influenced by its origins in the late nineteenth century. Even in the latest Swedish curriculum from 2011, there is great focus on handicraft, design, aesthetics, and cultural expression in sloyd (termed crafts in the official translation):

> Producing objects and processing material with the help of tools is one way for people to think and express themselves. Working with crafts is a type of creativity involving creating concrete solutions within the tradition of handicrafts and design based on needs in different situations. Crafts involve a combination of manual and intellectual work, which together

> develop creativity, and strengthen belief in the ability to manage tasks in daily life. These abilities are important, both for the individual and the development of society.
>
> Aim
>
> Teaching in crafts should aim at helping the pupils to develop knowledge of different handicrafts and the ability to work with different materials and forms of expression. Pupils should be given opportunities to develop their skills in a process where thinking, sensory experiences and action work together. (*Curriculum for the compulsory school, preschool class and the recreation centre 2011* 2011, p. 203)

There is also a section of the core content on the "sloyd process," which was important even in the previous curriculum and resembles the design process in Technology education ("Swedish Sloyd Curriculum, Lpo 94," 2000).

Concluding Discussion

One might sum up the historical development from Educational sloyd to Technology education as follows. In the late nineteenth and early twentieth centuries, as sloyd spread throughout the world, it included technical content such as comprehensive handicraft, tools, and cultural heritage in relation to the artisan and agricultural community of the time, not the emerging industrial and urban society. As the subject continued evolving through the 1920s, it came to include more design elements. Later on, and throughout the mid-twentieth century as societies were urbanized and industrialized, sloyd underwent a vocational–industrial transformation, while at the same time, it also partly inspired vocational and craft-based subjects such as the American industrial arts and English craft and design (Lewis and Zuga 2005; Whittaker 2014). However, sloyd was just one influence, as elements from vocational training, science, civics, and other subjects also influenced and were intertwined with the evolution of Technology education (de Vries and Mottier 2006). In Sweden, with both Technology and Sloyd education as separate subjects, the influence between the two subjects was of lesser importance during the 1960s and 1970s, but still they were seen as connected by important educational actors such as the National Board of Education (Elgström and Riis 1990; Hultén 2013).

In the 1980s, more comprehensive technology subjects aiming for technological literacy began emerging, at the same time as more vocationally oriented Technology education and Educational sloyd/Crafts continued to exist in some countries (de Vries and Mottier 2006; Jones et al. 2013). The modern conception of sloyd in the curriculum has mainly been investigated and developed in Sweden and Finland. Sloyd is nowadays partly a modern form of Technology education but also a subject emphasizing knowledge and skills rooted in a rural society, such as manual handicraft skills, tool management skills, aesthetic skills, and personal development (Borg 2001; Leponiemi et al. 2012; Whittaker 2014; Virtanen et al. 2015).

The content-related and method-related curriculum components outlined in this chapter are central to these two school subjects in both the curricula and the literature.

Figure 1 is an image of the relationship between Technology education and Educational sloyd in the curriculum, as these two subject domains have evolved in Sweden in particular. The chapter has naturally focused on the research on Technology education in relation to Sloyd education. For research on aspects of the subject content of Technology education and technological literacy per se, see other chapters in this book (and also, e.g., Barlex and Stevens 2012; Dakers 2006; Jenkins 1997; Jones et al. 2013; Stables and Keirl 2015).

The common elements of Technology education and Educational sloyd in Fig. 1 tell us, first of all, that sloyd has been modernized (not least outside of Sweden, for instance, in Finland) in parallel to a similar development in Technology education. However, the two knowledge domains have been modernized somewhat differently. The technology knowledge domain has become broader, which is also a general trend of the concept of technology in the twentieth century (e.g., Schatzberg 2006). While having been modernized and broadened, Educational sloyd also still depends a great deal on the legacy of Cygnaeus and Salomon, together with the design legacy contributed by Carl Malmsten in the 1920s and 1930s (Hallström 2009). There is also the prevalence of the sloyd cultural heritage and personal development which, as curriculum components, can only marginally be said to be part of Technology education.

However, the synchronous juxtaposition of curriculum components in Fig. 1 above all shows that the two subjects include very similar elements. Apart from subject content of the respective subject domains, there are also methodical components that have either an early origin or have evolved over the years, such as design, problem solving, and practical work. The similarity in the use of tools in both subjects is also notable, as shown by Johansson (2002) who studied the role of tools and machines as well as sketches and drawings in sloyd. She concluded that these also constitute tools in a sociocultural meaning, that is, as tools and support for thinking about and learning of the subject content. The pupils think, act, and learn in relation to and

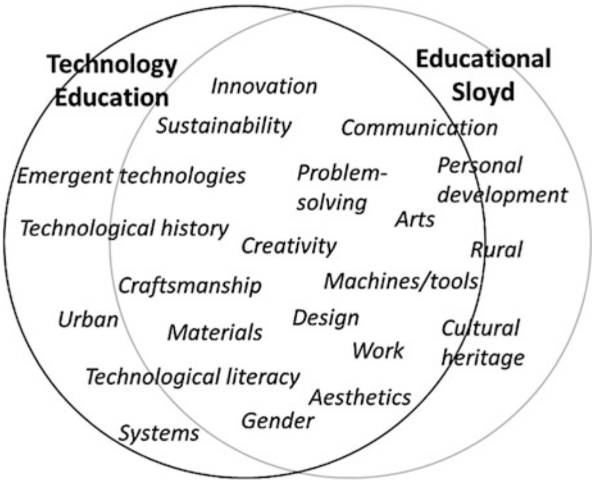


Fig. 1 Elements common to Technology education and Educational sloyd

through these tools, which is very similar in sloyd and Technology education (Johansson 2002, pp. 204–206; cf. Williams 2013).

The heart of the matter here is the different philosophical underpinnings of these two subjects. Technology education is about various aspects of the human-made world. Its main interest is technology itself; what it is, how it evolves, and how we as humans conceive, design, use, and manage technology (Hughes 2004; Pearson and Young 2002). Educational sloyd, on the other hand, is about what Whittaker calls "Hands, Head and Heart" (Whittaker 2014, p. 122), that is, mainly about human development, human capabilities of creating, crafting, working, and developing (cf. Borg 2001).

A major difference in curriculum components between Technology and Sloyd education, therefore, is that the kind of technology dealt with in sloyd is artifacts, whereas in many countries, including Sweden, much of the modernization of Technology education has been about including a systems component. In the present day, broad conception of technology, aimed at technological literacy, systems play a central part since much of modern technology is included in various technological systems (cf. Hallström et al. 2015). The fact that systems are included in Technology education, but not in Educational sloyd, testifies to the difference in focus; technology deals mainly with the human-built world, which is increasingly permeated by various technological systems (cf. Kaijser 2004).

Still, the overlap of similar curriculum components is substantial, and an obvious conclusion is that a major part of sloyd is also a part of the field of Technology education today, not the other way around (cf. Whittaker 2014, p. 123), because knowledge of the human-built world goes beyond the boundaries of Educational sloyd. But in a sense, yes; Cygnaeus was the founder of at least parts of the global field of Technology education today, and technology and sloyd thus share a common ancestry and, largely, common epistemological ground. Time will tell whether this will remain so since the technological landscape is ever changing and "rich with unintended consequences" (Hughes 2004, p. 2).

References

Andersson, Y. (1988). *Teknikämnet på grundskolans mellanstadium*. Linköping: Linköping University, Department of Education and Psychology.

Banks, F., & McCormick, R. (2006). A case study of the inter-relationship between science and technology: England 1984–2004. In M. J. de Vries & I. Mottier (Eds.), *International handbook of technology education: Reviewing the past twenty years*. Rotterdam/Taipei: Sense Publishers.

Barlex, D., & Stevens, M. (2012). Making by printing – Disruption inside and outside school? In T. Ginner, J. Hallström, & M. Hultén (Eds.), *The PATT 26 conference Stockholm, Sweden 26–30 June 2012, technology education in the 21st century*. Linköping: Linköping University Electronic Press.

Bjurulf, V. (2008). *Teknikämnets gestaltningar. En studie av lärares arbete med skolämnet teknik*. Karlstad: Karlstad University.

Borg, K. (1995). *Slöjdämnet i förändring 1962–1994*. Linköping: Linköping University.

Borg, K. (2001). *Slöjdämnet. Intryck – uttryck- avtryck*. Linköping: Linköping University.

Bungum, B. (2006a). Teknologi og design i nye læreplaner i Norge: Hvilken vinkling har fagområdet fått i naturfagplanen? *NorDiNa, 4*, 28–39.

Bungum, B. (2006b). Transferring and transforming technology education: A study of Norwegian teachers' perceptions of ideas from design & technology. *International Journal of Technology and Design Education, 16*, 31–52.

Carlgren, I. (2013). Hurusom teknik kom att skiljas från naturvetenskap i 'Skola för bildning'. In J. Hallström & C. Klasander (Eds.), *The Ginner handbook of technology education: Some theses about technology, school and society*. Linköping: Linköping University Electronic Press.

Compulsory School Syllabuses 2000. (2009). (Rev. Version 2008. ed.). Stockholm: Swedish National Agency for Education.

Curriculum for the compulsory school, preschool class and the recreation centre 2011. (2011). Stockholm: Swedish National Agency for Education.

Dakers, J. R. (Ed.). (2006). *Defining technological literacy: Towards an epistemological framework* (1st ed.). New York: Palgrave MacMillan.

de Vries, M. J. (1994). Technology education in Western Europe. In D. Layton (Ed.), *Innovations in science and technology education* (Vol. V). Paris: UNESCO Publishing.

de Vries, M. J. (2006). Two decades of technology education in retrospect. In M. J. de Vries & I. Mottier (Eds.), *International handbook of technology education: Reviewing the past twenty years* (pp. 3–10). Rotterdam: Sense Publishers.

de Vries, M. J., & Mottier, I. (Eds.). (2006). *International handbook of technology education: Reviewing the past twenty years*. Rotterdam/Taipei: Sense Publishers.

Elgström, O., & Riis, U. (1990). *Läroplansprocesser och förhandlingsdynamik. Exemplet obligatorisk teknik i grundskolan*. Linköping: Tema teknik och social förändring.

Grundskolan. Kursplaner, betygskriterier. (1996). Stockholm: Skolverket.

Gustavsson, B. (1996). *Bildning i vår tid. Om bildningens möjligheter och villkor i det moderna samhället*. Stockholm: Wahlström & Widstrand.

Hallström, J. (2009). Technical knowledge in a technical society: Elementary school technology education in Sweden, 1919–1928. *History of Education, 38*(4), 455–474.

Hallström, J. (2011). Looking back in order to move forward: The position of technology education in past Swedish curricula. In M. J. De Vries (Ed.), *Positioning technology education in the curriculum* (pp. 21–38). Rotterdam: Sense Publishers.

Hallström, J. (2013). Samhällslivet, tekniken och skolan. Teknik i fortsättningsskolans medborgarkunskap, 1918–1936. In J. Hallström, M. Hultén, & D. Lövheim (Eds.), *Teknik som kunskapsinnehåll i svensk skola 1842–2010* (pp. 147–165). Möklinta: Gidlunds.

Hallström, J., Hultén, M., & Lövheim, D. (2014). The study of technology as a field of knowledge in general education: Historical insights and methodological considerations from a Swedish case study, 1842–2010. *International Journal of Technology and Design Education, 24*(2), 121–139.

Hallström, J., Klasander, C., & Svensson, M. (2015). The black box and beyond: Introducing a conceptual model as a learning tool for developing knowledge about technological systems. In M. Chatoney (Ed.), *PATT 29 plurality and complementarity of approaches in design & technology education, Marseille, France, April 2015*. Marseille: Presses Universitaires de Provence.

Hartman, S. G., Thorbjörnsson, H., & Trotzig, E. (1995). *Handens pedagogik. Kulturarv och utveckling i skolslöjden*. Linköping: Linköpings universitet.

Hasselskog, P. (2010). *Slöjdlärares förhållningssätt i undervisningen*. Göteborg: Göteborgs universitet.

Herschbach, D. R. (1996). 'What is past is prologue': Industrial arts and technology education. *Journal of Technology Studies, 22*(1), 28–39.

Hughes, T. P. (2004). *Human-built world: How to think about technology and culture*. Chicago: University of Chicago Press.

Hultén, M. (2013). Technology as the language of schooling: Utopian visions of technology in Swedish general education in the 1960s. *International Journal of Technology and Design Education, 23*(3), 581–595.

Jenkins, E. W. (1997). Technological literacy: Concepts and constructs. *Journal of Technology Studies, 23*(1), 2–5.

Johansson, M. (2002). *Slöjdpraktik i skolan – hand, tanke, kommunikation och andra medierande redskap*. Göteborg: Göteborgs universitet.

Jones, A., & Moreland, J. (2002). Technology education in New Zealand. *Journal of Technology Studies, 28*(1/2), 130–134.

Jones, A., Buntting, C., & de Vries, M. J. (2013). The developing field of technology education: A review to look forward. *International Journal of Technology and Design Education, 23*(2), 191–212.

Kaijser, A. (2004). *The dynamics of infrasystems: Lessons from history.* Paper presented at the summer academy 2004 "Urban infrastructure in transition: What can we learn from history", Inter-University Research Centre for Technology, Work and Culture, Graz.

Kananoja, T. (1994). Technology education in the nordic countries. In D. Layton (Ed.), *Innovations in science and technology education* (Vol. V, pp. 45–58). Paris: UNESCO Publishing.

Klasander, C. (2010). *Talet om tekniska system. Förväntningar, traditioner och skolverkligheter.* Norrköping: Linköpings universitet.

Läroplan för grundskolan, Lgr 80, Allmän del. (1980). Stockholm: Skolöverstyrelsen.

Layton, D. (1994). A school subject in the making? The search for fundamentals. In D. Layton (Ed.), *Innovations in science and technology education* (Vol. V). Paris: UNESCO Publishing.

Leponiemi, T., Virtanen, S., & Rasinen, A. (2012). Design and assessment in technology education – Case: The "birdhouse band" project. In T. Ginner, J. Hallström, & M. Hultén (Eds.), *Technology education in the 21st century: The PATT 26 conference Stockholm, Sweden 26–30 June 2012* (pp. 460–467). Linköping: Linköping University Electronic Press.

Lewis, T., & Zuga, K. F. (2005). *A conceptual framework of ideas and issues in technology education*. Arlington: Technology Teacher In-service Education & National Science Foundation.

Liedman, S.-E. (2001). *Ett oändligt äventyr. Om människans kunskaper.* Stockholm: Bonnier.

Lövheim, D. (2010). An epistemology of one's own: Curricular (re-)construction of school technology and non-technology in Sweden, 1975–1995. *History of Education, 39*(4), 525–537.

Niiranen, S. (2016). Female technical craft teachers in a key role in developing Finnish technology education. In M. J. de Vries, A. Bekker-Holtland, & G. van Dijk (Eds.), *PATT-32 proceedings: Technology education for 21st century skills*. Utrecht: University of Applied Sciences.

Ödman, P.-J. (2007). *Tolkning, förståelse, vetande. Hermeneutik i teori och praktik*. Stockholm: Norstedts.

Pearson, G., & Young, A. T. (Eds.). (2002). *Technically speaking: Why all Americans need to know more about technology.* Washington: National Academies Press.

Postholm, M.-B. (2006). Assessment during project work. *Teaching and Teacher Education, 22*, 150–163.

Rasinen, A., Virtanen, S., Endepohls-Ulpe, M., Ikonen, P., Ebach, J., & Stahl von Zabern, J. (2009). Technology education for children in primary schools in Finland and Germany: Different school systems, similar problems and how to overcome them. *International Journal of Technology and Design Education, 19*(4), 367–379.

Riis, U. (2013). Teknik – mellan slöjd och naturvetenskap. In J. Hallström & C. Klasander (Eds.), *The Ginner handbook of technology education: Some theses about technology, school and society.* Linköping: Linköping University Electronic Press.

Samuelsson, M., Samuelsson, J., & Autio, O. (2015). Tracing patterns of sloyd teachers' efficacy beliefs at different stages of their professional careers. *Techne Series: Research in Sloyd Education and Craft Science, 22*(1), 30–43.

Schatzberg, E. (2006). *Technik* comes to America: Changing meanings of *technology* before 1930. *Technology and Culture, 47*(3), 486–512.

Sjögren, J. (1997). *Teknik – genomskinlig eller svart låda? Att bruka, se och förstå teknik – en fråga om kunskap*. Linköping: Linköping University, Department of Technology and Social Change.

Stables, K., & Keirl, S. (Eds.). (2015). *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures*. Rotterdam: Sense Publishers.

Subjects & Curriculum. (2015). Retrieved 9 Oct 2015, from eng.uvm.dk

Swedish Sloyd Curriculum, Lpo 94. (2000). Retrieved from: www.skolverket.se

Swedish Technology Curriculum, Lpo 94. (2000). Retrieved from: www.skolverket.se

Teknikämnet i träda. Teknikföretagens och CETIS rapport om teknikundervisningen i grundskolan. (2012). Stockholm: Teknikföretagen.

Virtanen, S., Räikkönen, E., & Ikonen, P. (2015). Gender-based motivational differences in technology education. *International Journal of Technology and Design Education, 25*(2), 197–211.

Whittaker, D. J. (2014). *The impact and legacy of educational sloyd: Head and hands in harness*. London/New York: Routledge.

Williams, P. J. (2013). Research in technology education: Looking back to move forward. *International Journal of Technology and Design Education, 23*, 1–9.

Zuga, K. F. (1997). An analysis of technology education in the United States based upon an historical overview and review of contemporary curriculum research. *International Journal of Technology and Design Education, 7*(3), 203–217.

Design and Technology Education and Its Curriculum Policy Challenges 18

Steve Keirl

Abstract

This chapter takes a global perspective on the kinds of issues faced by Design and Technology (D&T) curriculum policy-makers. In doing so, it recognizes both the *phenomenon* of our intimate human-technology relationship and what is seen as a huge educational *irony*, namely, that despite the ubiquitous and pervasive nature of technologies in our lives, education systems rarely offer curricula that can engage the phenomenon. This curriculum conundrum is explored using Nel Noddings' notion of "aims-talk" and William Pinar's recognition of curriculum as "complicated conversation." Rather than D&T perpetually reinforcing stereotypical orthodoxies of what technology is or should be in the public eye or pursuing a limited and instrumentalist skilling agenda for students, an aims-led conversation is advocated that engages matters of humanity, politics, ethics, democracy, sustainability, and, indeed, existence.

Much of D&T education is (being) tied to the service of a particular economic model and ignores multiple alternative educational possibilities. Such possibilities are seen here as presenting D&T not as "subject" or being governed by prescribed content but, rather, as a special way of knowing and being – drawing on multiple epistemologies and ontologies. The resultant case is one for a holistic, comprehensive formulation of a critical technological literacy that permeates whole-school curricula and learning. Good D&T curriculum design is core to developing students as global citizens capable of participation in democratic considerations with technological developments. Moreover, good D&T curriculum design is seen as valid and valued contributor to a global common good.

S. Keirl (✉)
Goldsmiths, University of London, London, UK
e-mail: s.keirl@gold.ac.uk

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_16

Keywords
Design and Technology curriculum • Epistemology • Ontology • Critique • Ideology • Politics

Contents

Introduction: Critiquing Educational Aims

> It has always been the fashion of philosophers of education to critique the aims of education in the light of their contemporary cultures. It has been another of their functions to criticize the society with respect to a vision of education. . . .(S)ome philosophers have started with a description of ideal or actual states from which they have derived recommendations for education. Others have started with a vision for the education of individuals and asked what sort of state might support that vision. Simply accepting the state as it is and the system as it is (merely pushing it to perform its perceived function more vigorously) is a dangerous (and lazy) strategy. I will argue that this is the policy we have followed for the past two decades, and it is likely to prove ruinous. (Noddings 2003/2009, p. 426)

Noddings' words encapsulate the concerns of this chapter. In many countries today, it is increasingly difficult to find philosophers of education; such is their demise. This is not for any loss of interest or lack of concern on the part of educationalists. Rather, it is the direct result of the very circumstances that Noddings critiques. Philosophy, or any political critique of education, is being driven from the academy, and the result is uncritical compliance with a system that is arguably dangerous to democracy and the environment alike.

Education is a political act. Also, because education systems are *designed with intention* to serve particular ends, they can be considered to be technologies. Thus, as a political technology, education is subject to considerable contestation. The Noddings' extract originates in her text *Happiness and Education* which is certainly not a phrase that is heard in educational discussions as we move through the second decade of the twenty-first century. Far more likely are pronouncements (not discussion) on "standards," "performance," and "league tables."

The extract is part of Noddings' address to *The Aims of Education*, and she shows how, for the best part of a century, educational discourse focused on what the aims of this or that education should be. Following the clarification of the aims of education, the shaping of the curriculum would follow. Rare today are discourses of *critique*, *vision*, *ideal states*, and *recommendations* – let alone talk of *happiness*.

Importantly, Noddings reminds us that any seemingly "agreed" position regarding a community's educational aims is never final but, rather, constitutes a part of an ongoing practice – which she refers to as "aims-talk." She says: ". . .one might argue that aims-talk is to education what freedom is to democracy. . . (W)ithout continual, reflective discussion of aims, education may become a poor substitute for its best vision. Moreover, just as freedom takes on newer and richer meanings as times change, so must the aims of education change" (Noddings 2003/2009, p. 426). As a consequence, she argues: ". . .failure to engage in vigorous discussion of educational aims has marked the movement toward standardization and high-stakes testing" (Noddings 2003/2009, p. 427).

(Design and) Technology education, while a constituent of most educational jurisdictions across the world (Layton and Layton 1994), has remained in the shadows of mainstream curriculum discourse. Quiet as it may be slumbering, there are good reasons why it warrants not only a global voice but also vibrant internal discussion and clarification around its own, multiple, curriculum contradictions and contestations. As Layton and Layton (1994) noted in his global review of technology education curricula: "School technology. . .is subject to a range of competing influences and the politics of technological literacy–who creates and controls the meanings of the phrase, how the imposition of meaning is attempted–is a central concern of technology education today" (Layton and Layton 1994, p. 13). Thus is D&T's curriculum lot: as it was then; as it is now: and as it ever will be even as our philosophical and political understandings of technological and design phenomena continue to grow.

This chapter proceeds with some discussion of, first, curriculum as a concept and field of professional study and, second, of technology itself. These two overviews are foundational to any proper understanding of the nature of Design and Technology curriculum which is contextualized against an indictment regarding a major educational shortfall. D&T is explored using a range of perspectives to illustrate the field's potential, its contradictions and contestations, and how its players are engaged or marginalized through differing curricular enactments. The chapter concludes by advocating a rich conceptualization of D&T curriculum – one warranting much-needed aims-talk.

Considering Curriculum

Understandings of what curriculum is, and attempts to define it, vary widely. It is sometimes taken, rather unhelpfully, to refer to that which is conducted within a particular *subject*. Thus some would talk of "D&T curriculum" in a constrained sense of *the content and procedures appropriate to the teaching* of the subject. Even more narrowly, curriculum is sometimes confused with *syllabus* (which is better understood as a prescriptive statement of content – what is to be taught). Alternatively, curriculum is narrowly viewed as a simple aggregation of subjects.

Educational jurisdictions may articulate their educational policy as a curriculum, for example, as a *national curriculum*. Such a curriculum policy can be referred to as the *formal* or *intended* curriculum. However curriculum policy can also amount to rhetoric, wishful thinking or a superficial rendition of serious challenges that exist. Curriculum researchers have long pointed out the power of the *hidden* curriculum in contrast to the actual, formal, or intended curriculum. For example, “It is the hidden curriculum that works most effectively to preserve the status quo, the ‘commonsense reality’ view of the world that tends to serve the interest of the dominant culture” (Smith and Lovat 2006, p. 37). Despite state policy or schools’ aims, there are always multiple values, positions, and unspoken messages at play – from society, communities, students, and, importantly, teachers. The hidden curriculum is pervasive, is values-rich, and can operate positively or negatively to constitute curriculum as a site of political contestation. (D&T curriculum is particularly fraught with contradictions. Nonetheless, it is also well endowed with opportunities.)

As with the term “technology,” attempts at defining “curriculum” can be problematic. Curriculum studies primers are informative (e.g., Print 1988/1993; Smith and Lovat 2006; Flinders and Thornton 2009) and show how a 100 years’ worth of interpretations of “curriculum” have reflected changing understandings of education in practice. Descriptions (or definitions) range from the narrowly instrumental and prescriptive to the comprehensively holistic and descriptive. Two of the latter are “The curriculum is all those discursive practices which affect what and how students learn, and what and how teachers teach” (Reid and Johnson 1999, p. ix) and “. . .the ultimate realisation for a complex enactment involving global, national, state, school, community, teacher and student actors, in terms of what students come to think, believe, know and do” (Boomer 1991/1999, p. 124). The spectrum of theorizations broadens if we accommodate Freire (1972) on intentionality as consciousness, Morris (1966/1990) on existentialism, or Pinar (2004) on Bildung and autobiography. Curriculum articulations that engage intentionality, existence, consciousness, and ethics all offer qualitatively different opportunities for D&T education than does any technical-instrumentalist formulation of the skilling type.

The fact that many curricula have moved in recent years from *debated aims* to *instrumental agendas* has been well documented (see, e.g., Apple 2001; Smith 2003; Pinar 2004; Reid 2004/2005; Darder et al. 2009; Kincheloe 2008/2010; Smyth 2011; and, on Design and Technology: Petrina 2000a, b; Keirl 2006, 2015a, b). In discussing the currently powerful neoliberal political players (along with neoconservatives and authoritarian populists among others), Apple (2001) points to the ambiguous “right way” (being not only claimed as the *right* and *only* way as well as to the political orientation of its perpetrators). This orientation positions the curriculum as an instrument of particular economic and social modeling that advances the interests of business and corporations above those of sovereign democratic states and constrains major sections of democratic curriculum to minor or nonexistence. Design and Technology education is inevitably entangled in these agendas.

As the cited curriculum researchers show, teachers are positioned not as professionals but as overworked technicians, constrained to deliver the curriculum as best they can with limited resources, with their “performance” ever subject to scrutiny and conformity. There is no room for the creative curriculum, vision, and teachers’ professional judgment, nor time for critical-reflective consideration of anything so purposeful as *aims*. Meanwhile, students are to be prepared in ways deemed appropriate for the needs of the economy. The rhetoric of “skills” and “lifelong learning” is used as code for “workplace ready” and “always adaptable to ever-changing market requirements.” The idea of the student as a well-rounded and fulfilled person and active citizen is anathema here. The humanities are marginalized, and first language (often English), mathematics, and science are privileged and awarded status by the high-stakes testing driven by one of the world’s strongest (despite being a minority of countries) capitalist groupings, the Organisation for Economic Co-operation and Development (OECD). This is the scenario Noddings alludes to as “ruinous,” and it is “dangerous” because it fails to properly respect any of ethics, sustainability (Stables and Keirl 2015), cultures, or democracy.

Fortunately, enlightened D&T educators know that there are alternatives. A socially critical approach to curriculum centers on the human and humans as persons capable of cooperative social progress. Social interaction and participatory democracy are highly valued, and economic and technological decision-making is subject to democratic control. The curriculum serves the common good by developing a critically reflective citizenry that participates in change for better and more equitable provision for all – for more desirable futures. In such a curriculum, aims-talk not only happens, but is mandatory. Here, students and their learning are central to curriculum development, and teachers are co-learners enabling negotiation and growth to enhance socially and democratically desirable qualities. Structurally, such curricula are articulated creatively by eroding “subject” barriers (knowledge silos); by using learning areas, literacies, and cross-curricular project activities, rich tasks, and essential learnings; by celebrating learning processes over content retention; and by resisting *disciplines* by applying integrated, interdisciplinary, cross-disciplinary, even anti-disciplinary practices.

Again, aims-talk is key. In a different, deeper, and more comprehensive vein eminent international curriculum, scholar William Pinar has advanced the idea of curriculum as *complicated conversation*, and this phrasing, drawn from his research, is highly applicable to our Design and Technology education curriculum situation.

> The *educational* point of the public school curriculum is *understanding*, understanding the relations among academic knowledge, the state of society, the processes of self formation, and the character of the historical moment in which we live, in which others have lived, and in which our descendants will someday live. It is understanding that informs the ethical obligation to care for ourselves and our fellow human beings that enables us to think and act with intelligence, sensitivity, and courage in both the public sphere – as citizens aspiring to establish a democratic society – and in the private sphere, as individuals committed to other individuals. (Pinar 2004, p. 187)

Consider now, *curriculum as a technology* (for technologies are far from being mere *things*), when Pinar says:

> Curriculum ceases to be a thing, and it is more than a process. It becomes a verb, an action, a social practice, a private meaning, and a public hope. Curriculum is not just the site of our labor, it becomes the product of our labor, changing as we are changed by it. . .It is an ongoing, if complicated, conversation. (Pinar 2004, p. 188)

Such consideration of curriculum is fundamental to a proper understanding of D&T's special curriculum contradictions. Our field is only beginning to develop a vocabulary and grammar to conduct its own complicated curriculum conversation. For example:

- Knowing the comprehensive theoretical issues underpinning *curriculum*, *technology,* and *design* alike
- Understanding the shrinking planet, multiple globalizations (Ong and Collier 2005), and their cultural impacts
- Critiquing and countering simplistic or seemingly "commonsense," sound-bite versions of what some would have count as D&T education

Considering Technology

D&T's complicated conversation demands an equal consideration of what constitutes technology. We can think of technology (big-T) as the collective phenomenon, a (mostly) human enterprise and focus of philosophical and political study. Meanwhile technology/technologies (small-t) constitute single or multiple potentially identifiable and specific technologies.

Party to D&T's curriculum challenge are the commonplace populist and tired stereotypes of technology concerning *things*, *applied science*, *computers*, only the *new*, only *hi-tech*, being *neutral*, and so on. All such senses of technologies are evidence of historically naïve beliefs, uncritical acceptance, or blindness to associated issues and are often reinforced through the media, advertising and politicians' sound bites. This uncritical approach is partly because technology is ubiquitous, that is, it is everywhere, omnipresent, in an indefinite number of places at once yet seemingly invisible. Because it is so much a part of the background of our lifeworlds, we neither think of it nor discuss it. Sclove (1995) who critiques our poor democracy-technology relationship has described technology as being *polypotent* – powerful in many ways. Meanwhile, phenomenologist Ihde (2002) describes technologies as being *multistable* – taking different forms in different contexts, circumstances, or perceptions.

When we consider the vast range of technologies that have a long history of existence, along with those currently part of our daily existences, along with those that are emerging, there is much for a curriculum to consider. Technologies are multiple, contested, and problematic, and they are deeply existence shaping. It is not an accident that, by design, technologies are becoming more humanized and humans more technologized.

As a species, we cannot define ourselves without reference to our technologies. If that is seen a relatively unproblematic statement, then consideration should certainly be given to the fields of trans- and post-humanism (see, e.g., Bostrom 2009; Kurzweil 2005; Keirl 2015b). In a recent interview, (Adams 2016) when asked if the massive ongoing expansion of artificial intelligence (AI) will take over soon as a more imminent threat than global warming, Bostrom says: "I doubt it. It will come gradually and seamlessly without us really addressing it" (Adams 2016, p. 17). Notably, what Bostrom doubts is the *timing* of the threat, not its enormity, its impact, nor the need for massively increased public awareness (education). Not only are biotechnologies, AI, nanotechnologies, xenotransplantation, neurotechnologies, and digital technologies emergent technologies (notwithstanding their decades-long developments), they are also *con*-vergent technologies. This convergence has also been called *singularity* (see Vinge 1993; Kurzweil 2005; Bostrom 2009 and on D&T, Keirl 2015b); Kurzweil (1999, p. 14) has considered that technology is "evolution by other means." (A different proposition is that, because of our uncritical acceptance of these and other technological developments into our lives, we are designing our own extinction.)

We can also see that all of *countries*, *capitalism*, *communism*, *democracy*, *schools*, *laws*, *education*, *hospitals*, *sports,* and more are examples of technologies. In that they manifest through phases of conception, design, realization, use, and consequences (Keirl 2009), they are no different from a window, a watch, or a washing-up brush. They have intended and unintended consequences. They are never neutral nor do they empower equitably. As technologies, all such entities warrant ongoing critique and vigilance. However, whatever the technology, there are also geopolitical and cultural dimensions to their distribution, nature, and impacts. Drawing on Jacques Ellul's (1964) differentiation between the technologies of modern Western cultures and those of non-Western cultures, Bowers (2006/2009, p. 416) critiquing technologies' environmental impacts notes that:

> . . .non-Western technologies do not undermine the local cultural and environmental commons in the way that many modern Western technologies *are designed to do.* (My italics) This difference can be accounted for by the fact that the modernizing technologies of the West are increasingly relied upon as the engine for expanding the economy. While many of these Western technologies have made important contributions to the quality of everyday life in both the West and non-Western countries, some technologies, such as computers, electricity, print, the internal combustion engine, and so forth, have a Janus nature in that they contribute both to the vitality of the local cultural commons while at the same time strengthening the economic forces that are enclosing them.

An Indictment: The Phenomenon and the Educational Irony

> The *phenomenon* can be put as follows: we humans cannot "be" without Technology and Technology "is" by human intention and (inter)action. That is, technologies and humans coexist intimately. However, despite this intimate human-technology phenomenon, there is a huge *irony*: why, then, do we not have a parallel education to help understand the phenomenon? Of course we do have Technology Education and its variants around the world and we might argue that it is not their place to wrestle with the complexities of the phenomenon itself but, rather, they should/can only attend to local matters in a timely and manageable way. However, on closer examination, we can see that the phenomenon and practice in schools are not readily separated – or if they are, only a partial technology education may be taking place (and I use the term "partial" here in both senses: of being limited and being biased). We soon see that the phenomenon and the irony both beg special attention through curriculum and teaching. (Keirl 2015c, p. 14)

One reason for the irony is that mainstream curriculum theorists and policy-makers rarely focus their attentions on Design and Technology education. It is forever marginalized or makes cameo appearances as a support act to science, vocationalism, computers, or making things. However, our field itself has much responsibility to bear if it only talks around its own kitchen table and doesn't take its case to the wider public or if we maintain narrow perspectives that compound the stereotypes. Ours is indeed a complicated conversation that demands aims-talk and there is much to do. This chapter cautions that we would be wise to work against (to return to Noddings) "simply accepting the state as it is and the system as it is."

Design and Technology as a way of Knowing and Being

I would like to suggest that we consider D&T as a way of knowing and a way of being. Both terms imply action in, and on, the world. After all, design is about intention toward our worlds.

A standard approach to curriculum is to consider what "knowledge" should be "taught," but there is an immediate issue here. The assumption is that the knowledge is identifiable and quantifiable. Further, there is a possible suggestion that, once identified, the knowledge can be imparted from teacher to learner. This is the traditional model of the prescriptive *syllabus*, *subjects,* and *content*. However, the (potential) educational beauty of D&T education is that it celebrates *multiple ways of knowing*, *multiple intelligences* (Gardner 1983), and *critical-creative pedagogies.*

Even from one orthodox epistemological understanding (Ryle 1949/1973), Design and Technology articulates equally *knowing how* and *knowing that* or, more formally, *procedural* and *propositional* or *declarative knowledge,* respectively. D&T practices in the classroom (a term used here to signify any D&T learning environment, e.g., kitchen, studio, workshop) are about procedures as well as production, and all good D&T teachers know that the process-product interplay is the site of powerful learning. To those beyond the classroom, the process isn't noticed for its educational value because the product is tangible. Wise professionals know that the process is where cumulative learning is happening.

As students assemble a growing repertoire of skills (or, at least, initiation into them), the kinds of knowledge engaged also grow. Here, "skills" are used in a comprehensive educational sense, that is, as far more than vocational training which is so often associated with the field. It is taken to embrace hard skills, soft skills, design skills, problem-finding and problem-solving skills, critiquing skills (Keirl et al. 2016a, b), skills of critical reflection, and more. As skill-knowledge develops, it becomes what is often called *tacit knowledge* – that which we have but which we can neither show nor accurately describe (Polanyi 1958/1974; Polanyi 1966/2009).

Polanyi has argued that the performance of skills amounts to ". . .examples of knowing, both of a more intellectual and more practical kind. . . These two aspects of knowing have a similar structure and neither is ever present without the other" (Polanyi 1966/2009, p. 6–7). This synergistic knowledge engagement is something that D&T readily celebrates, but a rich curriculum is necessary for it to take place.

Ingold takes matters further in two ways helpful to D&T. First, he resists the idea that skill might be considered the *application* of knowledge (important in refuting the applied science stereotype). But second, and most importantly, because "...acting in the world is the skilled practitioner's way of knowing it. The perceptual knowledge so gained is... an integral part of personal identity. Hence, in the constitution of their environments, agents reciprocally constitute themselves as persons" (Ingold 1993/1994, p. 443). Here the important ontological dimension of skills and skilling presents itself, and D&T's invaluable educational contribution to a person's being opens up, and their personal awareness, identity, fulfillment, and citizenship can all flourish.

When we understand how Design and Technology can engage with different interpretations of "knowledge," the more we appreciate its rich educational potential. Here, the postmodern pluralized *literacies*, *knowledges,* and *learnings* become preferred constructs over *subjects* and *disciplines*. Rather than listing content to be learned, curriculum can be articulated, as in the South Australian case 2001–2016 (DETE 2001; Keirl 2004) as three verbs: critiquing, designing, and making. (The key point to be grasped here is that *these three apply to every technology*. Using such an approach *negates any privileging of one technology over another*, *accommodates technological change*, and *resists specified content dominance*.) When *actions*, *practices,* and *doing* celebrate multiple knowledge engagements, it is no surprise that Design and Technology curriculum in rich, rather than impoverished, forms has been highly valued for its capacity to integrate the curriculum as a whole – most notably in the primary education sector. For students and society alike, this amounts to *knowledge in the making*.

If the educational irony is to be overcome and the phenomenon of technology is to be understood, then an instrumental technology curriculum will be quite inadequate. A starting point is to meet the phenomenon on its own terms, that is, by working to find valid and defensible educational strategies for engaging technologies' complexities. This means understanding technology in many ways – epistemologically, materially, existentially, phenomenologically, ethically, socially, and more. This is not to rebuild the academy. It is to argue that educational traces of all of these can be legitimately part of the learning of all children and can be adequately managed by committed teachers. It is to have faith in the Bruner's pithy hypothesis that: "...any subject can be taught effectively in some intellectually honest form to any child at any stage of development" (Bruner 1960, p. 33).

Whose Interests? Who Determines?

There are multiple competing interests at play in D&T curriculum, and assessing their respective claims is not straightforward. Fundamentally, as Noddings indicates, there are the interests of students and of society at large. This has always been one of the major balancing challenges in any democratic curriculum, and it is both complex and political.

In the realm of the general public (and in the minds of many policy-makers), matters are rapidly clouded when our field is expected to address the stereotypes. At one level, everyone is an educational expert because they once went to school. At another level, the media-driven, uncritical claims of a (never-ending and never-specified) "skills shortage" create other expectations. Another uncritical take is that there is some kind of "special relationship" between science and technology when, arguably, there are no less "special" and, in fact, more intimate relationships between design and technology, society and technology, history and technology, (increasingly) democracy and technology, and so on. A different threat to a critical-democratic, holistic D&T curriculum comes with what has been called "computing," an easy catch-all term that is seldom clarified. This is the ideal example of curriculum inclusion devoid of aims-talk. It manifests along a spectrum from keyboard-and-mouse skills through software manipulation to "computer science" – all introduced with little more critique than "because they're there" or "that's the way things are going." Here, we accede to technological determinism and students are conditioned to fulfil technology's needs.

Differently, we can consider the kinds of *stakeholder interests* that seek to shape D&T curriculum. For an informative take on the kinds of interests at play (as well as differing classroom formulations that technology education can take), see Layton and Layton's (1994) report. Undoubtedly, one of the claimant groups he reported (the *economic instrumentalists*) has strengthened their grip on education across the world since the report's appearance. (For a D&T take on how neoliberal economics and policies shape our field, see Keirl et al. 2016a.) But, drawing on Layton, what of others who might better match this chapter's concern for D&T curriculum that is holistic, democratic, global, ethical, design rich, student-centered, and more? Those concerned for sustainability, gender and race issues, participatory democracy, liberal education, civil liberties, and particular professional interests all want to influence what is taught in schools under the umbrella of D&T education.

Curriculum knowledge and curriculum interests can be brought together via Habermas (1971) who offers a useful epistemological critique of what he calls *knowledge interests*. He suggests we consider not only *what knowledge* but also *whose interests* are being served in developing that knowledge. Simply put, there are three knowledge interests: the *technical*; the *practical hermeneutic*, and the *critical emancipatory*. The first accommodates factual knowledge of the formal scientific kind and is what has shaped the dominant, traditional curriculum. The practical-hermeneutic knowledge interest facilitates meaning making whereby understanding is deepened. Here, knowledge is developed in new ways and in new situations by the learner. Meaning is made culturally, socially, and politically, that is, context plus applied knowledge as experience leads to understanding. The critical-emancipatory interest frees the learner "to be" in the world in ways that are reflective, emancipatory, and fulfilling. The idea of the autonomous but engaged citizen emerges. The Habermasian approach can work well for a rich D&T curriculum.

To echo Bowers (2006/2009), much of what has been said in this section can be charged with having a Eurocentric perspective toward knowledge and learning. Many curriculum writers critique such perspectives and argue for respect of local and indigenous ways of knowing rather than compounding the orthodoxies or profit, resource exploitation, and "growth" pursued by the minority world (see, e.g., Cole and O'Riley 2015; Gaotlhobogwe 2015; Schultz 2015; and Seemann 2015; among others, all in Stables and Keirl 2015). All such research offers enlightened ways of reconsidering how we educate and how we view students and their learning. It also serves as a reminder of how orthodox Western curriculum models and practices are increasingly instruments that constrain, rather than enhance, learning.

When we consider the question of who *determines* D&T curriculum, it is clear that there are multiple claims. Governments may try to determine curriculum by shaping, even dictating, policy, but they may also shape curriculum by allocating funding in preferential ways (e.g., toward vocational training). Increasingly (Smith 2003; Keirl 2015a) there is evidence of the neoliberal project's moves to conflate "the market" (sweet talk for "capitalism": see Galbraith 2004/2005) with democracy and force a kind of commonsenseism that positions education primarily as servant to the economy. It is no coincidence that, under this project, teachers are transformed from being professionals to becoming technicians administering curriculum as instrument. That said, teachers are also powerful curriculum players with their own value systems and special understandings of their students. As individuals and as members of their (D&T) communities of practice, teachers mirror the value spectrum of society at large. They may advance future-orientated change critically or uncritically. Equally, they may resist change and defend their traditional practices and vested interests. As ever, all the factors of the hidden curriculum are at play in the background too.

Aims-Talk and Our Ongoing Complicated Conversation

So far, a rough sketch of the challenges facing D&T curriculum has been presented. Many more issues present themselves throughout this book. Ours is a field that can be understood as one rich in controversies (Keirl 2012), and these controversies can actually be celebrated. To do this is to suggest a critical approach to our curriculum thinking, that is, an approach that problematizes in the face (after Noddings) of dangerous laziness. Our field lends itself all too readily to its stereotypes and to the ready sound bite at a time when greater vigilance than ever is needed regarding three of the greatest of human endeavors – technology, education, and democracy. In such a situation rich, rather than impoverished, curriculum understandings are called for.

Some key considerations are that:

- Technology is philosophically and politically controversial. So, then, is (design and) technology education.
- Design and Technology education engages multiple competing epistemologies. The idea of a "body of knowledge" for the field is arguably a mirage.
- D&T education finds itself in an ever-fluid condition among multiple binaries such as arts-science, utopia-dystopia, process-product, skills-design, vocational-liberal, and academic-practical (Keirl 2015c).

- D&T education is a site contested by multiple and, at times, ideologically incompatible stakeholder interests.
- Technology education is ever vulnerable to being uncritical of technologies, especially emergent ones. Controversy exists when what is done in the name of technology education is mere socialization toward technologies or training in their use.
- Widely varying local cultures and knowledges invite D&T education to adapt its curriculum in ways that are sensitive to multiple ways of knowing and of being in the world.
- Because there are millions of technologies in existence and more yet to be created, D&T curriculum cannot privilege any particular technology, profession, material, product, process, or system over others.

This range of issues is not exclusive, but it does inform a differentiation between rich and impoverished Design and Technology curricula. An impoverished curriculum would exclude much of the above, would probably be articulated as a subject with an identified body of knowledge, and would be taught using a limited pedagogy with a corresponding assessment regime. In support of such a curriculum construction, two other possibilities are illustrative. First, a configuration such as STEM allows for some "reach" among *some* other subjects but in doing so is in danger of compounding epistemological limitations, positioning the "T" as service subject to mathematics and science, and marginalizing design. Second, there is an argument to manage the issues raised by abandoning completely anything like "Design and Technology" and redistributing it across the remaining subjectified curriculum. Thus the various knowledges and learnings divide and regress to, for example, social studies, art, history, mathematics, and science. Models such as these (STEM or redistribution) may offer rather neat curriculum options, but they do little to respond to the indictment posed nor do they constitute a rich Design and Technology curriculum.

A rich Design and Technology curriculum should be *comprehensive* in two ways. First, it should be a part of the *general education* of every child, that is, as a minimum, throughout the years of compulsory education. Second, D&T curriculum should be articulated across the whole school as a literacy – noting that interpretations of design literacy, technological literacy, and technacy (Seemann 2003) are not consonant (see also ITEA 2000; Petrina 2000b; Dakers 2006; Keirl 2006). This comprehensive articulation is not a version of the redistribution model which is about fragmentation. A literacy approach engages holism and the phenomenon of human-technology interdependence. An ethical-critical literacy approach does this even better.

Conclusion and Future Directions

Within an ethical-critical D&T curriculum framework, Design and Technology can also hold a legitimate place as a subject or learning area celebrating multiple knowledge forms from the humanities, mathematics, and science (as fields servicing

D&T and not vice versa). As has been witnessed through 15 years of the South Australian curriculum, a three-dimensioned Habermasian critical technological literacy articulated through critiquing, designing, and making has eschewed orthodox content- and product-led models of curriculum in favor of design-rich learning using critical pedagogies that center the student, rather than the system, as the focus of learning. Here, content is determined according to varying design needs; critiquing and designing enable forms of learning that enhance critical abilities, identity, and fulfillment; and teachers develop a rich repertoire of pedagogies. This is not a curriculum of "right or wrong" answers but one of negotiation, understanding, and personal and collective meaning making. Such a curriculum is not inward looking but is alive to what is happening in the world at large and what *could be* in the world at large.

Design and Technology arguably has the potential to redesign itself to move to the center, rather than being at the periphery, of a much-needed global education, but this cannot happen while it remains servant to the epistemological and political interests of a few. In fact, precisely because D&T has some duty to address both the human-technology phenomenon *and* the polypotency and multistability of technologies, it can do so as a field grounded in advancing the common good – ethically, sustainably, and democratically. In such ways, aims-talk becomes a prerequisite to a flourishing, if complicated, curriculum conversation for Design and Technology education.

References

Adams, T. (2016). It will come gradually and seamlessly without us really addressing it. Interview with Nick Bostrom in the new review. *The Observer*, 14–17. London. 12th June 2016.

Apple, M. W. (2001). *Educating the "right" way: Markets, standards, god and inequality.* New York: Routledge Falmer.

Boomer, G. (1991/1999). Changing curriculum. In B. Green (Ed.), *Designs on learning: Essays on curriculum and teaching by Garth Boomer* (pp. 113–125). Canberra: Australian Curriculum Studies Association.

Bostrom, N. (2009). The future of humanity. In J. K. B. Olsen, E. Selinger, & S. Riis (Eds.), *New waves in philosophy of technology* (pp. 186–215). Basingstoke: Palgrave MacMillan.

Bowers, C. A. (2006/2009). The classroom practice of commons education. In D. J. Flinders & S. J. Thornton (Eds.), *The curriculum studies reader* (pp. 399–424). New York: Routledge.

Bruner, J. S. (1960). *The process of education*. Cambridge, MA: Harvard University Press.

Cole, P., & O'Riley, P. (2015). In(di)geneity in design and technology education: Animating an ecological cross-cultural conversation. In K. Stables & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 67–86). Rotterdam: Sense.

Dakers, J. R. (Ed.). (2006). *Defining technological literacy: Towards an epistemological framework*. Basingstoke: Palgrave MacMillan.

Darder, A., Baltodano, M. P. & Torres, R. D., (Eds.), (2009), The Critical Pedagogy Reader, (2nd Edn.), Routledge, London.

Department of Education, Training and Employment (DETE). (2001). *South Australian Curriculum Standards and Accountability Framework (SACSA)*. URL: http://www.sacsa.sa.edu.au

Ellul, J. (1964). *The technological society.* New York: Alfred Knopf.

Flinders, D. J., & Thornton, S. J. (Eds.). (2009). *The curriculum studies reader*. New York: Routledge.

Freire, P. (1972). *Pedagogy of the oppressed*. London: Penguin.

Galbraith, J. K. (2004/2005). *The economics of innocent fraud*. London: Penguin.

Gaotlhobogwe, M. (2015). A case study of education for sustainable development: The case of design and technology in Botswana. In K. Stables & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 207–218). Rotterdam: Sense.

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. London: Fontana.

Habermas, J. (1971). *Knowledge and human interests*. Boston: Beacon.

Ihde, D. (2002). *Bodies in technology*. Minneapolis: University of Minnesota Press.

Ingold, T. (1993/1994). Tool use, sociality and intelligence. In K. R. Gibson & T. Ingold (Eds.), *Tools, language, and cognition in human evolution* (pp. 429–445). Cambridge: Cambridge University Press.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston: ITEA.

Keirl, S. (2004). Critiquing and designing as keys of technological literacy: Matters arising from the meeting. In H. Middleton, M. Pavlova, & D. Roebuck (Eds.), *Learning for innovation in technology education: Proceedings of the 3rd biennial international conference on technology education research* (Vol. 2, pp. 91–98). Surfers Paradise. 9–11 Dec 2004.

Keirl, S. (2006). Ethical technological literacy as democratic curriculum keystone. In J. R. Dakers (Ed.), *Defining technological literacy: Towards an epistemological framework* (pp. 81–102). Basingstoke: Palgrave MacMillan.

Keirl, S. (2009). Seeing technology through five phases: A theoretical framing to articulate holism, ethics and critique in, and for, technological literacy. *Design and Technology Education: An International Journal, 14*(3), 37–46. URL: http://jil.lboro.ac.uk/ojs/index.php/DATE/article/view/1274/1239.

Keirl, S. (2012). Technology education as "controversy celebrated" in the cause of democratic education. In T. Ginner, J. Hallström, & M. Hulten (Eds.), *Technology education in the 21st century: Proceedings of the PATT 26 conference, Stockholm, Sweden, 26–30 June 2012* (pp. 239–246). Linköping electronic conference proceedings no 73. Linköping University, Sweden. URL: http://www.ep.liu.se/ecp/073/028/ecp12073028.pdf

Keirl, S. (2015a). Against neoliberalism; for sustainable-democratic curriculum; through design and technology education. In K. Stables & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 153–174). Rotterdam: Sense.

Keirl, S. (2015b). Global ethics, sustainability, and design and technology education. In K. Stables & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 33–52). Rotterdam: Sense.

Keirl, S. (2015c). 'Seeing' and 'interpreting' the human-technology phenomenon. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education* (pp. 13–34). Dordrecht: Springer.

Keirl, S. (2016a, Forthcoming). Critiquing as design and technology curriculum journey: History, theory, politics, and potential. In J. Williams & K. Stables (Eds.), *Critique in technology education*. Dordrecht: Springer.

Keirl, S. (2016b). Design and technology education as learning agency: And the fourfold of 'critiquing skills' In M. J. De Vries, A. Bekker-Holtland, & G. van Dijk (Eds.), *Proceedings of the PATT32 international technology education conference: Technology education for 21st century skills* (pp. 251–258). Utrecht. 23–26 Aug 2016. URL: https://www.iteea.org/File.aspx?id=39504&v=76e4030

Kincheloe, J. L. (2008/2010). *Knowledge and critical pedagogy: An introduction*. Dordrecht: Springer.

Kurzweil, R. (1999). *The age of spiritual machines: When computers exceed human intelligence*. St Leonards: Allen & Unwin.

Kurzweil, R. (2005). *The singularity is near: When humans transcend biology*. London: Penguin.

Layton, D. (Ed.). (1994). A school subject in the making? The search for fundamentals. In D. Layton (Ed.), *Innovations in science and technology education* (Vol. V., pp. 11–28). Paris: UNESCO.

Morris, V. C. (1966/1990). *Existentialism in education: What it means*. Prospect Heights: Waveland Press.

Noddings, N. (2003/2009). The aims of education. In D. J. Flinders & S. J. Thornton (Eds.), *The curriculum studies reader* (pp. 425–438). New York: Routledge.

Ong, A., & Collier, S. J. (Eds.). (2005). *Global assemblages: Technology, politics, and ethics as anthropological problems*. Oxford: Blackwell.

Petrina, S. (2000a). The political ecology of design and technology education: An inquiry into methods. *International Journal of Technology and Design Education, 10*, 207–237.

Petrina, S. (2000b). The politics of technological literacy. *International Journal of Technology and Design Education, 10*, 181–206.

Pinar, W. F. (2004). *What is curriculum theory?* New York: Routledge.

Polanyi, M. (1958/1974). *Personal knowledge: Towards a post-critical philosophy*. Chicago: University of Chicago Press.

Polanyi, M. (1966/2009). *The tacit dimension*. Chicago: University of Chicago Press.

Print, M. (1988/1993). *Curriculum development and design* (2nd ed.). St. Leonards: Allen & Unwin.

Reid, A. (2004/2005). Challenging the dominant grammars of an undemocratic curriculum. In C. Marsh (Ed.), *Curriculum controversies: Point and counterpoint 1980–2005* (pp. 97–105). Deakin West: Australian Curriculum Studies Association.

Reid, A., & Johnson, B. (1999). Contesting the curriculum. In B. Johnson & A. Reid (Eds.), *Contesting the curriculum* (pp. viii–xvii). Katoomba: Social Science Press.

Ryle, G. (1949/1973). *The concept of mind*. Harmondsworth: Penguin.

Schultz, T. (2015). Kartogrifa in-flux: A pedagogical tool to challenge eurocentrism in post-compulsory education for sustainable design. In K. Stables & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 193–206). Rotterdam: Sense.

Sclove, R. E. (1995). *Democracy and technology*. New York: The Guilford Press.

Seemann, K. (2003). Basic principles in holistic technology education. *Journal of Technology Education, 14*(2), 28. Spring.

Seemann, K. (2015). Design for cultural groups and humanization: Two ideas from design anthropology. In K. Stables & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 101–118). Rotterdam: Sense.

Smith, D. G. (2003). Curriculum and teaching face globalization. In W. F. Pinar (Ed.), *International handbook of curriculum research* (pp. 35–51). Mahwah: Lawrence Erlbaum Associates.

Smith, D. L., & Lovat, T. J. (2006). *Curriculum: Action on reflection* (4th ed.). South Melbourne: Thomson/Social Science Press.

Smyth, J. (2011). *Critical pedagogy for social justice*. New York: Continuum.

Stables, K., & Keirl, S. (Eds.). (2015). *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures*. Rotterdam: Sense.

Vinge, V. (1993). *What is the singularity?* URL: http://mindstalk.net/vinge/vinge-sing.html

Technology Education Standards in the United States: History and Rationale

19

Philip Anthony Reed

Abstract

In the international arena, the United States has a strong history of standards for the study of technology. Content, student assessment, professional development, and program standards have been developed for technology education and other disciplines such as mathematics, social studies, instructional technology, and science explicitly have technology standards within their respective sets of standards.

Keywords

Standards • Technological literacy • Content • Professional development • Student assessment • Program standards

Contents

Education reform over the past three decades in the United States is most notably attributed to recommendations made in the report *A Nation at Risk* (National Commission on Excellence in Education 1983). This report focused on the need to increase academic rigor within the United States in order for the workforce to remain competitive in the global economy. The result has been the creation of standards and assessments across disciplines to hold students, teachers, schools, and teacher education programs accountable in order to provide a strong workforce (Carnevale and Desrochers 2003).

P.A. Reed (✉)
STEM Education and Professional Studies, Old Dominion University, Norfolk, VA, USA
e-mail: preed@ou.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_9

Introduction

Technology education in the United States, like most disciplines, has a long history of standards but the initial impetus was driven by professional organizations within the field, not outside reports. As far back as 1927 the American Vocational Association (AVA) assembled a committee to identify what students should know and be able to do in junior high (AVA 1929). The bulletin from this committee's work was published from 1929 to1943 and resulted in the dissemination of over 27,000 copies. These standards were very prescriptive skill statements based on industrial practices of the time and have little relevance to contemporary technology education. One notable exception, however, is in the organization of the bulletin. Instructors were encouraged to stress the doing, knowing, and being with regard to the study of industrial arts. *Being* (worthy attitudes and habits) was used as the context to describe the objectives and how they were to be addressed by the instructor. *Doing* were unit lists of basic skills students should work on and *knowing* were unit lists of useful information students should obtain. This organization is strikingly similar to the National Academy of Engineering and National Research Council's three dimensions of technological literacy: knowledge, capabilities, and critical thinking and decision making (Pearson and Young 2002).

The International Technology Education Association (ITEA) led the effort in the 1980s to champion contemporary standards. The focus of these efforts shifted from industrial practice to the broader concept of technological literacy in what some perceive as bowing to business and industry for economic reasons (Petrina 2000). Early standards were developed by the profession (Dugger, Bame, Pinder, & Miller, 1981) but it was documents such as ITEA's *Technology: A National Imperative* (ITEA 1988) that refocused the profession toward a workforce agenda of technological literacy for all. In the 1990s a series of support documents and more contemporary standards were developed through the leadership of the International Technology Education Association (ITEA, now the International Technology and Engineering Educators Association, ITEEA) with funding from the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA). An increasing awareness that technology is an important area of study for all students has led many other professional organizations to add technology-specific standards to their frameworks. The contemporary content focus is on technological literacy delivered through standards across multiple disciplines but these current standards-based practices have evolved over three decades.

Standards for Industrial Arts Programs Project

The initial standards for contemporary technology education in the United States were program standards developed under the Standards for Industrial Arts Programs Project funded by the US Office of Education (USOE). The project spanned from 1978 to 1981 and was housed at Virginia Polytechnic Institute and State University under project director William E. Dugger and associate directors E. Allen Bame, Charles A. Pinder, and C. Daniel Miller. The project was funded in response to recommendations of the American Industrial Arts Association (AIAA; now ITEEA) and the Industrial Arts Division of the American Vocational Association (IAD/AVA; now the Engineering and Technology Education Division/Association for Career and Technical Education, ACTE).

Standards for Industrial Arts Programs (Dugger et al. 1981) was created through a project database from hundreds of surveys completed by teachers, administrators, consultants, and teacher educators between October 1978 and November 1979. National and local steering committees guided the project and ten regional workshops were conducted from February 1980 to May 1981 to validate the standards. The final document contained 235 program standards that were written primarily for secondary education although many standards could be applied to elementary and post-secondary programs. Table 1 lists the 10 standards topics and 33 sub-topics used to organize *Standards for Industrial Arts Programs* (Dugger et al. 1981). The program standards were published so each one could be marked "below standard" (∇), "meets standard" (o), or "exceeds standard" (Δ). A profile (percentage) for each of the ten standards topics was compiled by subtracting the standards marked "below standard" from those marked "meets standard" or "exceeds standard." The goal for each standard topic was 100% but program participation was voluntary.

Four documents in all were published within *Standards for Industrial Arts Programs* (Dugger et al. 1981): the standards, American Industrial Arts Student Association (AIASA; currently the Technology Student Association, TSA) Guide, Sex Equity Guide, and Special Needs Guide. The guides were to be used with the *Standards* to help programs address these three student populations recognized by the US Department of Education (formerly USOE).

The *Standards for Industrial Arts Programs* were recommended for all programs, not just those receiving federal funding. However, the federal backing, voluntary participation, as well as the breadth of the program standards were project limitations. Whereas the AVA standards (1929) were too prescriptive, the *Standards for Industrial Arts Programs* focused on broader aims and little on what students should know or be able to do. Additionally, the sheer number of standards left little room for state and local educational efforts.

The paradigm shift from industrial arts to technology education that occurred in the United States during the mid-1980s caused a revision to *Standards for Industrial Arts Programs*. The resulting *Standards for Technology Education Programs* (Dugger et al. 1985) were based on the initial research and the same standards topics and sub-topics found in Table 1. The most notable change was replacing *industrial arts* with *technology education* throughout the document but there were several other updates. Primarily, the number of standards increased from 235 to 241, and the standards were revised to better reflect the breadth of programs based on technological education, not industrial practices. For example, several standards focus on the social/cultural interactions of technology and society and others focus on broader program engagement (i.e., interacting with parents).

The introduction of *Standards for Technology Education Programs* was updated and several key terms were added including a definition for standards: "The word

Table 1 Standards topics for industrial arts (Dugger et al. 1981) and technology education (Dugger et al. 1985)

Standard topic 1: philosophy
1.1 Development
1.2 Utilization
1.3 Review and revise
Standard topic 2: instructional program
2.1 Goals
2.2 Objectives
2.3 Content
2.4 Scheduling
Standard topic 3: student populations served
3.1 Individual differences
3.2 Sex equity
Standard topic 4: instructional staff
4.1 Legal/regulatory qualifications
4.2 Professional responsibilities
4.3 Personal qualities
Standard topic 5: administration and supervision
5.1 Staffing
5.2 Planning and organizing
5.3 Budgeting
5.4 Directing and monitoring
5.5 Data collecting and reporting
5.6 Communicating
Standard topic 6: support systems
6.1 Human resources
6.2 Physical resources
6.3 Financial resources
Standard topic 7: instructional strategies
7.1 Planning
7.2 Implementing
7.3 Reviewing and revising
Standard topic 8: public relations
8.1 Target populations
8.2 Media
Standard topic 9: safety and health
9.1 Program
9.2 Physical environment
9.3 Records
Standard topic 10: evaluation process
10.1 Establishing a data collection and analysis system
10.2 Collecting and analyzing data
10.3 Reporting
10.4 Decision making

'standards' was defined as 'descriptive statements established by key professionals and used as a model to assess the degree to which a program meets qualitative and quantitative characteristics of excellence" (Dugger et al. 1985, p. 8). The program assessment method in *Standards for Technology Education Programs* was retained from *Standards for Industrial Arts Programs*, and the AIASA Guide, Sex Equity Guide, and Special Needs Guide were not revised or included. Additionally, the revised standards still focused on broader program aims and little on what students should know or be able to do.

Technology for All Americans Project

In the early 1990s when many other disciplines were developing content standards, technology education leaders realized they needed to inform educators and the general public as to "why" technology should be studied by all before actual technology content standards could be developed. In 1994, with funding from NSF and NASA, the Technology for All Americans (TfAAP) project assembled three groups to accomplish this task. The first group was the project staff headed by Project Director William E. Dugger. The second group, the National Commission for Technology Education, was comprised of experts from education, government, business, industry, and professional associations. The third group, the writing consultants, was a subgroup of the National Commission and compiled the TfAAP work into the project's initial publication, *Technology for All Americans: A Rationale and Structure for the Study of Technology* (ITEEA 1996). This document was important because it clearly outlined the need for the study of technology and highlighted that no other discipline was claiming the study of technology solely as its body of knowledge (Martin 2002).

The second phase of the TfAAP spanned 1994–2000 and created *Standards for Technological Literacy: Content for the Study of Technology* (STL; ITEA/ITEEA 2007). There were four groups assembled "during the development of STL- (1) the Advisory Group, (2) the Standards Team, (3) a committee of the National Research Council of the National Academy of Sciences, and (4) a focus group from the National Academy of Engineering." The advisory group consisted of members from the National Council of Teachers of Mathematics (NCTM), the National Science Teachers Association (NSTA), the American Association for the Advancement of Science (AAAS) Project 2061, the National Research Council (NRC), the National Academy of Engineering (NAE), ITEA, and the Foundation for Technology Education. The advisory group provided specific advice on the standards development process as well as integration with other disciplines. The standards team consisted of teachers, administrators, and teacher educators from technology education as well as other professionals from science, mathematics, and engineering. Finally, the last two groups from the NRC and NAE conducted a review of STL in 1999 and in 2000 released a statement endorsing STL (Dugger 2006).

Table 2 Organization of standards for technological literacy (ITEA/ITEEA 2007)

Chapter 1: preparing students for a technological world
Chapter 2: overview of standards for technological literacy
Chapter 3: the nature of technology
Standard 1. students will develop an understanding of the characteristics and scope of technology
Standard 2. students will develop an understanding of the core concepts of technology
Standard 3. students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study
Chapter 4: technology and society
Standard 4. students will develop an understanding of the cultural, social, economic, and political effects of technology
Standard 5. students will develop an understanding of the effects of technology on the environment
Standard 6. students will develop an understanding of the role of society in the development and use of technology
Standard 7. students will develop an understanding of the influence of technology on history
Chapter 5: design
Standard 8. students will develop an understanding of the attributes of design
Standard 9 students will develop an understanding of engineering design
Standard 10. students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving
Chapter 6: abilities for a technological world
Standard 11. students will develop the abilities to apply the design process
Standard 12. students will develop the abilities to use and maintain technological products and systems
Standard 13. students will develop the abilities to assess the impact of products and systems
Chapter 7: the designed world
Standard 14. students will develop an understanding of and be able to select and use medical technologies
Standard 15. students will develop an understanding of and be able to select and use agricultural and related biotechnologies
Standard 16. students will develop an understanding of and be able to select and use energy and power technologies
Standard 17. students will develop an understanding of and be able to select and use information and communication technologies
Standard 18. students will develop an understanding of and be able to select and use transportation technologies
Standard 19. students will develop an understanding of and be able to select and use manufacturing technologies
Standard 20. students will develop an understanding of and be able to select and use construction technologies
Chapter 8: call to action

Table 2 lists the chapters and content standards from STL (ITEA/ITEEA 2007). Chapter 1 explains why all students should study technology. This chapter establishes the importance of both knowing technological content and doing technology through engaging, design-based learning. Additionally, several key definitions are presented in chapter one. The distinction between technology education (a field of study) and instructional technology (using technology to enhance teaching and learning) is clarified. Technology is defined as "the modification of the natural environment in order to satisfy perceived human needs and wants" (ITEA/ITEEA 2007, p. 7) which helps clarify the field from other disciplines. Finally, technological literacy is defined as the "ability to use, manage, assess, and understand technology" (ITEA/ITEEA 2007, p. 7) and a technologically literate person increases these abilities in more sophisticated ways over time.

Chapter 2 (Table 1) describes the format of the 20 standards and their 286 enabling benchmarks. For each standard, it is written in sentence form and then has a narrative explanation. Benchmarks are listed by grade levels (K-2, 3-5, 6-8, 9-12), and a grade-level essay details the knowledge and abilities that students must attain to meet each standard. This structure mirrors other standards projects of the time but a unique feature to technology education was the introduction of the profession to standards and benchmarks at the primary and elementary levels.

The Nature of Technology, Chapter 3, is the first chapter that contains standards. This chapter mirrors *The Nature of Science* section outlined in the American Association for the Advancement of Science's (AAAS) publication *Science for All Americans* (AAAS 1989) in that it defines technology by explaining the core concepts and how they permeate technology. This chapter is important since it adds to earlier documents outlining the rationale for the study of technology as well as what makes it a unique subject. Additionally, this chapter explains the relationship among the study of technology and other fields.

Chapter 4 explains how technology affects and is affected by society. This chapter also focuses on environmental issues associated with technology and the role of technological development through a historical lens. The content of this chapter reflects the call by some to situate technology education within cultural studies but this may have been minimized in the United States due to the emphasis on the politics of technological literacy in the context of economics and employment (Petrina 2000).

Chapter 5 focuses on design with a particular focus on understanding the design processes, especially engineering design. Problem solving is discussed with an emphasis on troubleshooting, research and development, invention and innovation, and experimentation.

Chapter 6 also addresses design but differs from Chapter 5 because it focuses on design abilities. Standards 12 and 13 in this chapter focus on student abilities to use and maintain technological products and systems as well as assess the impacts of technological products and systems.

Chapter 7 contains the largest number of standards and includes standards in major organizational areas (Dugger 2002). This chapter clearly illustrates content connections to past content organizers of the field, most notably those in *Jackson's Mill Industrial Arts Curriculum Theory* (Snyder and Hales 1981) and *A Conceptual Framework for Technology Education* (Savage and Sterry 1990). Additional standards in this chapter round out the breadth of content covered in STL, especially topics such as agricultural, biological, and medical technologies. These are topics that traditionally have received little focus (Savage and Sterry 1990; Snyder and Hales 1981; Wells 1994).

Chapter 8 is the final chapter and calls for action among the following groups and organizations: curriculum development and revision; learning environments, instructional materials, textbooks, and other materials; technology education profession; students; overall educational community; parents and the community; engineering profession; other technology professionals; business and industry; researchers; and additional standards (ITEA/ITEEA 2007, p. 200). Many of these topics have been addressed since release and revision of STL and will be discussed further in the *Implications* section below.

The chapters in STL provide detailed explanations of standards and benchmarks that were validated over a long period by a wide range of experts. Subtle updates were provided in 2002 and 2007 but questions linger as to who provides ongoing validation. As Pearson (2004) points out, mathematics education validates itself through the work of mathematicians, and science education maintains legitimacy through the work of scientists. The multidisciplinary nature involved in the study of technology confounds the validation of content. Do we focus on the work of engineers, historians, philosophers, or anthropologists, among others? To a large degree, content validation post STL has been shaped by groups such as FIRST Robotics, the National Science Foundation, and The National Academies through their activities and publications (LaPorte 2002; Reed 2007).

The third phase of the TfAAP spanned from 2000 to 2006 and produced *Advancing Excellence in Technological Literacy: Student Assessment, Professional Development, and Program Standards* (*AETL*) (International Technology Education Association/International Technology and Engineering Educators Association 2003). This compendium of three sets of standards was developed by hundreds of professionals, compiled by the TfAAP Writing Team (27 people), and overseen by the TfAAP Advisory Group (11 people). These standards are designed to be used with STL and, like STL, are not curriculum. All four sets of standards are designed to be used by educators to design curriculum, student assessments, professional development, and programs (for teachers and administrators). Table 3 lists the standards in AETL.

Each standard in AETL contains a number of guidelines that must be addressed to enable the user to meet a given standard. It is not recommended that users eliminate any of the guidelines; however, guidelines may be added to meet state, provincial, or local requirements (Dugger 2005).

Additional documents and updates have been produced since the inception of many of the TfAAP publications. For example, STL itself was updated in 2002 and in 2007 to include, among other edits, a connection with the standards developed in AETL. The 1996 publication *Technology for All Americans* was also revised and underwent a name change to *Technological Literacy for All: A Rationale and Structure for the Study of Technology* (ITEEA 2006). This revised document provides an updated rationale why all students should study technology and a

Table 3 Student assessment (A), professional development (PD), and program (P) standards in AETL (International Technology Education Association/International Technology and Engineering Educators Association 2003).

A-1. assessment of student learning will be consistent with *Standards for Technological Literacy: Content for the Study of Technology* (*STL*)
A-2. assessment of student learning will be explicitly matched to the intended purpose
A-3. assessment of student learning will be systematic and derived from research-based assessment principles
A-4. assessment of student learning will reflect practical contexts consistent with the nature of technology
A-5. assessment of student learning will incorporate data collection for accountability, professional development, and program enhancement
PD-1. professional development will provide teachers with knowledge, abilities, and understanding consistent with *Standards for Technological Literacy: Content for the Study of Technology* (*STL*)
PD-2. professional development will provide teachers with educational perspectives on students as learners of technology
PD-3. professional development will prepare teachers to design and evaluate technology curricula and programs
PD-4. professional development will prepare teachers to use instructional strategies and enhance technology teaching, student learning, and student assessment
PD-5. professional development will prepare teachers to design and manage learning environments that promote technological literacy
PD-6. professional development will prepare teachers to be responsible for their own continued professional growth
PD-7. professional development providers will plan, implement, and evaluate the pre-service and in-service education of teachers
P-1. technology program development will be consistent with *Standards for Technological Literacy: Content for the Study of Technology* (*STL*)
P-2. technology program implementation will facilitate technological literacy for all students
P-3. technology program evaluation will ensure and facilitate technological literacy for all students
P-4. technology program learning environments will facilitate technological literacy for all students
P-5. technology program management will be provided by designated personnel at the school, school district, and state/provincial/regional levels

connection between the ten universals of technology (processes, knowledge, and contexts) and the 20 STL standards.

Four addenda to STL and AETL have been produced by ITEA's Center to Advance the Teaching of Technology and Science (CATTS; now ITEEA's STEM Center for Teaching and Learning). These addenda consist of *Measuring Progress: A Guide to Assessing Students for Technological Literacy* (ITEA/ITEEA 2004), *Realizing Excellence: Structuring Technology Programs* (ITEA/ITEEA 2005c), *Planning Learning: Developing Technology Curricula* (ITEA/ITEEA 2005b), and *Developing Professionals: Preparing Technology Teachers*

(ITEA/ITEEA 2005a). Each of these documents includes useful processes, examples, and worksheets to help implement *Standards for Technological Literacy*.

The breadth and depth of the TfAAP cannot be understated. Some of the more salient aspects recently reported by the project director include:

- Used in 41 US states.
- *STL* has been translated into Chinese, Japanese, Finnish, German, and Estonian. *AETL* has been translated into Japanese.
- National Assessment of Educational Progress (NAEP) created a Technology and Engineering Assessment (starting in 2014) using *STL* as its framework.
- In 2012, the State of Palestine adopted *STL* as the content organizer for its mandatory curriculum in Grades 5–10.
- *STL* cites “engineering” 150+ times, “science” 60+ times, and “mathematics” 50+ times (Dugger 2013, p. 5).

There are other measures that signify the widespread adoption of publications produced by the TfAAP. Key curriculum efforts such as Engineering is Elementary (EiE), Project Lead the Way (PLTW), and Engineering by Design (EbD) are all aligned to *Standards for Technological Literacy* (ITEA/ITEEA 2007). Additionally, ITEEA conference sessions in areas emphasized by TfAAP have received increasing focus. In particular, sessions focusing on technological literacy, engineering, and elementary education have drastically increased during the 1990s and 2000s (Reed and LaPorte 2015). These are three areas highlighted in the TfAAP that were not a part of earlier standards within technology education. Various TfAAP publications state that the path to technological literacy is multidisciplinary, and this has certainly proven to be the case within the STEM (science, technology, engineering, mathematics) disciplines. Many disciplines have demonstrated this symbiotic relationship through technology content within their standards.

Technology Standards from Other Disciplines

An important milestone in US educational reform after *A Nation at Risk* (National Commission on Excellence in Education 1983) came in 1989 when President George H.W. Bush met with state governors in the first National Education Summit to discuss educational goals. Discussion at the summit focused on national education standards (National Research Council 2002). Some disciplines such as technology, mathematics, and science had created or were in the process of creating standards and throughout the late 1980s and 1990s consensus grew with state and national policymakers that standards could help improve education.

The proliferation of standards within the US education system, however, produced varying reactions from several prominent groups. McREL International (Mid-continent Research for Education and Learning) identified five significant problems with the standards movement: (1) multiple documents, (2) varying definitions of standards, (3) differing types of content description, (4) differing grade ranges, and

(5) varying levels of generality (McREL 2014). McREL has analyzed standards documents from multiple disciplines and created compendium documents to help address some of these problems. They also provide materials, assessments, and training services to help state and local school systems with their educational efforts. A significant part of McREL's work is based on the understanding that knowledge can be procedural, declarative, or contextual (Anderson 1990) and that standards often focus on one type of knowledge. A second organization, The Center for Occupational Research and Development (CORD), focused their work on contextualizing core standards (i.e., mathematics and science) for application in the classroom. Both McREL and CORD highlight the narrow focus of most standards and the importance of not just knowing content but also engaging students through their capabilities and thought processes.

Many disciplines that created standards during the past three decades explicitly highlighted connections with technology. In 1989 the National Council of Teachers of Mathematics (NCTM) released *Curriculum and Evaluation Standards for School Mathematics* (NCTM 1989). These initial standards, along with three other documents, would help shape the types and format of standards in other disciplines: *Professional Standards for Teaching Mathematics* (NCTM 1991), *Assessment Standards for School Mathematics*, (NCTM 1995), and *Principles and Standards for School Mathematics* (NCTM 2000). Technology is listed as one of the major themes in *Principles and Standards for School Mathematics* "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (NCTM 2000, p. 11). While this is a limited view of instructional technology, other links have been made to technology in standards dealing with patterns, visualization, spatial reasoning, and systems (see Newberry and Hallenbeck 2002).

Science education has an equally long history of standards as mathematics education but it has a stronger connection to technological education. In 1989, through its Project 2061, the American Association for the Advancement of Science (AAAS) published *Science for All Americans*. The focus was on science literacy and the first three chapters (The Nature of Science, The Nature of Mathematics, and The Nature of Technology) clearly highlight the interdisciplinary approach outlined to reach that goal. The AAAS also published its *Report of the Project 2061 Phase I Technology Panel* in 1989 (Johnson 1989). This report opens by clarifying its charge and need for a better understanding of technology education:

> Although the primary charge to the Technology Panel was to consider content in future curricula, the panel concluded early in its deliberations that technology, unlike science and mathematics, currently has little or no place in elementary and secondary school programs. Thus, the panel believed it should start by suggesting how technology should be integrated into future elementary and secondary school programs. It does so, however, without making any pretense of expertise in curriculum design or theories of education. (Johnson 1989, p. 3)

This foundational document articulates the diverse history of technology education in US schools through manual training, industrial arts, vocational education, and "some" science courses (p.5). The widely held perception of technology as merely artifacts is addressed and the Panel addressed technological processes, the interactions of technology and society, and a section on "technologies" that mirrors many of the designed world standards in *Standards for Technological Literacy* (ITEA/ITEEA 2007).

Additional science education work emerged in 1993 with *Benchmarks for Science Literacy* (AAAS 1993). The benchmarks used cognitive development to establish core concepts by grade level. These were not introduced as standards and were meant to be used with the previous AAAS publications. Simultaneously, the National Science Teachers Association (NSTA) published its *Scope, Sequence, and Coordination of Secondary School Science* (1992). All of these documents set the basis for the National Research Council (NRC) project to develop the *National Science Education Standards* (NRC 1996). These standards contain very strong connections between science and technology, including design, evaluating technological designs or products, and communicating the technological design process of technological design (Foster 2005).

The most recent science education standards, the *Next Generation Science Standards* (NGSS 2013), contain very strong connections between science, technology, engineering, and mathematics. However, NGSS is clear that these disciplines are used throughout the standards to perpetuate the study of science, not be content unto themselves. A significant factor in NGSS is that the engineering design process is raised to the same level as scientific inquiry. This makes a strong statement on how all science educators should teach the multiple ways humans investigate phenomena, problem solve, and design solutions.

The National Council for the Social Studies (NCSS 1994) and Geography Education Standards Project (GESP 1994) have also developed standards that focus on the interactions of technology and society. These standards move beyond the science, technology, and society paradigm by engaging students in ways to utilize technology. For example, history classes have long discussed technological inventions and milestones but now students can use tools to gather, analyze, and report data in ways that broaden their interdisciplinary studies (Foster 2005).

Implications and the Future of Technology Education Standards

Clearly there has been a sustained effort to develop standards focused on technology within the United States. Aside from the projects and standards discussed above, many organizations have published well-articulated positions on the importance for the study of technology. Perhaps the most coherent is the National Academies' *Technically Speaking, Why All Americans Need to know more about Technology* (Pearson and Young 2002). In light of the educational reform movement, interest in this area has also shifted to the assessment of technological literacy. A large-scale review of assessments in *Tech tally: Approaches to assessing Technological Literacy* (Garmire and Pearson 2006), however, indicated that this is an underdeveloped area in education at all levels. But this too is evolving.

The National Assessment Governing Board (NAGB) has been working for several years to develop an assessment under the National Assessment of Educational Progress (NAEP; i.e., *The Nation's Report Card*). The NAEP Technology and Engineering Literacy Assessment (TEL) framework (WestEd 2012) was based heavily on *Standards for Technological Literacy* (ITEA/ITEEA 2007) and the educational technology standards produced by the International Society for Technology in Education (ISTE 2007). The NAEP TEL framework and subsequent assessment illustrate the previously explored notion that technology education and instructional technology are one in the same (Petrina 2003).

There are signs that the standards-based educational reform movement in the United States is slowing. For example, the National Academy of Engineering and the National Research Council recently concluded several studies with mixed recommendations. In *Standards for K-12 engineering education* (National Academy of Engineering 2010), the primary recommendation was to not develop K-12 engineering standards for a variety of reasons, including the crowded curriculum in K-12 schools. A second report, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* stated the following: "The committee believes that the value of K-12 engineering curricula and of professional development for teachers of K-12 engineering would be increased by stronger connections to technological literacy, as described in such documents as the *Standards for Technological Literacy: Content for the Study of Technology*." (Katehi et al. 2009, pp. 158–159).

Disciplines are also realizing how many sets of standards are already developed and are creating tools to help teachers facilitate curriculum development. Most of the standards that have been developed are content standards and expressly claim they are not curriculum. The National Council of Teachers of Mathematics (NCTM) and the International and Technology and Engineering Educators Association (ITEEA) have each published *Focal Points* documents to help educators create curriculum from multiple, cross-walked standards and other guiding documents.

In summary, it is clear the industrial arts/technology education standards movement that started in the United States during the 1980s has had profound impacts on all areas of professional practice. The current climate, however, has technology and engineering standards incorporated into the standards of multiple disciplines. This interdisciplinary approach has long been a cornerstone of the standards movement (National Research Council 2002) but the profession is still wrestling with identity. Some believe the focus should be technological literacy (Loveland and Love 2016), while others claim the focus should be engineering (Strimel et al. 2016). Whatever direction the profession heads in the United States, the interdisciplinary focus surrounding technology education appears to be growing. The maker movement, Repair Cafes, competitive events, and overall STEM mania (Sanders 2009) persists. Development or even updating standards in such an environment would be a daunting endeavor. Care must be taken, however, that the unique identity of technology education is not lost within the other STEM disciplines (Jones et al. 2011). Likewise, as states organize programs and curriculum under the National Career Clusters Framework (Advance 2017), technology education should not be relegated to the STEM Cluster. A review of the 16 Career Clusters and their respective

79 Career Pathways reveals that technological literacy, as defined by the TfAAP, is a significant component of them all (Reed 2007). This duality of prevocational education as well as technological literacy for all is something the profession continues to grapple with and will continue to do so as future standards are developed.

References

Advance CTE. (2017). Career clusters. Retrieved 6 Jan 2017 from https://www.careertech.org/career-clusters.

American Association for the Advancement of Science. (1989). *Science for all Americans*. Washington, DC: Author.

American Association for the Advancement of Science. (1993). *Benchmarks for science for science literacy*. Washington, DC: Author.

American Vocational Association. (1929). *Improving instruction in industrial arts: Bulletin on standards of attainment in industrial arts teaching*. Washington, DC: Author.

Anderson, J. R. (1990). *Cognitive psychology and its implications*. New York: W. H. Freeman and Company.

Carnevale, A. P., & Desrochers, D. M. (2003). *Standards for what? The economic roots of K-16 reform*. Princeton: Educational Testing Service.

Dugger, W. E. (2002). Standards for technological literacy: Content for the study of technology. In J. M. Ritz, W. E. Dugger, & E. N. Israel (Eds.), *Standards for technological literacy, the role of teacher education* (pp. 59–78). Peoria: Glencoe McGraw-Hill.

Dugger, W. E. (2005). *Twenty years of educational standards for technology education in the United States. A paper for the PATT conference*. Reston: International Technology and Engineering Educators Association.

Dugger, W. E. (2013). *The progression of technology education in the United States*. Paper presented at the Pacific Rim Conference, Nanjing, China.

Dugger, W. E., Bame, A. E., Pinder, C. A., & Miller, D. C. (1981). *Standards for industrial arts programs*. Blacksburg: Industrial Arts Program, Virginia Tech.

Dugger, W. E., Bame, A. E., Pinder, C. A., & Miller, D. C. (1985). *Standards for technology education programs*. Reston: International Technology Education Association.

Foster, P. N. (2005). Technology in the standards of other school subjects. *The Technology Teacher, 65*(3), 17–21.

Garmire, E., & Pearson, G. (2006). *Tech tally: Approaches to assessing technological literacy*. Washington, DC: National Academy Press.

Geography Education Standards Project. (1994). *Geography for life: National geography standards 1994*. Washington, DC: National Geographic Research & Exploration.

International Society for Technology in Education. (2007). *National educational technology standards for students (NETS.S) and performance indicators for students*. Washington, DC: Author.

International Technology Education Association/International Technology and Engineering Educators Association. (1988). *Technology: A national imperative*. Reston: Author.

International Technology Education Association/International Technology and Engineering Educators Association. (1996). *Technological literacy for all: A rationale and structure for the study of technology* (1st ed.). Reston: Author.

International Technology Education Association/International Technology and Engineering Educators Association. (2003). *Advancing excellence in technological literacy: Student assessment, professional development, and program standards*. Reston: Author.

International Technology Education Association/International Technology and Engineering Educators Association. (2004). *Measuring progress: A guide to assessing students for technological literacy*. Reston: Author.

International Technology Education Association/International Technology and Engineering Educators Association. (2005a). *Developing professionals: Preparing technology teachers*. Reston: Author.

International Technology Education Association/International Technology and Engineering Educators Association. (2005b). *Planning learning: Developing technology curricula*. Reston: Author.

International Technology Education Association/International Technology and Engineering Educators Association. (2005c). *Realizing excellence: Structuring technology programs*. Reston: Author.

International Technology Education Association/International Technology and Engineering Educators Association. (2006). *Technological literacy for all: A rationale and structure for the study of technology* (2nd ed.). Reston: Author.

International Technology Education Association/International Technology and Engineering Educators Association. (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed.). Reston: Author.

Johnson, J. R. (Ed.). (1989). *Technology: Report of the Project 2061 phase 1 technology panel*. Washington, DC: American Association for the Advancement of Science.

Jones, A., Buntting, C., & de Vries, M. J. (2011). The developing field of technology education: A review to look forward. *International Journal of Technology and Design Education, 23*(2), 191–212.

Katehi, L., Pearson, G., & Feder, M. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press.

LaPorte, J. E. (2002). Are we there yet? *Journal of Technology Education, 13*(2), 2–4.

Loveland, T. R., & Love, T. S. (2016). Technological literacy: The proper focus to educate all students. *The Technology and Engineering Teacher, 76*(4), 13–17.

Martin, G. E. Rationale and structure for standards for technological literacy. In: Ritz, J. M., Dugger, W. E., & Israel, E. N. (Eds.). (2002). Standards for technological literacy, the role of teacher education. Peoria: Glencoe McGraw-Hill, 47-58.

Mid-continent Research for Education and Learning. (2014). *About the standards*. Retrieved 14 Jan 2017 from http://www2.mcrel.org/compendium/docs/history.asp.

National Academy of Engineering. (2010). *Standards for K-12 engineering education?* Washington, DC: National Academies Press.

National Commission on Excellence in Education. (1983). *A nation at risk: The imperative of educational reform*. Washington, DC: U.S. Government Printing Office.

National Council for the Social Studies. (1994). *Expectations of excellence: Curriculum standards for social studies*. Washington, DC: Author.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston: Author.

National Council of Teachers of Mathematics. (1991). *Professional standards for teaching mathematics*. Reston: Author.

National Council of Teachers of Mathematics. (1995). *Assessment standards for school mathematics*. Reston: Author.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston: Author.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.

National Research Council. (2002). *Investigating the influence of standards: A framework for research in mathematics, science, and technology education*. Washington, DC: National Academies Press.

National Science Teachers Association. (1992). *Scope, sequence, and coordination of secondary school science*. Washington, DC: Author.

Newberry, P., & Hallenbeck, L. S. (2002). Role of standards in different subject areas. In J. M. Ritz, W. E. Dugger, & E. N. Israel (Eds.), *Standards for technological literacy, the role of teacher education* (pp. 11–46). Glencoe McGraw-Hill: Peoria.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press. doi:10.17226/18290.

Pearson, G. (2004). Collaboration conundrum. *Journal of Technology Education, 15*(2), 66–76.

Pearson, G., & Young, A. T. (2002). *Technically speaking: Why all Americans need to know more about technology.* Washington, DC: National Academies Press.

Petrina, S. (2000). The politics of technological literacy. *International Journal of Technology and Design Education, 10*(2), 181–206.

Petrina, S. (2003). The educational technology is technology education manifesto. *Journal of Technology Education, 15*(1), 64–74.

Reed, P. A. (2007). The journey towards technological literacy for all in the United States – Are we there yet? *The Technology Teacher, 67*(3), 15–22.

Reed, P. A., & LaPorte, J. E. (2015). A content analysis of AIAA/ITEA/ITEEA conference special interest sessions: 1978-2014. *Journal of Technology Education, 26*(3), 38–72.

Sanders, M. E. (2009). STEM, STEM education, STEMmania. *The Technology and Engineering Teacher, 68*(4), 20–26.

Savage, E., & Sterry, L. (Eds.). (1990). *A conceptual framework for technology education*. Reston: International Technology Education Association/International Technology and Engineering Educators Association.

Snyder, J. F., & Hales, J. A. (Eds.). (1981). *Jackson's Mill industrial arts curriculum theory.* Reston: International Technology Education Association/International Technology and Engineering Educators Association.

Strimel, G. J., Grubbs, M. E., & Wells, J. G. (2016). Engineering education: A clear decision. *The Technology and Engineering Teacher, 76*(4), 18–24.

Wells, J. G. (1994). Establishing a taxonometric structure for the study of biotechnology. *Journal of Technology Education, 6*(1), 58–75.

WestEd. (2012). *Technology and engineering literacy assessment and item specifications for the 2014 national assessment of educational progress (Pre-Publication Edition)*. San Francisco: Author.

The Importance of the Conceptual in Progressing Technology Teaching and Learning

20

Cliff Harwood and Vicki J. Compton

Abstract

This chapter argues that technology education has a key role in enabling young people to actively participate in a world facing complex sociocultural and environmental challenges and an economy that is shifting from being knowledge driven to being innovation led. The aim of technology education internationally is to develop student technological literacy, and in New Zealand this literacy has been described as becoming increasingly "broad, deep, and critical" in nature as it progresses (Compton and France 2007; Compton and Harwood 2008). Further work in New Zealand to explore the transformatory nature of this literacy, as learning in technology progresses, resulted in three phases being identified as foundational, citizenship, and comprehensive technological literacy (Compton et al. 2011).

The chapter discusses what teachers need to know and do, to support student learning in technology and become more technologically literate, particularly related to foundational and citizenship technological literacy. It also discusses how the relationship between student decision-making and their undertaking of technological practice supports their progression toward a more comprehensive technological literacy. Findings from New Zealand classroom-based research are provided to support these discussions.

C. Harwood (✉)
Chanel College, Masterton, New Zealand
e-mail: c.d.harwood@mohsl.co.nz

V.J. Compton
Ministry for Primary Industries, Wellington, New Zealand
e-mail: vicki.compton@mpi.govt.nz

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_17

Keywords
Phases of technological literacy (foundational • citizenship • and comprehensive) • Learning environments • Strategic processing • Subject matter knowledge • Pedagogical content knowledge

Contents

Introduction

The Organization for Economic Cooperation and Development (OECD) in 2012 reported that "innovation" will play a central role in addressing the current disconnect between economic growth and people's well-being. To do this, communities need to move beyond having a simple focus on economic growth and place emphasis on improving the overall well-being of all groups in society (OECD 2015). Critical to addressing this disconnect is the capacity of people to develop innovative solutions to the "numerous, complex and urgent" social challenges communities face (OECD 2011, p. 7). These challenges include aging societies, climate change, energy efficiency, resource management and sustainability, and security. Formal education through schooling is identified as a key mechanism for developing people who can contribute to conversations about these social challenges and think through the "not yet thought and unthinkable" (Wheelahan 2010, p. 68) to imagine alternative future solutions. Technology education, which asks students to develop innovative solutions to problems embedded in real-life contexts, is ideally poised to prepare students to engage in conversations which enable innovative solutions to be created that address current and likely future sociocultural and environmental challenges.

As discussed elsewhere (Compton et al. 2011), general education internationally is now focused on the development of multiple literacies, one of which is technological. The development of multiple literacies has been argued as a means of supporting an overarching "literacy for citizenship" that prepares students for "self-expression, participatory action, and solidarity in a pluralistic society" (Elmose and Roth 2005, p. 21). Such a focus emphasizes a need for critical dialogue and decision-making as enablers for students to develop as "empowered citizens" (Skovmose 1998). According to Elmose and Roth, developing this criticality relies upon three forms of knowing – "knowing that, knowing how, and knowing why" (2005, p. 22).

The three strands that define the technology in the New Zealand Curriculum [NZC] (Ministry of Education 2007) are underpinned by these three forms of knowing and provide a framework to enable students to develop a technological literacy which is broad, deep, and critical in nature (Compton and France 2007). For this to be realized in classrooms, key conditions are needed that support student learning in technology and encourage the development of this technological literacy. The remainder of this chapter discusses these conditions, drawing from New Zealand and international literature and classroom-based research findings.

Technological Literacy: Phases of a Transformatory Journey

Considerable classroom-based research funded by the New Zealand Ministry of Education has been undertaken in New Zealand to determine the nature of progression that underpins learning related to the level 1–8 achievement objectives presented in the NZC (Ministry of Education 2007). The critical social science framework employed across this research allowed for the use of both constructivist and sociocultural learning theories (Greeno 1997; Packer and Goicoechea 2000; Compton and Harwood 2004; Compton et al. 2011). As described by Greeno (1997), bringing different perspectives together allows different aspects of learning and thinking to be in focus for different purposes. For example, "the cognitive perspective emphasizes conceptual understandings and strategies of problem solving and reasoning; and the situative perspective emphasizes participation in practices of inquiry and sense making of a community, and development of individual's identities as thinkers and learners" (1997, p. 87).

The research which focused on understanding how learning progressed within the curriculum strands of the technology (e.g., Technological Practice see Compton and Harwood 2005; Technological Knowledge see Compton and Compton 2013a; Nature of Technology see Compton and Compton 2013b) primarily employed constructivist perspectives. This was to emphasize the procedural and conceptual learning required for students to show achievement across the levels of each curriculum component. This research resulted in the development of Indicators of Progression (available at http://technology.tki.org.nz/Technology-in-the-NZC/Indicators-of-progression) and the Learning Progression Diagrams (available at http://technology.tki.org.nz/Technology-in-the-NZC/Indicators-of-progression/Learning-Progression-Diagrams).

The *Technological literacy: Implications for teaching and learning* (*TL: Imps*) (Compton et al. 2011; Compton 2013) also used constructivist perspectives when supporting teachers to implement the 2007 New Zealand technology curriculum components over a 2-year technology program and when analyzing data to develop understandings as to how the components best work together at each level. However, when exploring and documenting notions of technological literacy, a sociocultural perspective was emphasized to better capture the transformation of students as a result of engagement in their technology programs (Compton et al. 2011). While such transformations occur in a complex and spiraling manner for individual students, Alexander (2003) argues it is useful to identify phases of learning in any domain. This research therefore sought to identify phases to gauge how students progress their technological literacy and guide teachers to support future student learning in relation to the leveled curriculum achievement objectives. The resulting description of phases is presented below.

Foundational technological literacy reflects the transformation of students once they have achieved curriculum level 3 across all 8 technology achievement objectives (Ministry of Education 2007). Consistent implementation of technology programs based on technology in the NZC (Ministry of Education 2007) in the first 6 years of schooling would lead to the majority of students working at curriculum level 3 by age 10 (approximately). Students exhibiting a foundational technological literacy can be described as having an understanding of the key concepts and practices in technology as a discipline, can comprehend the implications of these across a broad range of contexts, and can apply this knowledge in reasonably straightforward ways to undertake their own technological practice. More specifically, they can typically:

- State the purpose of technology, describe what technological practice involves, and differentiate between technological and non-technological outcomes.
- Describe how and why particular technological outcomes have changed over time and provide examples of how technological practices and outcomes have impacted on the made, natural, and social world.
- Describe the relationship between the physical and functional nature of technological outcomes and how this can be used to judge the outcome as a "good" or "bad" design.
- Explain why different forms of functional modeling and prototyping are used in technology and explain benefits and limitations of models.
- Describe properties of common materials and the inputs, outputs, and transformations of simple systems and how materials and components enable technological products and systems to work.
- Generate design ideas for products and systems that meet given needs or opportunities, establish key attributes, and use these to evaluate and refine design ideas to develop conceptual designs.
- Identify key stages and timelines, select appropriate materials and components for use from resources provided, and explain progress made and next steps when making products and systems.
- Use a range of different materials and equipment with guidance to make a variety of different products and systems, evaluate final outcomes against key attributes, and explain how well they meet the need or opportunity.

Citizenship technological literacy reflects the transformation of students once they have achieved curriculum level 5 across all 8 technology achievement objectives (Ministry of Education 2007). Consistent implementation of technology programs based on technology in the NZC (Ministry of Education 2007) in the first

10 years of schooling would lead to the majority of students working at curriculum level 5 by age 14 (approximately). In New Zealand, technology is required to be offered to all students as a compulsory subject for 10 years. Students exhibiting a citizenship technological literacy show an increased depth of understanding related to the key concepts and practices in technology, can analyze developments in terms of technical feasibility and social acceptability, can explain diverse drivers and impacts, and can synthesize their own and other's knowledge and experience to undertake informed and creative technological practice. More specifically, they can typically:

- Explain how technology changes the capability of individuals and/or groups and how past experiences of technology influence perception and acceptance of technology.
- Explain how technological development relates to social acceptability and technical feasibility and how it often involves trade-offs that require functional and practical reasoning to support decision-making.
- Explain how and why technological knowledge becomes codified, and discuss examples of creative and critical thinking that has led to technological innovation.
- Analyze technological outcomes to determine design intent, function, user/s, and location in place and time, and explain why the judgment of technological outcomes as "fit for purpose" can change over time and across different contexts.
- Explain how technological outcomes are realized to meet technically feasible and socially acceptable specifications based on knowledge of material manipulation, transformation, and formulation.
- Identify needs and opportunities, and generate design ideas for creative solutions that reflect technical feasibility and social acceptability considerations.
- Undertake research and functional modeling to test design ideas and competently use a range of equipment and materials to produce and trial prototypes to evaluate "fitness for purpose."
- Analyze, select, and use planning tools to effectively record key stages, review points, and effectively manage time and other resources, to ensure completion of their outcome.

Comprehensive technological literacy is the transformation seen in people that have developed significant expertise within the discipline of technology. It is reasonable to think this may require years of experience to develop. Students after 10 years of engagement in compulsory technology programs, followed by a further 3 years of technology as a specialist subject in senior secondary schooling, can only be expected to exhibit movement toward a more comprehensive technological literacy. That is, they can exhibit more specialized knowledge related to concepts and practices in particular sectors of technology. They also show increased ability to critically analyze complex scenarios and developments and can explain the complexity of balancing technical feasibility and social acceptability of technological outcomes. They also show an increasing ability to undertake technological practice within authentic contexts and employ sophisticated, functional, and practical reasoning to support decision-making that allows them to develop innovative solutions that can be evaluated and justified as “fit for purpose in its broadest sense.” Fitness for purpose in its broadest sense extends the idea of fitness for purpose of an outcome to also include the fitness for purpose of the practices involved in the development of the outcome (Compton 2007; Compton and France 2007). More specifically, students demonstrating a comprehensive technological literacy may typically exhibit some of the following:

- Critically analyze and discuss the interactions between technological outcomes, people, and social and physical environments, and explain how technology impacts on and is influenced by complex sociocultural factors – including those related to global issues.
- Discuss technology as a site of human endeavor that is based on competing factors, contestations, interdisciplinary collaboration, functional and practical reasoning, and critical evaluation and informed creativity to determine priorities and support compromises required for innovative technological decision-making.
- Explain how and why technological developments may produce differing costs and benefits for different individuals, groups, and environments, and discuss the role of technological modeling in risk identification and mitigation and in justifying decisions to push boundaries based on “acceptable” risk.
- Critically analyze examples of past and contemporary technological developments to identify known and unknown, intended and unintended consequences and justify a position on whether technologists (as individuals or collectively) have social and/or environmental responsibilities above and beyond those of the general public.
- Critically analyze technological outcomes to determine their “fitness for purpose in its broadest sense” as based on the relationship between their physical and functional nature and the socio-technological environment in which they were positioned.
- Justify how and why innovative technological outcomes are realized based on specialist knowledge and practices within technology, shifts in other disciplines, and wider environmental and sociocultural contexts.
- Explore authentic contexts to establish issues and related needs or opportunities and justify potential outcomes taking account of wider contextual considerations.
- Develop design ideas informed by research and critical analysis of a range of relevant technological outcomes, knowledge of material and/or process innovation, and/or “solutions” found in the natural world.
- Critically analyze, select, and use functional modeling and evaluative practices to ensure decision-making is based on sophisticated functional and practical reasoning.
- Establish specifications that reflect social acceptability and technical feasibility, resources available, and the appropriate practices used to design, develop, maintain, and ultimately dispose of the outcome.
- Skillfully use equipment and materials to produce and trial quality prototypes to gain evidence to make a justifiable decision to refine, modify, or accept the prototype as “fit for purpose in its broadest sense.”

- Critically analyze project management techniques, and use this to inform management of the project through effective and efficient coordination, resource management, and informed and justified decision-making based on critical reviews of progress, to ensure a quality outcome is completed.

The Learning Environment: Teachers' Pedagogical Practices and Learning Contexts

Historically, teacher pedagogy in technology education has emphasized, through authoritative instruction and modeling, the development of student's declarative and procedural knowledge, with a focus on function through offering students a variety of teacher-led practical "doing" experiences (Parkinson and Hope 2009). As a result, students developed a technological literacy that emphasized the development of procedural knowledge, and declarative knowledge focused on knowing "that" as opposed to developing concepts of knowing "how" or "why." According to Keirl (2006), the learning environment in this instance is "transmissive," simply encouraging students to recall "factual knowledge" and replicate this within discussion and the technological outcomes they create. As a result, the technological literacy students developed from this pedagogical approach could be described as "functional" in nature (Compton and Harwood 2008).

According to Lave (1988) when teachers present learning environments that require authentic socio-technical problems to be resolved through "real" design activity, students are offered an opportunity to mediate theoretical (concept) knowledge "into practice," instead of it solely residing as an "in the head" experience. When these learning environments are also "transformative" (Mezirow 2000), students are encouraged and supported to be critically aware of their own and others' tacit understandings and expectations and how these influence decision-making. Key to such learning environments is the balance between teachers supporting student's understanding of appropriate declarative knowledge (knowing that) and providing them the opportunity to develop conceptual understandings (knowing how and why) (Harwood 2014). Thompson (1990) suggests that when teachers impose their own "pre-digested experience and expectations. . ." on students, this leads to them displaying ". . . a lack of creative and individual thought through the development of uniformity, dependence and acceptance" (p. 104). On the other hand, when students engage in technological practice without appropriate teacher intervention, this can result in "learner helplessness" and the constrained and restricted use of knowledge, skills, and practices (Compton and Harwood 2001). However, if teachers are discerning as to "whether, when, and how" to intervene in student technological learning, students have the opportunity to develop their intellectual skills (Johnson 1997; Harwood 2014) and begin to develop an understanding of the network of concepts that underpin technology education (de Vries 2013). The knowledge teachers bring to the learning environment therefore plays an important role in the nature of student learning in technology and the resulting technological outcomes they produce.

What Should Technology Teachers Know?

Rohaan (2009) reviewed the literature available in the area of technology education (focused mainly on primary education) and identified six technology-specific knowledge aspects, which she further organized into three categories that work together to support effective teaching in technology. These categories were:

- *Subject matter knowledge* (SMK): This includes technological concepts and the concept of technology as discipline.
- *Pedagogical content knowledge* (PCK): This includes knowledge of student interest, prior knowledge, and/or misconceptions related to technological concepts, knowledge of technology as a subject. It also includes knowledge of pedagogical approaches and teaching strategies suitable to address student needs.
- *Attitude:* This includes a teacher's attitude to and confidence in teaching technology. (summarized from Rohaan et al. 2010).

The *TL: Imps* research, discussed above, employed the *Model of Domain Learning* (MDL) (Alexander 2003), both to support teacher professional development and as a tool to analyze data (see Compton and Compton 2013a, b). The MDL recognizes three categories similar to those identified by Rohaan et al. (2010) for effective teaching in technology. These are *subject matter*, including both situated topic knowledge and generic domain knowledge; *strategic processing*, including surface level and deep processing strategies; and *motivational interest*, including individual (general/professional) and situational interests (Alexander 2003, p. 11). The use of the MDL enabled the *TL: Imps* research to explore Rohaan et al.'s (2010) aspects of SMK and PCK and identify how these interacted to support effective teaching and learning within and across the phases of technological literacy.

Strategic Processing

As explained by Alexander, "surface-level strategies allow learners to function when content is unfamiliar or task demands are novel or complex, whereas deep-processing strategies permit learners to query the message in a more critical, analytic manner" (2003, p. 11). Exploring the link between strategic processing and student knowledge was of particular interest in the *TL: Imps* research due to concerns about the "open" inquiry learning approach commonly employed in technology in New Zealand primary schools. Open or "true" inquiry encourages students to formulate their own research question(s), design and follow through with a developed procedure, and communicate their findings and results (Banchi and Bell 2008). Banchi and Bell continue to describe this approach as requiring domain-specific reasoning and placing a high cognitive demand on the student (Banchi and Bell 2008). Effective open inquiry learning relies on the student knowing about and employing deep-processing strategies, and this in turn relies on the student having sufficient domain knowledge (Alexander 2003). The research found that the use of this open inquiry learning with the majority of students was ineffective in supporting student learning. Given this research included a focus on the then five new components of the Technological Knowledge and Nature of Technology strands of technology in the NZC (Ministry of Education 2007), many of these students, even those in the higher-year groups, were unfamiliar with the concepts and were therefore working well below curriculum level 4. In addition, many held misconceptions that served as a barrier to their learning (for details please see Compton and Compton 2013a, b; Compton 2013). This would suggest employing open inquiry learning would only be effective when students were working at curriculum level 4 or above.

When age-appropriate surface level strategies were used to support these students in a more "guided inquiry" approach, they were able to engage in the learning activities, and many, particularly the older students, developed their domain knowledge up to and including level 3 across all 8 achievement objectives of technology in the NZC (Ministry of Education 2007). This in turn allowed them to exhibit characteristics of a foundational technological literacy.

The research also identified that when the SMK of teachers was not strong, they found it difficult to provide students with effective deep-processing strategies to progress student learning past curriculum level 4 and toward the citizenship phase of technological literacy. This was particularly apparent in the concepts related to the curriculum components of Characteristics of Technology and Technological Modeling (Ministry of Education 2007). To address this, the researchers introduced specific deep processing support tools. These tools proved to be effective in the development of both teacher and student conceptual understanding of these components. For example, to support deeper and more critical understandings related to Characteristics of Technology, the "model of techno-historical interplay" (Hallstrom and Gyberg 2009) was used to help identify, describe, and evaluate the drivers and impacts of developments in technology (for details please see Compton and Compton 2011a). Similarly, to support broader and more critical understandings related to Technological Modeling, the use of an ethical thinking tool (Biotechnology Learning Hub 2009) was used to focus on ways technological modeling is used to explore aspects of social acceptability alongside technical feasibility (for details please see Compton and Compton 2011b).

Motivational Interest

The research also explored student interest in technology, particularly in emerging and/or disruptive technologies. Many of the students showed a deep individual interest in such technologies, often displaying far more topic knowledge related to these technologies than their teachers did. This topic knowledge was a result of their exposure to everyday encounters with such technologies as toys, games, and increasingly "smart" information and communication technologies. The research identified that when these technologies were utilized effectively in learning activities, and students were encouraged to use them as a context for learning domain knowledge (key generic technology concepts and practices), they were highly motivated to learn. In the past teachers had resisted using such technologies as they felt their own experience with them was too limited. By drawing on the students' topic knowledge and making explicit links to the teacher's domain knowledge, this resistance reduced and the learning environment improved. As a result, teachers also developed a better understanding of new technologies, further strengthening their SMK.

Combining Rohaan et al.'s (2010) categories, the following points provide a summary of the key understandings teachers exhibited when they were effective in supporting student learning related to the leveled technology achievement objectives in the NZC (Ministry of Education 2007) and their developing technological literacy.

Understanding:

- The key concepts and practices underpinning the achievement objectives and how they progress from curriculum level 1–8 (SMK and PCK)
- How topic knowledge relates to domain knowledge and vice versa in selected learning contexts and the need to make these links explicit for students (SMK and PCK)
- How student's prior understanding is related to domain and topic knowledge – particularly knowledge of student misconceptions, partial understandings, and/or alternative conceptions related to each achievement objective (see Compton and Compton 2013a, b for discussion of these as related to Technological Knowledge and Nature of Technology) (PCK)
- The importance of situational interest for students working at lower curriculum levels and how to develop student individual interests to drive learning of domain knowledge (PCK)
- The importance of terminology and consistent use of this across a range of learning experiences (SMK and PCK)
- The need for students to be presented with multiple learning experiences over time to introduce, explore, and consolidate their learning (PCK)
- The need for teaching resources (including reference material, templates, examples, etc.) to support student strategic processing appropriately to ensure that learning opportunities are maximized (PCK)
- The importance of "real" examples rather than symbolic representations of these (i.e., when asking students to categorize objects, provide the object itself rather than pictures or text descriptions of the object, particularly for students whose understanding is at lower curriculum levels) (PCK).

The research also indicated that, as students began to progress from a foundational technological literacy toward citizenship and a more comprehensive technological literacy, teachers needed to focus more specifically on supporting student's deep strategic processing skills and provide them with increasingly "rich" learning environments that encourage and support them to take risks and become more critical. Such environments need to value innovation and creativity in order to support the development of curious minds that value new ways of thinking and doing and stimulate informed decision-making.

What Should Students Know to Enhance Decision-Making During Technological Practices?

Decision-making is often referred to as a mental process that deliberates on multiple options (or alternatives) to select one that best meets the goals of the decision maker (Hardy-Vallée 2007; Milkman et al. 2008). The outcome of decision-making manifests itself as a conscious action or "opinion of choice" (Bohanec 2009, p. 24) that may in turn lead to a change in a decision maker's disposition toward a certain topic (Ferrand 2007). While such deliberation on alternatives may be "explicit and complex or implicit and rapid, without consideration of alternatives no decision making can be said to have taken place" (Galotti 2002, p.2). Considering alternatives within an informed decision-making process is therefore important for determining which alternative or decision to follow. While decision-making is the process of determining what to do or selecting an alternative (Beyth-Marom et al. 1991), it is reasoning that enables assessment of the probable success of considered alternatives (Fischhoff et al. 1999). "Reasoning" is a process that allows humans to change (or not change) their views and conclude a proposition that is reflective of their present-day understandings (Harman 2009). As such, reasoning allows beliefs and desires to be integrated into intentions or actions (Carruthers 2003), supporting decisions to be made.

Functional and practical reasoning are identified as important forms of reasoning in the New Zealand technology curriculum statement (Ministry of Education 2007). These two forms of reasoning are considered to underpin and support student decision-making when undertaking technological practice and analyzing the practice and outcomes of others. The use of functional reasoning within technology enables the technical feasibility of design ideas and outcomes to be explored allowing an understanding of "how to make things happen" and an understanding of "how it is happening" to be developed (Compton and France 2007). Practical reasoning within technology supports social considerations such as moral, cultural, and ethical viewpoints surrounding a design idea and the testing of an outcome to be explored (Compton and Compton 2010; Compton and France 2007). This form of reasoning uses normative understandings to regulate action (Railton 1999). When students use normative practical reasoning in the act of developing outcomes that are "fit for purpose," it provides them with a framework from which to consider diverse opinions on knowledge types and views of the world and explore potential impacts on immediate and wider community stakeholders and environments.

The technological modeling achievement objectives in the NZC (Ministry of Education 2007) explicitly present the need for students to develop conceptual understandings about the importance of these two forms of reasoning (Compton and Compton 2010). However, it is the learning environment that teachers present to students and the pedagogies that they adopt that determine how well (if at all) these develop and are therefore available to take into practice (Harwood 2014).

A study conducted by Harwood (2014) demonstrated that when teachers focus their support on developing student conceptual understanding of practical and functional reasoning, the student's reasoning becomes more sophisticated. This however relies on a learning environment where explicit teaching and authentic contexts are used and students are encouraged to employ their understandings of practical and functional reasoning for their own decision-making, when developing technological outcomes. This study identified that students who possessed sophisticated reasoning could discuss conceptually how practical and functional reasoning worked together to determine risk and support informed and justifiable design decisions to be made. This led to the students being able to justify and defend the technological outcomes they developed as "fit for purpose in its broadest sense," or not. These findings support Breukelen et al. (2016) call for a greater learning focus on supporting students to develop understandings of the concepts underpinning technology, when developing technological outcomes.

The findings from this study also supported Rowell's (2004) contention that when teachers assist students to take their conceptual understandings into their technological practice, it equips them to be able to develop increased understandings of *knowledge in technological practice* (Rowell 2004). Rowell (2004) describes this as the knowledge that helps to define a problem and determine the physical and functional features required in a "fit for purpose" outcome and the actions and their sequence required when developing such an outcome. When such knowledge is combined with understandings about the nature of technology and technological developments, particularly that focused on ensuring that outcomes from technological practice are socially acceptable as well as technically feasible, then this knowledge is considered to be critical for students developing technological outcomes that address the complexities of authentic needs and opportunities (Compton and Harwood 2005). This emphasis on developing student conceptual understandings and supporting them to take these into their practice offers opportunity to develop in students the aptitude to contribute to conversations about, and create solutions to, the social challenges they will likely face in the future.

Conclusion

Learning in technology can cultivate minds that are curious, critical and creative in nature. It allows progression in technological literacy that enables people to do things differently, as they participate in society's current debates and make contribution to the future. Technology needs to be taught by teachers who possess an in-depth understanding of technology *subject matter knowledge* and *pedagogical content knowledge* and whose *attitude* inspires in students a sense of curiosity and willingness to accept challenge. Teachers need to know *whether*, *when,* and *how* to intervene in a student's technological learning, including decision-making that supports innovative problem solving. They will also need to increasingly engage students in authentic socio-technical problems to inspire them to be critically reflective and to effectively utilize conceptual and procedural knowledge in their undertaking of technological practice to address such problems.

Students in technology programs can then be supported to participate in a transformational journey, which allows them to first establish a *foundational* technological literacy and move beyond to become critical consumers and therefore possess a *citizenship* technological literacy. Some may continue their journey to a more *comprehensive* technological literacy enabling them to be socially and environmentally attuned developers of future innovative technologies, as well as critical consumers.

References

Alexander, P. A. (2003). The development of expertise: The journey from acclimation to proficiency. *Educational Researcher, 32*(8), 10–14.

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children, 46*(2), 26–29.

Beyth-Marom, R., Fischhoff, B., Jacobs-Quadrel, M., & Furby, L. (1991). Teaching decision making to adolescents: A critical review. In J. Baron & R. V. Brown (Eds.), *Teaching decision making to adolescents* (pp. 19–60). Hillsdale: Lawrence Erlbaum Associates.

Biotechnology Learning Hub. (2009). Ethical thinking tool. Retrieved 1 Mar 2011 from http://biotechlearn.org.nz/thinking_tools/ethics_thinking_tool/ethics_thinking_tool#/login

Bohanec, M. (2009). Decision making: A computer-science and information-technology viewpoint. *Interdisciplinary Description of Complex Systems, 7*(2), 22–37.

Breukelen, D. H. J., Vries, M. and Schure, F. A., (2016) Concept learning by direct current design challenges in secondary education.

Carruthers, P. (2003). The mind is a system of modules shaped by natural selection. In C. R. Hitchcock (Ed.), *Contemporary debates in philosophy of science*. New York: Blackwell.

Compton, V. J. (2007). *The role of technology education in supporting a democratic literacy*. Paper presented at *technology education New Zealand*, Biannual conference, Auckland 3–5 Oct 2007. Retrieved 25 June 2009, from: http://www.tenz.org.nz/2007/2007-conference-papers.htm

Compton, V. J. (2013). Technological literacy: Implications for teaching and learning – Final report to ministry of education.

Compton, V. J., & Compton, A. (2010). Technological knowledge and the nature of technology: Implications for teaching and learning – Summary of final report. Retrieved 13 May 2016 from: technology.tki.org.nz/index.php/content/. . ./TKNOT-Implications.docx

Compton, A., & Compton, V. J. (2011a). Strategies for progressing student understanding of the characteristics of technology. *Published in conference proceedings of technology education New Zealand, 8th biennial conference*. Dunedin. 26–28 July 2011.

Compton, V. J., & Compton, A. (2011b). Strategies for progressing student understanding of technological modelling. *Published in conference proceedings of technology education New Zealand, 8th biennial conference*. Dunedin. 26–28 July 2011.

Compton, V. J., & Compton, A. (2013a). Teaching technological knowledge: Determining and supporting student learning of the technological concepts. *International Journal of Design and Technology Education, 23*(3), 637–674.

Compton, V. J., & Compton, A. (2013b). Teaching the nature of technology: Determining and supporting student learning of the philosophy of technology. *International Journal of Design and Technology Education., 23*(2), 229–256.

Compton, V. J., & France, B. (2007). Redefining technological literacy in New Zealand: From concepts to curriculum constructs. *Proceedings of the Pupils' Attitudes Towards Technology*

(PATT 18). International design and technology education conference: Teaching and learning technological literacy in the classroom (pp. 260–272). Glasgow.

Compton, V. J., & Harwood, C. D. (2001). Developing technological literacy: A framework for technology education in New Zealand. *Published in conference proceedings of Technology Education New Zealand, Biannual conference* (pp. 39–54). Wellington. 1–3 Oct 2001.

Compton, V. J., & Harwood, C. D. (2004). Technology education achievement standards: Are they fit for the purpose? *Published in peer reviewed conference proceedings from the 3rd biennial international conference on technology education research. Learning for Innovation in Technology Education* (Vol. 1, pp. 140–149). Gold Coast: Crowne Plaza Hotel Surfers Paradise. 9–11 Dec 2004.

Compton, V. J., & Harwood, C. D. (2005). Progression in technology education in New Zealand: Components of practice as a way forward. *International Journal of Design and Technology Education., 15*(3), 253–287.

Compton, V. J., & Harwood, C. D. (2008). Discussion document: Design ideas for future technology programmes. Retrieved 10 Jan 2009 from: http://nzcurriculum.tki.org.nz/content/download/482/3705/file/technology-design-ideas.doc

Compton, V. J., Compton, A., & Patterson, M. (2011). Exploring the transformatory potential of technological literacy. *Proceedings of the joint Pupils' Attitudes Towards Technology international design and technology education conference and Creativity in Primary Technology conference (PATT 25/CRIPT 8)*. London. 1–5 July 2011.

Elmose, S., & Roth, W.-M. (2005). Allgemeinbildung: Readiness for living in a risk society. *Journal of Curriculum Studies, 37*, 11–34.

Ferrand, F. (2007). Natural decision. In B. Hardy-Vallée (Ed.), *Cognitive decision making: Empirical and foundational issues* (pp. 1–14). Cambridge Scholars Publishing: Newcastle.

Fischhoff, B., Crowell, N. A., & Kipke, M. (1999). *Adolescent decision making: Implications for prevention programs. Summary of a workshop*. Washington, DC: National Academy Press. (ERIC Document Reproduction Service No. ED441185).

Galotti, K. M. (2002). *Teaching reasoning and decision-making in introductory cognitive science courses*. Retrieved 23 Apr 2011 from: http://www.linguistics.pomona.edu/Hewlettcognitivescience/essays/assets/GalottiReasoning.pdf

Greeno, J. (1997). Theories and practices of thinking and learning to think. *American Journal of Education, 106*(1), 85–126.

Hallstrom, J., & Gyberg, P. (2009). Technology in the rear-view mirror: How to better incorporate the history of technology into technology education. *International Journal of Technology and Design Education, 21*(1), 3–17.

Hardy-Vallée, B. (2007). *Cognitive decision-making: Empirical and foundational issues*. New Castle: Cambridge Scholars Publishing.

Harman, G. (2009). Practical aspects of theoretical reasoning. Retrieved 23 Dec 2009 from: http://docs.google.com/viewer?a=v&q=cache:w0VnxNSjylkJ:citeseerx.ist.psu.edu/viewdoc/download%3Fdoi%3D10.1.1.94.9271%26rep%3Drep1%26type%3Dpdf+practical+reasoning+pdf&hl=en&gl=nz&pid=bl&srcid=ADGEEShm1zepQF9w5fFwAnq8k1EwxWVuszsBsM3IdCn0JcGIpp2ATDMRimOggy52OB5VqzKOsTRlTF1q_-Rd6Zxiocoy8qsekB15i6xvURP4b60TwHrYOoRxZ5YoZ4DS7FAK38w0_s0&sig=AHIEtbQLrqDBm71DidM38me2tn92LOx-_w

Harwood, C. D. (2014). Enhancing student decision making in technological practice: A thesis submitted for the degree of PhD Education. Palmerston North: Massey University. Retrieved 13 May 2016 from: http://mro.massey.ac.nz/handle/10179/5494#sthash.jLEZcniI.dpuf

Johnson, S. D. (1997). Learning technological concepts and developing intellectual skills. *International Journal of Technology and Design Education, 7*(1–2), 161–180.

Keirl, S. (2006). Ethical technological literacy as democratic curriculum keystone. Chapter 6. In J. Dakers (Ed.), *Defining technological literacy: Towards an epistemological framework* (pp. 81–102). New York: Palgrave MacMillan.

Lave, J. (1988). *Cognition in practice. Mind, mathematics and culture in everyday life*. New York: Cambridge University Press.

Mezirow, J. (2000). *Learning as transformation: Critical perspectives on a theory in progress*. San Francisco: Jossey Bass.
Milkman, K. L., Chugh, D., & Bazerman, M. H. (2008). How can decision making be improved? Retrieved 2 Jan 2010, from: http://www.hbs.edu/research/pdf/08-102.pdf
Ministry of Education. (2007). *The New Zealand curriculum*. Wellington: Learning Media.
OECD. (2011). Fostering innovation to address social challenges. Retrieved 2 Jan 2016 from: https://www.oecd.org/sti/inno/47861327.pdf
OECD. (2012). Innovation for development a discussion of the issues and an overview of work of the OECD directorate for science, technology and industry. Retrieved 2 Jan 2016 from: http://www.oecd.org/innovation/inno/50586251.pdf
OECD. (2015). OECD innovation strategy 2015 an agenda for policy action. Retrieved 2 Jan 2016 from: https://www.oecd.org/sti/OECD-Innovation-Strategy-2015-CMIN2015-7.pdf
Packer, M. J., & Goicoechea, J. (2000). Sociocultural and constructivist theories of learning: Ontology, not just epistemology. *Educational Psychology, 35*(4), 227–241.
Parkinson, & Hope, G. (2009). Beyond knowing how to make it work: The conceptual foundations of designing. *Design and Technology Education: An International Journal, 14*(1), 49–55.
Railton, P. (1999). Moral explanation and moral objectivity. *Philosophy and Phenomenological Research, 58*(1), 175–182.
Rohaan, E. (2009). *Testing teacher knowledge for technology in primary schools*. Published doctoral thesis. Eindhoven University of Technology, The Netherlands.
Rohaan, E., Taconis, R., & Jochems, W. M. G. (2010). Reviewing the relations between teachers' knowledge and pupils' attitude in the field of primary technology education. *International Journal of Technology and Design Education, 20*, 15–26.
Rowell, P. (2004). Developing technological stance: Children's learning in technology education. *International Journal of Technology and Design Education, 14*, 45–59.
Skovmose, O. (1998). Linking mathematics education and democracy: Citizenship, mathematical archaelology, mathemacy and deliberative interaction. *International Reviews on Mathematical Education, 30*(6), 195–204.
Thompson, E. (1990). Promoting individuality and originality. In L. Tickle (Ed.), *Design and technology in primary classrooms*. London: Falmer Press.
de Vries, M. J. (2013). Understanding technology structure and function. In J. Hallstrom & C. Klasander (Eds.), *The Ginner handbook of technology education. Some theses about technology, school and society* (pp. 156–166). Sweden: Elanders.
Wheelahan, L. (2010). Why knowledge matters in curriculum: A social realist argument. In *New studies in critical realism and education*. Oxfordshire: Routledge.

Informal, Out-of-School Technology Education

21

Yvonne M. Spicer

Abstract

This chapter will provide a perspective on the impact of technology education in informal, out-of-schooltime (OST) settings. The framework will explore: (1) the meaning of informal and technology education; (2) a variety of informal, out-of-schooltime settings; (3) building a global perspective; (4) the resources that are available; and (5) the outcomes and implications. The research on the pivotal role informal institutions such as community organizations, clubs, camps, science centers, and zoos have played in enhancing technology education is growing. In the United States, it is estimated that nearly seven million youths are involved in informal out-of-schooltime activities. The programs offered in these settings provide an opportunity for youth to build upon their own learning and expand their ideas that reinforce technology education content. Informal institutions around the world have been working collaboratively to develop innovative programs and partnerships for children and youth engagement. Building the capacity to offer innovative programs and resources serves to highlight the importance of informal institutions as a community asset.

Keywords

Out of school time • Informal • Technology • Education • Youth engagement • Youth programs

Contents

Y.M. Spicer (✉)
National Center for Technological Literacy, Museum of Science, Boston, MA, USA
e-mail: yspicer@mos.org

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_19

Introduction

The growing demand for informal, out-of-schooltime (OST) programs for children and youth has created myriad of options over the past decade. According to the research, nearly seven million youth in the United States are involved in informal, out-of-school programs that serve a variety of needs. Harvard Family Research Project (Little et al. 2008) conducted a 10-year study of out-of-schooltime programs and concluded that afterschool programs improve academic performance and social and developmental outcomes, contribute to healthy lifestyle options, and prevent many risky behaviors. The key factors in supporting positive outcomes include access to and sustained participation in quality programming with strong partnerships with schools, families, and the community.

This chapter will explore: (1) the meaning of informal and technology education, (2) a variety of informal out-of-schooltime settings, (3) building a global perspective, (4) the resources that are available, and (5) the outcomes and implications. Informal education experiences occur outside of the classroom and often are deemed as activities for enjoyment or entertainment but not always viewed as educational. Researchers contend these experiences are indeed educational and support youth in constructing their own understanding of knowledge. According to D'Angelo et al. (2009), constructivism is a practice of helping learners construct their own understanding of knowledge. The theory has its historical roots in the work of Vygotsky, Dewey, and Piaget. Vygotsky contends there is a connection between individual, interpersonal, and cultural historical factors that affect learning, John Dewey asserts the importance of prior knowledge and interest in building new knowledge. While Piaget theorizes that we acquire new knowledge by accommodation and assimilation. In the OST setting, this creates an opportunity for young people to explore and construct new knowledge based on prior knowledge and understandings in a meaningful way. The informal environment fosters in the atmosphere of "discovery learning" which engages learners in problem-solving to make a discovery (Mayer 2004; Papert 1980). Discovery learning postulates that learners are more likely to retain knowledge if they discover it on their own.

The National Institute on Out-of-School Time (NIOST) is a 35-year-old organization designed to raise the bar for quality out-of-schooltime programming with a focus on research, standards, and professional development to provide high-quality programs for youth. The research literature about out-of-schooltime experiences for children highlights three overarching outcomes: (1) improved academic performance, (2) improved social and emotional behavior, and (3) healthier lifestyle. The crucial component of NIOST research is to validate access to quality programs, create strong partnerships, and support adequate funding.

Defining Informal, Technology Education

Informal, out-of-schooltime (OST) activities occur in many venues, and according to Jeffs and Smith (2005), informal education is defined as a "wise, respectful and spontaneous process of cultivating learning. It works through conversation, and exploration and enlargement of experience." There are many out-of-schooltime environments that embody the same beliefs about informal learning and creating experiences that cultivate relationships and build capacity for greater content knowledge acquisition. These venues also are great resources for building self-esteem and capacity in technology education which opens the door to career awareness for our youth. For example, community and civic organizations such as the 4-H clubs, Boys & Girls clubs, Boy & Girl Scouts, and YMCA and cultural institutions such as aquariums, museums, science centers, and zoos.

According to Ash and Klein (2000), learning is a social process driven by the learners' curiosity. Their groundbreaking work explored how qualities of informal learning – self-directed playfulness and cooperation – might be included more in the formal setting. Many of the aforementioned organizations have a proven track record of offering engaging activities, consistent programming, and strong partnerships. According to the Harvard Family Project (Little et al. 2008) study, critical factors to maintain success for out schooltime programs include: (1) access to and sustained participation, (2) quality programming, and (3) partnership with families, other organizations, and schools. The structure of most OST programs is designed to meet the needs of participants on a short-term or long-term basis and serves multiage groups in the following areas:

1. Before school and afterschool programs that serve youth from earlier elementary through high school
2. Camps that operate in the summer or during school breaks and vacations
3. Drop-in centers or small-scale programs/experiences that allow used to explore, tinker, design, and build project

Out-of-Schooltime Impact and Implications

Out-of-schooltime (OST) technology education is an interesting dynamic especially as it relates to the intersection of science centers and other informal environments. According to the Association of Science Technology Centers (ASTC) which represents approximately 383 science museums and science centers across the United

States, 56% of the science centers offer afterschool programs. The successful OST programs strive to enhance learning opportunities, focus on creating engaged youth, and develop the capacity and competencies needed to contribute to their community and the innovation economy. Experiences outside school can be equally as important as what happens in school in setting and influence a child's direction, activating their interest and developing their understanding of the role of technology education in shaping their world (Noam et al. 2014).

Afterschool programs have been shown to have positive educational effects, especially on "populations that are underrepresented in science, technology, engineering and mathematics (STEM) fields" as well as increase "parental awareness" and support (Afterschool Alliance 2011). According to the recently released report by Williams, McCullough, McMahon & Goodyear (2016) on engineering education in Massachusetts, the informal educational space (e.g., out-of-school, afterschool, and nonschool programs and opportunities) has also served as a conduit for engineering education activities. Afterschool programs, competitions, summer programs, and websites have played a role in facilitating how students engage in engineering-related activities. Given the nature of informal learning, there are opportunities to reach diverse audiences and demographics in ways that differ from traditional, formal learning. In this context, the learning experiences are not bound by frameworks, learning assessments, and other traditional forms of teaching and learning (p. 7).

Defining Technology Education

It is prudent to unpack what is meant by technology education and the role that it has played in the access and integration of science, technology, engineering, and mathematics (STEM). Technology is a term used frequently in reference to the use of computers or electronic devices (Sanders 2008). For the purpose of this chapter, the term "technology education" will be defined in a broader context, as a discipline that encompasses critical thinking and the application of knowledge and skills. Research has illustrated that knowledge is developed effectively through interdisciplinary real-world connections to content or practices (National Research Council 2012; Schwartz et al. 2009). Therefore technology education experience cannot occur without integrating other disciplines such as science, mathematics, and the arts and using prior knowledge and skills to solve problems. Exploring some of the unique ways informal environments reinforce, the interdependence of content and knowledge application is crucial to evaluate effective technology education experiences.

From a historical perspective, technology education is defined as a field the study in which students "learn about the processes and knowledge related to technology." As a field of study, it covers the human ability to shape and change the physical world to meet needs, by manipulating materials and tools with techniques (ITEA 2000). This is a broad definition of technology education; however the field has evolved over the past 100 years as societal needs, wants, and technologies have changed. In the early 1980s, the term technology education evolved from industrial arts and its predecessor's manual arts. The perception was that these titles did not fully encompass the field of study, which included creativity, design, and problem-solving. As a discipline, technology education is taught in many schools and in some cases is considered a core discipline in formal education curriculum. In some informal settings, the environment in which we use tools and materials to create a solution to a problem is sometimes referred to as *Maker Spaces*, *Tinkering* labs, and *Innovation or Invention Studios*. Regardless of the name we assign, the ultimate goal is for youth to be able to use content knowledge to solve challenges and create multiple solutions that have a positive impact on society. A critical need is an awareness and understanding of what is technology and engineering education and why is it important both in informal and formal settings.

Intersection of Science and Technology/Engineering Education

According to the Center for Advancement of Informal Science Education (CAISE), Informal Science Education (ISE) is lifelong learning in science, technology, engineering, and math (STEM) that takes place across a multitude of designed settings and experiences outside of the formal classroom (http://www.informalscience.org/). CAISE is a national science-funded resource center for the Advancing Informal STEM Learning (AISL) program. Falk and Dierking (2010) contend that the United States enjoys a vibrant, free-choice science learning landscape – filled with a vast array of digital resources, educational television and radio, science museums, zoos, aquariums, national parks, community activities such as 4-H and scouting, and many other scientifically enriching enterprises (p. 486). The variety of resources has the potential to engage audiences on many levels; however if we are not focused in our pursuit of experiences, it can be haphazard with little or no coherence.

In an effort to further illustrate and strengthen content knowledge, exploring the intersection of science, technology, and engineering is essential. The National Research Council released the *Framework for K–12 Science Education* (NRC 2012), a critical first step to the development of the *Next Generation Science Standards* (NGSS). The NRC *Framework* reflected the most current research on science and student learning of science, and it identified the science all K–12 students should know from the perspective of scientists and engineers and the educational research community. Chapter 3 of the framework identifies eight essential practices of science and engineering:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)

7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (NRC 2012, p. 42)

Using the National Research Council (2011) framework as a guide, 26 states participated in the development of the *Next Generation Science Standards* (NGSS) which were released in April 2013. The NGSS standards create the foundation for states to critically analyze the intersection of science and technology education as well create a road map to decide what it should look like PreK–12. The development of a comprehensive set standards that have national recognition is a huge milestone that will have a significant impact on informal and formal settings.

A Variety of Informal, Out-of-Schooltime Settings

Informal institutions are proving to be a powerful resource for extended learning and building technology education capacity. There are a plethora of programs that address a wide array of interests including the arts, languages, and sports. For the purpose of brevity in this chapter, I will focus on out-of-schooltime organizations that have a science, technology, engineering, or math (STEM) target that are community based or cultural institutions. The content for these out-of-school programs integrate real-world problems with defined activities and opportunities for youth to focus on design and innovation.

National 4-H Council

The 4-H club is a 100-year-old nonprofit institution that serves youth in rural, urban, and suburban communities around the world. The organization has its roots in agriculture but over the years has branched out to incorporate civics and technology such as rocketry, robotics, and computer science. The focus of the three program tracks is STEM and agricultural programs; youth can focus on three areas: environmental science and alternative energy, engineering and technology, and plant and animal science.

In a longitudinal study conducted by Tufts University, researchers Lerner and Lerner (2013) examined the impact of 4-H clubs participation on positive youth development. In the study they measured what they defined as the five C's: competence, confidence, connections, character, and caring. The researchers postulated that the five C's lead to a sixth C, contribution – contribution to self, to family community, and to institutions of civil society. The researchers concluded that 4-H youth is nearly twice as likely to participate in science, engineering, and computer technology programs during out of schooltimes (grades 10–12); 4-H girls are two times more likely (grade 10) and three times more likely (grade 12) to take part in science programs compare to other girls and other out-of-schooltime activities.

FIRST Robotics

For Inspiration and Recognition of Science and Technology (FIRST) is an international out-of-schooltime organization designed for ages 6–18 that operates age-appropriate robotics activities and competitions around the globe. Founded in 1989 by Dean Kamen and Woodie Flowers, the organization serves approximately 400,000 youth. A 3-year study conducted by the Center for Youth & Communities at Brandeis University (2016) contends, "FIRST continues to show significantly greater impacts on girls than their male counterparts on all of the STEM-related measures" (p. 5). The research concludes, "Students who persist in FIRST for more than one year showed significantly greater gains than those who left after a single year, though both groups show significant impacts relative to the comparison students" (p. 5). For youth that has access to the program, FIRST has had a significant impact on student interest and career choices of science and engineering. A challenge for the program is cost and the opportunity for access to programs for all students.

Boys & Girls Clubs of America

Boys & Girls Clubs annually serve nearly four million young people, through membership and community outreach, in over 4200 club facilities throughout the United States and BGCA-affiliated youth centers on US military installations worldwide. The clubs serve mostly youth ages 6–18 representing racially and culturally diverse backgrounds. The offerings align with participant interest, such as character/leadership, education/career, health/life skills, sports/fitness, and the arts.

Aligned with education/career is *DIY STEM* which is a hands-on, activity-based STEM curriculum which connects youth to science themes they encounter regularly. Special attention is paid to connections of theory and application and the common interactions members have with these scientific principles. *DIY STEM* includes five modules: Energy and Electricity, Engineering Design, Food Chemistry, Aeronautics, and the Science of Sports: Football.

Cultural Institutions

Cultural institutions such as aquariums, museums, science centers, and zoos have long served to engage youth in out of schooltime in the United States that have been working diligently to connect technology education in informal settings. As Chi et al. (2015) contend, based on the review of literature (Bevan et al. 2010; Sneider and Burke 2011), long-term impact of STEM learning programs managed in museum includes the following:

- Afterschool programs that occur during the week after school hours or on weekends that serve a consistent group of enrolled participants and have a particular focus or set of learning goals
- Camps that occur over summer and during school breaks that are focused on science, math, engineering, and/or technology activities and enroll youth for one week (or longer) in a sequence of activities
- Youth explainer or docent programs that provided intensive, multiyear engagement for youth in the life of the institution, including opportunities for STEM teaching, learning, and mentoring
- Research experiences in which youth assist with ongoing research or create their own investigations through longer-term opportunities over the course of a school year
- Making, tinkering, or innovating spaces offered through ongoing programs during afterschool hours or weekends to promote youth-driven making or tinkering experiences (p. 4)

A critical factor for informal cultural institutions is to effectively measure impact over time and through in-depth engagement and experiences. Many informal institutions have the capacity to be a hub for the community and to leverage resources for change in STEM education. In Coll et al. (2003) study of free choice learning in zoos, the researchers concluded that general visitors, school teachers, and school groups do not necessarily associate zoo visits with learning (p. 20). However, the researchers suggest that free choice learning occurs whether or not it is recognized as such by visitors. Cultural institutions must continue to engage in research that evaluates programs in technology education longitudinally, as there is a dearth of literature on the long-term impact of programs and the transference of skills and knowledge to formal education and career pathways. Perhaps there are strategies and opportunities to build capacity within formal education institutions which will support technology education as integral part of a well-rounded learning experiences globally.

Building a Global Perspective

At the 2014 Science Centre World Summit hosted in Mechelen, Belgium, the goal was to develop a global network of diverse organizations that could bring the message of science centers to society in a comprehensive manner. The summit included 443 participants from 58 countries to discuss and develop what is known as the Mechelen Declaration (http://www.scws2014.org/home/mechelen-declaration/), a set of seven (7) concrete actions for enhancing public engagement to impact a better world. The action step that is closely related to this body of work is #5, which states that “We will take the lead in developing the best methods for engaging learners and optimizing their education in both formal and informal settings using appropriate technologies in widely varying context.” There are over 3000 science centers worldwide that are building momentum to offer hands-on, inquiry-based programming for over 310 million visitors. The next summit is scheduled to be hosted by Tokyo in 2017; the focus of the summit will be to examine the progress of the action steps and build capacity.

In Falk et al.'s (2014) research of International Science Centre Impact Study (ISCIS), a study representing 17 science centers in 13 countries and five continents, using surveys, data was collected from youth (14–15-year-olds) and adults (18 years and older). The design of the study was to investigate understanding, interests, engagement, and confidence of youth and adults. The researchers were able to extrapolate correlations between youth and adults who visit science centers which are: (1) improved science and technology knowledge and understanding, (2) science and technology interest and curiosity, (3) engagement with out-of-school science technology-related activities, (4) engagement with and interest in science as a school subject (youth), (5) personal identity and confidence in science and technology, and (6) a positive, but less strong, correlated relationship between science center experiences and increased participation in science and technology-related vocations and avocations (p. 41). As the researchers suggest, the results of the study are correlational and not causal which means visits to science centers cannot attribute to these outcomes; however it does provide an opportunity to examine large international sample that reinforces the notion that having an active science center does create and/or maintain a scientifically and technologically literate, informed, engaged, and literate public. Moreover it allows us to explore resource tools that can strengthen connections.

The Resources Available

The resources that are available online, in-print, and developed by informal teacher educators and OST providers are invaluable. For example, to support out-of-schooltime engagement in technology and engineering education, the Museum of Science, Boston, has developed *Engineering Adventures* (http://eie.org/engineering-adventures) and *Engineering Everywhere* (http://eie.org/engineering-everywhere). These are innovative (OST) activity units designed to engage children in real-world engineering experiences. *Engineering Adventures* engages kids in the engineering design process through a multicultural and real-life context. The six to ten activities are written at a 3–5 grade level with flexible scheduling options. *Engineering Everywhere* is a bit more sophisticated and designed for grades 6–8 where youths are solving engineering problems relevant to today's world. The program aims to challenge youth to think critically and creatively. The program contains eight to ten activities, each about an hour long. The early results of *Engineering Adventures* and *Engineering Everywhere* have been promising, and we are still exploring ways to expand our reach and broaden our audience engagement. Having access to the resources and activities are important, but also it is important to have space to build and create.

The maker movement has exploded nationally and internationally as a means of creating spaces where innovative thinking can happen as well as design and creation. Science centers and other informal environments have seen this as a way to reinforce content and develop creativity and exploration. Maker Space is a global phenomenon that is impacting the research on visitor engagement in science centers, and influencing the development of programs for children and adults. According to Bevan, B., Gutwill, J.P., Petrich, M., & Wilkerson, K. (2014), tinkering and making a potentially powerful context for learning but all though they have deep roots in leading theories of pedagogy in the present era of educational accountability they challenge many stakeholder ideas of what learning looks like (p. 118). Bevan asserts, the informal science field has been challenged to articulate learning that is possible or that has been realized from tinkering programs (p. 100). Bevan et al. (2014) developed a list of learning dimensions that might prove to be useful in evaluating tinkering spaces. The list includes engagement, intentional, innovation, and solidarity (p. 102).

The Exploratorium in San Francisco, California, has created the Tinker Studio which is a *Maker Space* on their exhibit floor which engages visitors in innovative projects and provides the experience of designing, creating, and building. Arguably, this is one of the busiest spaces within the museum, and the momentum is catching on at other science centers and OST facilities (https://tinkering.exploratorium.edu/about).

The Science Museum of Minnesota (SMM) is offering Saturday hands on activities entitled, "*Play. Tinker. Make.*" An interactive experience for visitors to use an assortment of materials, tools, and technologies to explore and create. Design and play-based activities are experimental, fun, and intended to create opportunities for open-ended exploration. In addition, the SMM has a *Cardboard Gallery* that encourages audiences to build and create structures out of cardboard in their 3500 square foot space. The SMM has been a leader in innovative exhibits and embracing their role as a community resource and partner in technology education (https://www.smm.org/).

Questacon National Science and Technology Centre in Canberra, Australia, opened its new learning center on October 2015 with a focus on invention and innovation and strives to promote greater understanding and awareness of science and technology within the community with a commitment to making that experience fun, interactive, and relevant. The Ian Potter Foundation Technology Learning Centre (IPTLC) stimulates an interest and awareness of the way things are made, shows how components fit together, and demonstrates how innovation can solve everyday problems – from simple devices to higher end technology (https://www.questacon.edu.au/visiting/ian-potter). The facility serves as a hub of this initiative to build capacity particularly in disadvantage regions of Australia through a project called *Smart Skills*. A four-pronged approach to outreach that includes programs that are offered in metropolitan and regional communities through creative events and activities based on design and create workshops, national challenges, and teacher training. Videoconference and web technologies extend the IPTLC's activities to students and special interest groups across Australia.

The TELUS Spark museum in Alberta, Canada, offers numerous workshops for youth and adults that have K–12 technology education focus. The extensive resources are aligned with national content standards which are posted on their site. In addition, they offer professional development for educators to build their knowledge and integration of technology education in classrooms. *Shift Lab* is a 1-year immersive program that includes a 5-day workshop and ongoing support throughout a year to build capacity in human-centered design and content knowledge. Participants experience interdisciplinary hands on STEAM activities in a collaborative environment and opportunities to build their resources to bring back to the classroom.

Tinkering and making have carved out a significant place in OST activities in after school programs, science centers, museums, and other informal settings. As Bevan et al. (2014) concludes, more research is needed to further develop our understanding and expand our examples of learning through tinkering across a wide array of communities, participants, and organized settings (p. 118). Perhaps the art of tinkering can benefit problem-solving skills and resourcefulness but more importantly build lifelong learning.

Implication for the Future of Informal, Out-of-Schooltime Technology Education

From an educational perspective, there are many components necessary for effective technology education programs in out-of-schooltime setting. First and foremost is the importance of youth engagement; young people need the “wow” factor, the spark that grabs their attention and keeps the momentum going. This is the challenge, to build the relevance of technology and engineering in our youth everyday lives. To sustain these efforts in classrooms and schools, many informal institutions are offering professional development for educators and administrators to build confidence and content knowledge and align to standards. The goal is to create continuity, connection to content, and clear focus of twenty-first-century careers and skills (Cunningham, LaChapelle & Lindgren-Streicher, 2006).

The cornerstone of the NCTL is the *Gateway to Technology and Engineering Project* (https://www.mos.org/gateway-project), a professional development program which was created to support school districts to strategically plan and implement PreK–12 technology and engineering education. Since 2005, *Gateway* has reached over 100 school districts and 600 educators that are serving urban, suburban, and rural school districts. In 2012, *Gateway to Technology and Engineering* was recognized by the Massachusetts Governor’s STEM Council as a scalable promising practice in STEM education. This designation recognizes the long-term impact on school district and the potential to be replicated to create systemic and sustainable change district wide.

There is a well-established body of research on the impact of out-of-schooltime activities to foster student engagement. The research on informal technology education is a relatively new initiative. The resurgence of *Maker Spaces* and *Tinkering Studios* reinforces the value of technology education as a mechanism to support STEM content through the application of knowledge and skills of design, creativity, and innovative experiences in OST settings. As a former technology education teacher and administrator, currently working in a museum environment, I am inspired that there is a renewed energy and emphasis that we learn by doing. Informal, out-of-school organizations have a role to play in solving real-world problems and impacting student career interest, creativity, and engagement.

References

Alliance, A. (2011). *STEM learning in afterschool: An analysis of impact and outcomes*. Washington, DC: STEM and Afterschool.

Ash, D., & Klein, C. (2000). Inquiry in the informal learning environment. In J. Minstrell & E. H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science*. Washington, DC: American Association for the Advancement of Science, Association of Science Technology Centers (ASTC). www.astc.org

Bevan, B., Dillon, J., Hein, G. E., Macdonald, M., Michalchik, V., Miller, D., Root, D., Rudder, L., Xanthoudaki, M., & Yoon, S. (2010). *Making science matter: Collaborations between informal science education organizations and schools. A CAISE inquiry group report*. Washington, DC: Center for Advancement of Informal Science Education (CAISE).

Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2014). Learning through STEM-rich tinkering: Findings from a jointly negotiated research project taken up in practice. *Science Education, 99*, 98–120. 2015.

Center for Advancement of Informal Sciences. (2016, October) CAISE guide to resources for broadening participation in STEM. http://www.informalscience.org/caise-guide-resources-broadening-participation-stem. Retrieved 13 May 17

Center for Youth and Communities, Brandeis University. (2016, March). FIRST longitudinal study findings at follow-up/executive summary. Retrieved 2 Feb 2017, http://www.firstinspires.org/sites/default/files/uploads/resource_library/impact/first-longitudinal-study-summary-of-preliminary-findings-year-3.pdf

Chi, B., Dorph, R., & Reisman, L. (2015). *Evidence & impact: Museum managed STEM programs in out-of-school setting. Summary report*. Berkeley: Lawrence Hall of Science, University of California. Online at http://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_089887.pdf

Coll, R. K., Tofield, S., Vyle, B. & Bolstad, R. (2003). Zoos as a source of free choice learning. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Philadelphia, 23–26 March 2003.

Cunningham, C., Lachapelle, C., & Lindgren-Streicher, A. (2006). Elementary teachers' understandings of engineering and technology. Proceedings of the 2006 American Society for Engineering Education Annual Conference & Exposition. Chicago, Illinois. Retrieved from https://peer.asee.org/200.

D'Angelo, C., Touchman, S., & Clark, D. (2009). Constructvism.Education.com. Retrieved 28 Jan 2017, https://www.education.com/reference/article/constructivism/

Drew, D. E. (2011). *STEM the tide: Reforming science, technology, engineering, and math education in America*. Baltimore: The Johns Hopkins University Press.

Falk, J. H., & Dierking, L. D. (2010). The 95 percent solution: School is not where most Americans learn most of their science. *American Scientist, 98*, 486–493.

Falk, J. H., Needham, M. D., Dierking, L. D.,& Prendergast, L. (2014) International Science Centre Impact Study Final Report. http://visitors.org.uk/wp-content/uploads/2012/07/international-science-centre-impact-study-international-science-centre-impact-study-final-report.pdf. Accessed 19 Oct 2016.

ITEA. (2000). *Standards for technological literacy; content for the study of technology. Executive summary* (p. 242). Reston: ITEA.

Jeffs, T., & Smith, M. K. (1997, 2005, 2011). "What is informal education?". *The encyclopaedia of informal education*. http://infed.org/mobi/what-is-informal-education/. Retrieved 3 Feb 2017.

Lerner, R. M., & Lerner, J.V. (2013, December).The Positive Development of Youth: Comprehensive Findings from the 4-h Study of Positive Youth Development. Institute for Applied Research and Youth Development Tufts University. Retrieved on 15 May17. http://cdn.4-h.org/wp-content/uploads/2016/02/4-H-Study-of-Positive-Youth-Development-Full-Report.pdf?_ga=2.232337247.1385641948.1495716108-2011172795.1494963438

Little, P., Wimer, C., & Weiss, H.B. (2008). After school programs in the 21st Century: Their potential and what it takes to achieve it. Harvard Family Research Project. Number 10.

Mayer, R. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *American Psychologist, 59*(1), 14–19.

Mechelen Declaration. http://www.scws2014.org/home/mechelen-declaration/. Accessed: 24 May 17.

Museum of Science and Industry. www.msichicago.org. Accessed 8 Oct 2016.

Museum of Science. *Engineering is Elementary, Engineering Adventures. http://eie.org/engineering-adventures*. Accessed 21 Nov 2016.

Museum of Science. *Engineering is Elementary, Engineering Everywhere. http://eie.org/engineering-everywhere*. Accessed 21 Nov 2016.

Museum of Science. *Gateway to Technology and Engineering*. https://www.mos.org/gateway-project. Accessed 21 Nov 2016.

National Research Council. (2011). *Successful K-12 Stem education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: The National Academies Press.

National Research Council (NRC). (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

Noam, G. G., Krishnamurthi, A., & Ballard, M. (2014). *Examining the impact of afterschool STEM programs*. Washington, DC: Afterschool Alliance.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.

Questcon. https://www.questacon.edu.au/outreach/programmes/questacon-smart-skills-initiative#term1534. Accessed 22 Nov 2016.

Sanders, M. E. (2008). Integrative STEM education: Primer*. *The Technology Teacher, 68*(4), 20–26.

Schmidt, W. H., Cogan, L. S., & McKnight, C. C. (2010) Equality of educational opportunity: Myth or reality in U.S. schooling. *American Educator*. Winter 2010–2011, 12–19 Retrieved at: http://www.aft.org/sites/default/files/periodicals/Schmidt_1.pdf

Schwartz, M. S., Sadler, P. M., Sonnert, G., & Tai, R. H. (2009). Depth vs. breath: How content coverage in high school science courses relates to later success in college science coursework. *Science Education, 93*, 798–826.

Science Museum of Minnesota (SMM). https://www.smm.org. Accessed 18 Nov 2016.

Sneider, C. I., & Burke, M. (2011). *The legacy of YouthALIVE!* Center for the Advancement of Informal Science Education. http://caise.insci.org/uploads/docs/Sneider_%20Burke_LegacyofYouthALIVE.pdf

The Tinkering Studio. (2016). The Exploratorium, San Francisco. http://tinkering.exploratorium.edu/about. Accessed 28 June 2016.

Williams, D., McCulloch, C., McMahon, T, & Goodyear, L. *Engineering for every K–12 student: A landscape analysis of K–12 engineering education in the greater Boston region.* 2016. National Science Foundation report #DRL-1450532.

Williams, D.N., McCulloch, C. ,McMahon, T.and Goodyear, L. (2016). Engineering for Every K-12 Student: A Landscape Analysis of K-12 Engineering Education in the Greater Boston Region. MEIDC Report. Tufts University and Education Development http://ceeo.tufts.edu/documents/researchMEIDCreport.pdf. Accessed 13 May 2017

Part III

Domains in Technology Education

Teaching and Learning Technology in Different Domains: Tradition and Future Developments

22

Moshe Barak

Abstract

This chapter summarizes the eight chapters featured in part "Domains in Technology Education" in the *Handbook of Technology Education*.

Keywords

Domains of technology education • Instructional approach • Using information and computer technologies

Contents

Introduction

Section three of the *International Handbook* comprises eight chapters referring to teaching technology in several domains: textile, food, materials, robotics, electronics, sketching and drawing, digital technologies, and the maker movement. Examining teaching technology in these domains is central to the discussion on the objectives and methods of technology education, because teaching and learning, in general, and technology education, in particular, are always context-bound and cannot take place in a vacuum. The term "contextual learning," which is derived

M. Barak (✉)
Department of Science and Technology Education, Ben-Gurion University of the Negev, Beer Sheva, Israel
e-mail: mbarak@bgu.ac.il

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_69

from the constructivist learning theory, stresses the need to anchor teaching and learning in students' diverse life contexts.

An important angle for examining the chapters in the present section is the contribution of each domain to achieving the objectives of technology education, as often discussed in the literature (De Vries 2009; Mioduser 2009; Barak and Hacker 2011). For example, supplying all citizens with core knowledge and skills concerning technology and the artificial world; fostering higher-order capabilities such as problem solving, critical thinking, creative thinking, and system thinking; understanding the social–cultural dimensions of technological design and problem solving; or reinforcing the learning of other school subjects such as natural sciences, mathematics, or computer science.

A second aspect of examining the chapters in the present section is the instructional methodologies and the learning environment for technology education discussed in each domain. The educational literature of the past few decades has strongly emphasized the need to shift education from the traditional "instructivist" teaching method to student-centered "constructivist" instructional strategies such as project- or problem-based learning (PBL). However, one must take into account that the notion of minimal guidance during learning does not always work, and students must frequently reach some basic knowledge and skills in a certain subject before being engaged effectively in PBL in this area (Kirschner et al. 2006). Therefore, it is advisable to examine to what extent and how could educators implement constructivist instruction strategies in teaching each domain.

A third perspective to examine the chapters included in the current section of the *International Handbook* is the type and extent of using digital technologies or information and computer technologies (ICT) in teaching and learning technology. Today, it is difficult to think about teaching technology without using computer technologies or ICT, for example, drawing, designing, simulating, or controlling technological systems such as robots. Therefore, technology education is becoming increasingly one of the most obvious learning areas where new technologies enhance teaching and learning (De Vries 2009). This might increase the confusion between the terms "technology education" and "educational technology," in which educators often use technology as a black box, without trying to understand what is in the box, as expected in technology education.

Overview of the eight chapters

Now, let us briefly observe the content of the various chapters discussed in the present section, and examine to what extent and how each chapter addressed the points mentioned above or raised other interesting aspects of teaching and learning technology emerging from each domain discussed in this section.

Marion Rutland examines the history of the teaching of food in England and its current removal from technology education (D&T) for pupils aged 14–18 years. The concept of food technology is explored as an intellectually challenging subject based on an understanding of the properties of food in order to design and make food products, thus enabling pupils to develop basic practical cooking skills underpinned by a scientific, technological, and nutritional understanding of food. Marion Rutland shows that a rising concern regarding obesity in England has highlighted cooking as a “life skill,” resulting in the introduction by the government of a new examination for 16year olds outside D&T focused on learning cooking skills. The elimination of food from D&T for pupils aged 14 to 18 years is discussed. The author refers briefly to the situation in other countries and suggests that food teaching plays an important role in educating our children in the twenty-first century due to its complex nature and wide-ranging objectives. The chapter stresses the value of exploring internationally what children should know, understand, and learn about food and how this can be achieved successfully.

Belinda von Mengersen discusses the rapidly evolving and complex field of textiles, suggesting many opportunities for the evolution of textiles application in design and technology education. Opportunities discussed overview how the expanding field of textiles research can inform critique through engagement with sustainability and ethics and question the reduced “value” of textiles in contemporary society. The author also addresses aspects such as how STEM projects can be developed and integrated into interactive textile prototypes; how cultural textile research and narrative can enable students’ understanding of the complexity of textile design systems and the intriguing sociological role that textiles play in society; and finally, how textile concepts can be used to explore design futures and future thinking within design and technology.

Owain Pedgley and Bahar Sener take forward the central theme that materials are selected for use in projects on the basis of a combination of technical capabilities and experiential possibilities. They stress the need for materials within design and technology education to be built around “materials experience” as the first-hand generation of materials knowledge, values, and skills to resolve real-world design problems. At the heart of their work is a conviction that the “human” side of materials is an essential differentiator for studying materials within a design and technology context.

Electronics is undoubtedly one of the central ingredients of modern technology. Moshe Barak highlights a number of required reforms in teaching electronics in school to reflect the technological and pedagogical changes of the twenty-first century. One reform is, for example, the shift from teaching basic components such as the diode or transistor to teaching broad technological systems and concepts such as control, feedback, amplification, conversion, modulation, and filtering of electronic signals. A second reform is the shift to using microcontrollers and programmable devices, which replace traditional circuits and hardware. Another reform required in the electronics class today is engaging students in project-based learning (PBL) as a substitute for traditional teaching methods or doing predesigned lab experiments. In summary, this chapter shows that electronics offers a rich, flexible, and friendly learning environment for teaching technology and engineering in K-12 education and for fostering students’ broad competences such as design, problem solving, creative thinking, and teamwork.

Starting with a pedagogically extended view, Martin Fislake outlines the benefits and options of teaching robotics. He gives access into teaching processes and the contribution of robotics in education, differs between different understandings of robotics and robots, shows the spectrum of the current technology, and opens a connection to the history of robotics. The author discusses robotics as a tool and as a concept for (general) education while he explains how to teach coding and building mechanical/electronic artifacts using open materials or educational-driven robotics systems. Finally, he presents an excursion to competitions and contests for educational robotics before finishing with an outlined sketch of future technology aspects.

Diarmaid Lane addresses the important role of freehand sketching within design and technology education. Through an analysis of contemporary literature, she examines the nature of sketching through a visual cognition lens and skill-building intervention lens. The author explores the potential of sketching and drawing in the classroom by providing details of activities that promote the use of sketching as a problem-solving tool and conceptual design tool. Finally, Diarmaid explores the role of pencil-and-paper-based sketching and its compatibility with digital technologies in twenty-first century learning environments.

As digital technologies become more and more important in everyday life, Jacques Ginestie shows that their generalization and banalization also develop daily; they constitute the common environment of kids and impact school organizations. Design and technology education (DTE) has been dealing for many years with using computer technologies such as computer-aided-design (CAD) or digital control of technological systems. The author points out that the development of the possibilities of simulations and the ability to integrate more and more parameters are increasing the opportunity to extend problem-solving approaches and project-based methods. He discusses the impact of computer technologies on the teaching–learning process in DTE and the applications of digital technologies on the practice of DTE in general.

The maker movement in education, which has a history of 100 years, now enjoys wide acceptance in many countries worldwide. Paulo Blikstein identifies the conceptual and technological pillars – such as constructionism and low-cost technologies – that have enabled the maker movement and five societal trends that made it possible for the movement to achieve large dissemination in education, such as a greater acceptance of progressive education and changes in the global economy. Blikstein then discusses educationally sound design principles for makerspaces, as well as strategies for adoption in large educational systems, such as the inclusion in national standards and the local generation of maker curricula by schools.

Conclusions

The collection of chapters in the present section in the *International Handbook* examines in depth the expected changes in technology education in a number of domains in light of the pedagogical and technological changes taking place at the beginning of the twenty-first century. Hopefully, this analysis will contribute to empowering the role of technology education as part of general education in the long run.

References

Barak, M., & Hacker, M. (2011). *Fostering human development through engineering and technology education*. Rotterdam: Sense Publishers.

De Vries, M. (2009). The developing filed of technology education: An introduction. In A. T. Jones & M. J. de Vries (Eds.), *International handbook of research and development in technology education* (pp. 1–9). Rotterdam: Sense Publishers.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*, 75–86.

Mioduser, D. (2009). Learning technological problem solving – *A cognitive/epistemological perspective*. In A. T. Jones & M. J. de Vries (Eds.), *International handbook of research and development in technology education* (pp. 391–406). Rotterdam: Sense Publishers.

Food in the School Curriculum: A Discussion of Alternative Approaches 23

Marion Rutland

Abstract

This chapter examines the historical background to the teaching of food in England and the current situation with its removal from technology education (D&T) for pupils aged 14–18 years. Specific reference will be made to what children should know, understand, and learn about food and how, and where, it could be taught in schools.

The concept of food technology within D&T is explored as an intellectually challenging subject based on an understanding of the properties of food in order to design and make food products. This approach ensures that pupils develop basic practical cooking skills underpinned by a scientific, technological, and nutritional understanding of food. Increasing concern regarding obesity in England has highlighted cooking as a necessary "life skill," resulting in the introduction by the government of a new examination for 16 year olds outside D&T focused on learning "cooking skills" and the elimination of food from D&T for pupils aged 14–18 years.

It is suggested that food teaching has an important role in the school curriculum and concludes that, due to its complex and broad nature and varying aims and objectives, a range of professional people and organizations should be involved in deciding how and where the various elements should be taught in schools and the world outside school. The chapter questions the approach of addressing all agendas for food in one curriculum area, if it is to achieve its full potential as a significant and major contributor to our children's preparation for their life in the twenty-first century. It advocates considering the relevance to the situation currently found in England and exploring an international perspective on food education in the school curriculum.

M. Rutland (✉)
Department of Education, University of Roehampton, London, UK
e-mail: m.rutland@roehampton.ac.uk

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_25

Keywords
Food • School curriculum • Food technology • Cooking • Life skills • Employment

Contents

The Introduction of Food Teaching in English Schools

There is a long history associated in the teaching of food. It was first introduced as cookery into the elementary school curriculum in England in the mid to late 1800s for philanthropic or utilitarian reasons. This coincided with a population move from a rural setting to urban industrial centers where family members were employed in factories. Cookery had a low status and aimed to teach the basic cooking skills to girls of the working classes to raise the standard of living of the poor to improve their health and prepare their girls for low-paid employment. It was not until the early twentieth century that it also appeared as domestic science in grammar schools for the more academically able girls focusing on nutrition, though essentially remaining a practical subject with little attempt to teach underlying scientific principles (Rutland 1997, 2006; Rutland and Owen-Jackson 2015a). Penfold (1988) pointed out that initial attempts to introduce manual instruction, later known as craft design technology (CDT), for boys into schools, was met with hostility, partly because of its association with the working class. Key issues that have influenced the early development of the teaching of food in schools were its association with girls and the less able and its status in the curriculum (Rutland 2006).

Both cookery and CDT focused on the mechanical drill of useful practical skills (Eggleston 1992) and included traditional teaching style directly related to the development of routine and mechanistic skills or "training." This was distinct from "education," which involved a body of knowledge and the development of concepts. It was not until the 1970s that it was recognized that, although manipulative dexterity and the ability to use tools safely and efficiently were important, other skills such as experimental work, organization and management skills, and ability to communicate should be included (DES 1978). England traditionally has two distinct education systems, independent or private schools for fee-paying pupils and a state system for the rest of the population. The aims of elementary state education were to provide a basic education. Practical subjects were not a high priority in the independent, private schools, and academically able girls missed needlework to study Latin, with lessons in hygiene for those not taught Latin. Secondary state schools, created following the Education Act of 1902, were based on the traditional academic curriculum taught in the private grammar and independent sector. Cooking or housecraft continued to be taught in secondary schools for the less able with domestic science for the more academically able up to the early 1970s.

Developments from 1970 to 1990

The Sex Discrimination Act (1975) was a landmark making sexual discrimination unlawful in schools and required curriculum equality access for boys and girls. This was specifically relevant for food teaching and CDT for all pupils up to 14 years, though there was no additional teaching time allocated on the timetable. Cookery became known as home economics, focusing on the study of food for family consumption. The Nuffield Home Economics project (1982) of the early 1980s introduced a more scientific, investigative approach to practical food activities, aiming to provide pupils with a sound knowledge of the major concepts and underlying scientific knowledge and principles. These courses required teachers to have a basic knowledge and understanding of the underpinning scientific principles, yet many home economics teachers were least qualified and interested in these aspects of the subject (Davies 1981), thus resulting in little long-term change in classroom practice.

A document (DES 1978) written by the Her Majesty's Inspectors (of Schools) (HMI) defined the subject area as "studies of the needs of the individual in the community and the best uses of human and physical resources in the context of home and family life." HMI explored the aims of home economics and saw its primary aim as helping prepare "boys and girls for some aspects of everyday living and the adults' responsibilities of family life" (DES 1985: 1) and concerned with hygiene, safety, health, and diet. On the other hand, when 2 years later HMI published guidance for CDT (DES 1987), the emphasis was on designing practical solutions and creative problem-solving activities, a philosophy that was reflected in National Curriculum Technology. Indeed, Newton (1990) argued that CDT teachers were more able to relate to the central philosophy of the *design process* in the National Curriculum Technology document when it arrived (DES 1990), because their HMI paper was closer to its requirements.

The National Curriculum (1990)

The National Curriculum (NC), the first government-controlled curriculum in the UK, was compulsory for all pupils aged 5–16 years and created a new subject called Technology comprising of design and technology (D&T) and information technology. A D&T Working Group developed a curriculum where pupils designed and made useful objects or systems, thus developing their ability to solve practical problems (DES 1988). Within D&T, including home economics, pupils combined their designing and making skills with knowledge and understanding to design and make products (DfF 1995). Some home economics teachers, including the National Association of Teachers of Home Economics (NATHE), saw this alignment with D&T as securing a future for food in the school curriculum. Following long discussions and an initial vote to explore members' thinking, a final vote was taken for the amalgamation of NATHE with the Association for D&T. The overwhelming decision was to proceed and the amalgamation took place in 2000.

The Development of Food Technology

It was following the introduction of the NC and the inclusion of food within D&T that food technology as a concept was developed by the members of NATHE and the Association for D&T. The change of emphasis from food for the domestic arena to food product development was not easy for teachers. Many were confused and alienated by the terminology used in official documents (DES 1990); yet with a determined effort, the production of resources and the introduction of an external examination for pupils aged 16 years, called the General Certificate of Education (GCSE) Food Technology progress, was made. On the positive side, the status and associated gender issues did improve, and the subject was taught to the full ability and age range. The intended knowledge content was rigorous and required pupils to combine "thinking and doing" with an ability to make informed decisions in food product development with a learning style based on problem-solving rather than on rote learning (Rutland 2006). In 2003 the GCSE Food Technology examination entries were the second highest entry for D&T, with 25% of the total entry (DATA 2004).

HMI recommended that the nature of food technology should be clarified (Ofsted 2006) and that learning in food technology should be more intellectually challenging and include "designing, product development, empirical testing and applying maths and science" (Ofsted 2008: 35), with more in-depth nutritional knowledge and greater scientific understanding and technical rigor (Ofsted 2011). Unfortunately this clarification did not occur. There were other causes for concern including a shortage of well-qualified food technology teachers and some examination boards placing too high an emphasis on "industrial practices" and the use of larger-scale equipment to the detriment of knowledge, understanding, and basic skills needed in food product development (Rutland 2006). A further major concern was the interpretation of "designing" in food, misinterpreted as the requirement to "draw" when designing food products. There was a lack of understanding that designing with food is essentially a hands-on-activity where pupils foster and use their knowledge and understanding of the physical, chemical, and nutritional properties of foods by exploring and experimenting when developing their food products (Rutland and Owen-Jackson 2015b).

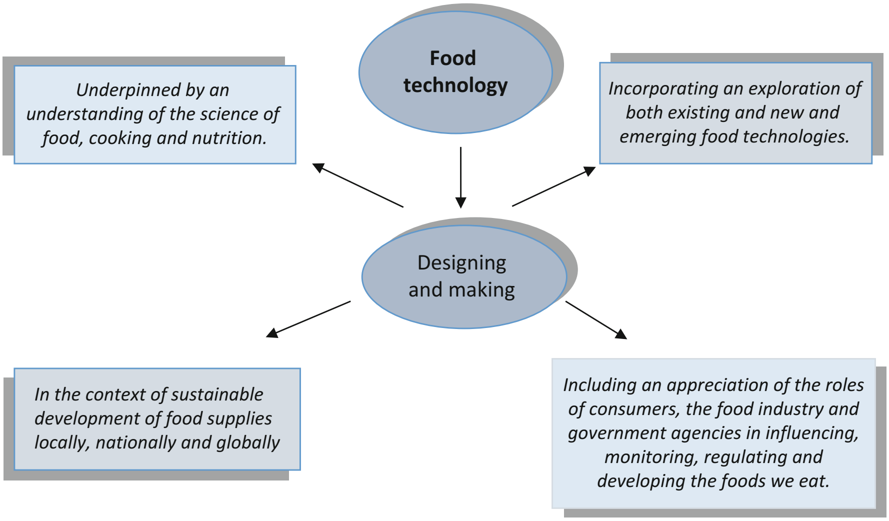


Fig. 1 A conceptual framework for a modern food technology curriculum (Rutland 2010)

In England, areas of D&T modernized to meet the needs of the twenty-first century through the STEM (science, (design and) technology, engineering, and mathematics) agenda and government funding for the "Digital Design and Technology" – Electronics in schools, CAD/CAM Initiative. There were attempts to modernize food teaching. A research project (Rutland 2009), supported by the Design and Technology Association, investigated what secondary school pupils in England should learn, understand, and be able to do in a modern food technology curriculum. The outcome was a conceptual framework (Fig. 1).

So What Is the Value of Food Technology?

Food technology develops an understanding of the properties of food materials and an ability to apply this to *developing food products*. Brian Arthur in his book *The Nature of Technology: what it is and how it evolved* (2009) defines technology as the exploitation of the phenomena revealed by science. If the activities and the learning that takes place in food technology are viewed in this light, then an understanding of some science should underpin learning. The useful starting points for devising learning that is true to Arthur's definition are examples of phenomena that are important for pupils to understand in food product development and food technology, for example, the gelatinization of starch and the production of a sol to thicken sauces; the coagulation of proteins in eggs as a thickening agent in mayonnaise or an egg custard; the formation of a solid foam in meringues, cakes, pastries, and bread; the dextrinization of starch in the crust of baked products or toast; and the caramelization of sugar when making toffee. Many other examples based on the knowledge and understandings of food science support the development of food products (Lean 2006). Knowledge of nutrition is also essential in product development for particular groups such as young children, athletes, vegetarians, pregnant women, diabetics, or families on a low income. These aspects of food technology sit alongside the practical cooking skills that are required in the making processes.

Research (Rutland and Owen-Jackson 2015a) indicates that pupils aged 11–14 years need a broader and more challenging food technology curriculum that prepares them for robust examination courses. These courses should include a wider range of appropriate designing strategies that can change the flavor, texture, nutritional qualities, shape and finish of foods together with the methods and processes that are used. There should be progression and continuity for children aged 5–11 years in the products they design and make and the scientific, nutritional, and technological knowledge and understanding that underpins their work. It is important, especially for pupils aged 11–16 years, that this learning is integrated into the teaching of basic recipes and practical cooking skills. This is a more complex, sophisticated, and effective educational approach rather than pupils just following a given recipe without any understanding. They will learn how to design, control, and change the ingredients and processes without compromising the effectiveness and quality of the final outcome.

Essentially, designing and making with food is a problem-solving activity. Pupils are set a brief example to develop products that are high in fiber to sell in the chilled cabinet of a supermarket, a main course for family with young children, for a vegetarian, a low-calorie product, for an athlete or a food bank. In the lower-age range, pupils may only have to deal with one or more criteria, for example, specific ingredients or limited cost. This will become more complex and could include ingredients, cost, nutrition, cooking methods, shelf-life, or packaging. Initially, their design may be an adaption of an existing recipe but they will learn how to successfully devise new combinations of ingredients, nutritional content, or flavors (Rutland and Owen-Jackson 2015b). For pupils aged 5–11 years, the learning environment is likely to be a traditional classroom that is adapted with suitable resources to be suitable for working safely and hygienically with food. For pupils aged 11–16, specialist food rooms are available, and there may be a separate area for experimental food work and the use of a wider range of specialist equipment and resources for older pupils; for pupils aged 16–18 years, access can be arranged to a science laboratory for some lessons.

The model for design decisions for food (Fig. 2) illustrates that pupils will learn to think in a systematic manner about their design decisions to modify or change the products that they designed and made. It can be used by the teacher as a planning tool to ensure that the pupils make technical, aesthetic, constructional, and marketing design decisions and show progress across a sequence of design tasks. Pupils can use the model to reflect on the design decisions they make when developing their product. Decisions may be made about just one or several different aspects in order to generate and develop a product to suit the set brief.

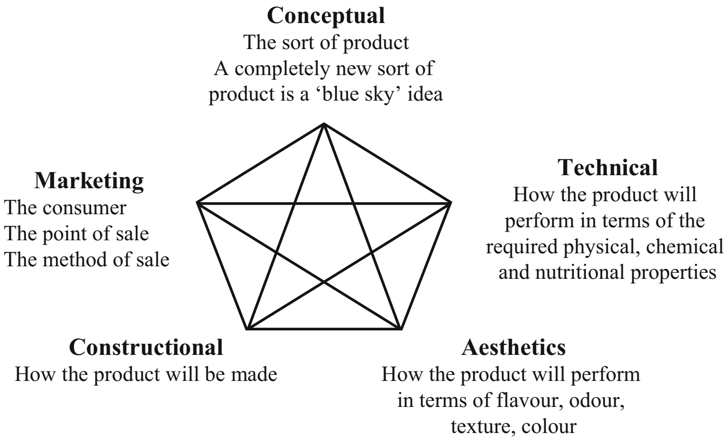


Fig. 2 Modified design decision model for food technology (Rutland et al. 2005)

Other Recent Factors Affecting the Teaching of Food in England

A key concern has been the conflict between the importance of pupils learning to cook as a life skill (Rutland 2008) and the study of food technology as an academic, rigorous study of worth. Learning to "cook" can contribute to a healthy lifestyle, while food technology involves studying food as an academic subject to motivate, challenge, and support the development of higher-order thinking skills and an understanding of scientific concepts. HMI have commented that "confusion about the basic aims of food technology underlies some of the weaknesses in the curriculum" (Ofsted 2006: 5) and "a tension exists between teaching about food to develop the skills for living and using food as a means to teach the objectives of D&T" (ibid: 6). The best food technology teaching sets relevant aspects of product development "into scientific context, for example in the chemistry of food materials, the changes to their functional and nutritional properties through aging and processing and the biological and chemical bases of human nutrition or the impact of food processing on nutrition." (ibid: 12).

A second strand of food teaching has recently been highlighted (Ofsted 2006: 9). The Government initially focused on a whole school approach of "personal development" based on the "Every Child Matters" (ECM) policy (DES 2003) for pupils aged 11–14 years to promote their well-being as healthy, enterprising, and responsible citizens in society. Schools were encouraged to develop a "healthy school" status through the Healthy Schools Program, funded jointly by the Department for Children, Schools and Families (DCSF) and the Department of Health (DH). There were a range of additional enhancement and enrichment activities to encourage children to eat healthy foods and become involved in cooking. The main aim was the development of whole school food policies (Rutland and Barlex 2009).

In England, a non-statutory entitlement to learn to cook for pupils aged 11–16 years was introduced through a government initiative called "License to Cook" (DES 2008). Schools were provided with appropriate facilities to provide "cooking lessons" to encourage healthy eating. For most schools, it was intended that the initiative would be integrated in the food technology curriculum, though it could be taught in lunch-time sessions or after-school clubs. There were concerns regarding the timetable allocation and resources to successfully support both the initiative and food technology (Rutland 2008). However, where the initiative was applied thoughtfully and supported by good preparation, it did have a positive effect on students' motivation, acquisition of food preparation skills, and awareness of healthy lifestyles. However, the teaching of practical nutrition, when learning how to make a dish, was missed in some lessons, though many students enjoyed the greater emphasis on practical learning (Ofsted 2011: 38).

Other initiatives included increasing the quota for trained food teachers, the revision of GCSE examination criteria, and planning to fund extra food technology accommodation (Ofsted 2008). Schools were expected to provide opportunities outside the D&T curriculum for pupils to learn and extend their practical "cooking" skills, for example, through vocational courses such as catering and enrichment activities such as cooking clubs. Foresight, a government department investigating the issue of obesity, was aimed to guide government thinking with the key message that a coordinated cross-government department approach was required. "An essential step in tackling the task is the education of students at school, not simply to develop the habits of healthy eating but to help them appreciate the complexity of the problem and its "whole society" nature" (Government Office for Science 2007: 4). The project promoted a cross-curricular approach to tackle the obesity issue through the Personal, Social and Health Education (PSHE) curriculum.

Current Situation in England 2013–2016

These dual, sometimes conflicting, strands for the teaching of food became a key issue in the 2013 review of the NC for D&T for pupils aged 5–14 years. Food was retained within D&T with the inclusion of term such as "ingredients" and "food"; however there was a separate "cooking and nutrition" section (DfE 2013).

This caused some confusion, while pupils are expected to design and make with food ingredients, working in home and wider industrial contexts; they are also required to "learn how to cook." This was described as a "crucial life skill" but the curriculum document did not make clear how this aligned with the nature of D&T as a whole, nor was it clear how learning to cook, without an understanding of ingredients, food science, and modern food technologies, prepares pupils for their future lives or employment in the twenty-first century.

Following the implementation of the new D&T curriculum for pupils aged 5–14 years, all GCSE and A Level subject content (DfEa 2014) were reformed. It was decided by the DfE that food would be taught through GCSE Cooking and Nutrition which built "upon the best of previous titles such as food technology, home economics and hospitality and catering." (ibid: 6). Advice from a range of D&T subject experts, though who they were is not clear, was that a food qualification at this level should focus on ensuring students acquire a good understanding of food and nutrition together with excellent cooking skills (ibid: 6–7). The draft GCSE Subject Content for D&T (DfEc 2014) did not include food as material in the context of designing and making.

The core knowledge in the new GCSE (DfEb 2014) "will enable students to choose ingredients to cook with, taking into account nutritional needs and through a detailed knowledge of cooking processes, prepare a wide range of recipes" (DfEa: 10). Discussions regarding the drafting of the new GCSE content were "highly confidential," and unlike other subjects (except religious education), they were taken away from the Awarding Organizations. The Lead Food Technology Consultant for the D&T Association acted as an "independent consultant drafter" for the DfE. No other members of the Design and Technology Association, food teachers, or educators were present at the DfE Stakeholders meetings. Subject experts cited as been consulted during this process included catering and hospitality professionals, representatives from nutrition and health organizations, and the government (DfEa: 16).

During the consultation process, a group consisting of ten experienced food teacher educators and teachers was drawn together to represent the Design and Technology Association's response. The group's view was that combining three existing subjects focusing on general, vocational, and the "life skills" was not desirable or effective; that the GCSE would have breadth but lack depth; and that it would attract pupils of lower academic ability and would not prepare pupils for work in the food industry, other than catering. There was too high emphasis on teaching "life skills," practical food skills, and "cooking" at the expense of pupils developing a scientific and technological understanding of food in the context of the twenty-first century, and there was a lack of progression for food technology below and above the GCSE. Following the consultation, the name was changed to GCSE Food Preparation and Nutrition, but the content remained the same except for the insignificant rewording and numbering of the last paragraph on page 7 (DfEa 2015).

The new GCSE focuses on teaching practical cooking skills, developing an understanding of nutrition, food provenance, and the working characteristics of food materials. Aspects of food science are required, but with the long list of other content, particularly the extensive list of skills to be learnt, it is difficult to see how food science can be taught in any depth. The assessment consists of a written examination (50%) on the theoretical knowledge of food preparation and nutrition; two non-examination food tasks (50%); a food investigation (15%) on the working characteristics and functional and chemical properties of ingredients; and a 3-h practical task (35%) where candidates prepare, cook, and serve a pre-planned menu of three dishes. Barlex (2014) says of the new examination "one of its main intentions is to equip pupils to choose and cook food that is healthy with regard to combating the obesity crisis," reflecting political concerns about levels of obesity in the UK.

The government considers that the primary purpose of A Level examinations (for pupils aged 18 years) is to prepare them for undergraduate study (DfEb 2015: 7).

However, food technology has been removed as an endorsed route with D&T and a separate food A level will not be developed as there are already a number of high-quality vocational qualifications available post-16. Confectionary/butchery was cited as examples of such courses. For students progressing to a degree in food nutrition or science, top universities are looking for science as entry qualification to degrees in these areas rather than food-related A levels (ibid: 17). So, pupils interested in engineering could follow a D&T course alongside their other science and mathematics courses and similarly psychology and sports science. However, there is currently no route through an A level examination for pupils wanting to study a food-related A level alongside their science and mathematical subjects. It can be argued that undergraduates who have studied a revised and rigorous A Level Food technology course and already have an in-depth understanding of food from their school-based courses would be good candidates for food-related undergraduate courses and more cognizant and informed as future employees of the food industry.

Discussion

As predicted by Mathiesion (1979), eating patterns and habits in society have changed radically, and there is a wide range and variety of foods and ready-cooked products available for individuals and families to buy. It is very doubtful that the clock can be reversed to where all the foods eaten are cooked at home. Food product development, as taught in food technology, can help pupils develop the ability to prepare foods from basic ingredients in the home. However, in addition, they will acquire a critical awareness of the potential benefits and implications to their health and well-being of eating the wide range of the many highly processed but tasty foods available in modern food outlets, shops, and supermarkets. This is a relevant and academically challenging approach for all pupils in the twenty-first century. Together, with other science-based subjects, food technology provides a pathway for those continuing their food studies in higher education and employment in the catering and hospitality arena and the food industry and teaching.

The increasing prevalence of obesity is a major issue for the UK government, and there is the view that teaching children "cooking skills" will ensure that they make healthy food choices and this will lead to a reduction in obesity. Yet, it is known that there are multiple and complex factors that contribute to obesity, for example, socioeconomic conditions and the availability and accessibility to food. McGowan et al. (2015) note that there is limited dietary change related to the association between domestic cooking skills and food skills and that other psychological components (e.g., attitudes) and external barriers (e.g., budget, access to equipment, food storage, etc.) need to be taken into account. Despite this, the new GCSE Food Preparation and Nutrition has a focus on "cooking" to combat obesity and attempts to cover the general and vocational aspects of food education and the "life skill" of cooking, with progression no longer possible to an academic A Level course.

Discussion and debate of these issues are not confined to this country. Other countries have varying approaches to the teaching of food. For example, in Wales, food is taught as a material area within D&T; in Northern Ireland, it is taught as home economics, while in Scotland, food is in both the Technologies and Health and Well-being curriculum areas, the former focusing on design and make work with food and the latter on food and health. In Australia, there are similar approaches. Turner (2013: 483) noted that "many educators consider food preparation and safe handling essential life skills." However, she sees an urgent need for the repositioning of food technology as a rigorous study in food science and innovation as practiced in industry and clarification of the content of hospitality courses. In New Zealand, the "Technology" curriculum clearly teaches food technology. Today, in many countries, there are concerns about health issues relating to diet, obesity (particularly in children), cancer, heart disease, hypertension, diabetes, and undernutrition, though food is not taught in any form in some countries.

The emphasis on developing practical food skills and nutrition underpinning healthy eating is a desirable goal and one to be encouraged, but food teaching should also develop technological and scientific understanding of food. In the England, the debate continues with some expressing agreement with the emphasis on the teaching of "life skills" and cooking. Others argue that, while continuing to learn basic food preparation, cooking skills, hygiene, and nutrition, pupils would also be taught the underlying scientific and technological principles of the ingredients and processes involved in food product development, so making food technology more relevant, sophisticated, and challenging for pupils in the twenty-first century.

Conclusion

This chapter has outlined the current English governments' attempt to combine all the highly desirable and appropriate aims of food teaching into one course. Essentially, food teaching is a broad and complex area of study ranging from teaching the life skills of cooking to the study of food as a specialist subject within the curriculum as an academic and vocational route into the food industry, hospitality and catering industry, teaching, and related careers such as health care and nursing. There is a clear argument for ensuring that primary and lower secondary pupils developed cooking "life skills," but if this should be alongside, and not at the expense of, more rigorous, academic learning. There is also a view that it would be more effective for the teaching of the "life skill" of cooking to have its own place in the school curriculum to reduce the pressure on what can be covered in a food technology curriculum.

It is concluded that, due to the complex and broad nature of the teaching of food and varying aims and objectives, a range of people and organization should be involved in deciding how and where the various elements should be taught in schools and the wider society. These should include government policy makers but, unlike the recent situation in England, involve curriculum planners, curriculum advisers, professional organizations, senior management in schools, and food teachers. The tensions that have arisen with the pressures brought by government on issues such as cooking as a life skill, healthy eating, obesity etc., all have a perfectly legitimate connection with the teaching of food in schools. However this array of potential demands can and does stretch the exact nature of its delivery and purpose and poses the question of whether it is possible to address and do justice to all agendas in just one curriculum slot.

How, where and what pupils should learn about food are important issues. Should it all be in one subject area or through a range of separate subject areas with routes with academic, vocational, and general options available? Or would a cross-curricular subject approach be more effective? Food teachers can act as advisers in the development of whole school policies for food, but their main role should be food teaching within the school curriculum. Should children learn to cook at home and could links be made with organizations outside school? In England, ways of establishing a food-related academic A Level course preferably in D&T, or outside if appropriate, should be urgently explored. There should be discussions between the DfE, examination awarding bodies, the food industry, and universities offering food-related degrees to identify what they require from their applicants in a revised A Level Food course. "Teaching about food in the school curriculum is more than the transmission of practical skills or preparing young people for work in the food industry, it should ensure that our children become informed and responsible" (Owen-Jackson and Rutland 2016: 70). Food teaching can make an important and major contribution to the preparation of our pupils for their life in twenty-first century, and how this can be achieved should be a matter for continuing debate in England and internationally.

References

Arthur, W. B. (2009). *The nature of technology*. London: Allen Lane.

Barlex D. (2014). *The case for food technology within D&T.* https://dandtfordandt.wordpress.com/2014/10/01/the-case-for-food-technology-within-dt/. Accessed 17 July 2016.

DATA. (2004). *Annual survey*. Wellesbourne: D&T Association.

Davies, M. (1981). An investigation of home economics teachers' interest in the contributory areas of the subject. *London: Journal of Consumer Studies & Home Economics, 5*, 148–155.

DES. (1978). *Curriculum 11–16: Home economics*. London: DES.

DES. (1985). *Home economics from 5–16 curriculum matters 5*. London: HMSO.

DES. (1987). *Craft, design and technology from 5–16*. London: HMSO.

DES. (1988). *National curriculum design and technology working group: Interim report – The Parkes report*. London: HMSO.

DES. (1990). *Technology in the national curriculum*. London: HMSO.

DES. (2003). *Every child matters*. https://www.gov.uk/government/publications/every-child-matters.

DES. (2008). *Licence to cook.* http://webarchive.nationalarchives.gov.uk/20100413151441/http://licencetocook.org.uk/information/faqs.aspx. Accessed 17 July 2016.

DfE. (1995). *Design and technology in the national curriculum*. London: HMS.

DfE. (2013). *Design and technology. Programmes of study for key stages 1–3*. London: Department for Education.

DfEa. (2014). *Reforming GCSE and a level subject content consultation*. London: Department for Education.

DfEa. (2015). *Food preparation and nutrition GCSE subject content*. London: Department of Education.
DfEb. (2014). *Cooking and nutrition. Draft GCSE subject content*. London: Department for Education.
DfEb. (2015, July). *Reformed GCSE and a level subject content consultation*. London: Department for Education.
DfEc. (2014). *Design and technology draft GCSE subject content*. London: Department for Education.
Eggleston, J. (1992). *Teaching design and technology*. Buckingham: Open University Press.
Government Office for Science. (2007). *Foresight, tackling obesities: Future choices – Teacher's guide (Vol. 4)*. London: HMSO. file:///F:/Springer%20book/Teacher%20Guide%203%20Foresight%20report.pdf.
Lean, M. (2006). *Fox & Cameron's food science, nutrition & health* (7th ed.). London: Hodder Education.
Mathieson, A. (1979). Home economics – The future. *The Journal of Consumer Studies and Home Economics, 3*, 205–214.
McGowan, L., Caraher, M., Raats, M., Lavelle, F., Hollywood, L., McDowell, D., Spence, M., McCloat, A., Monney, E., & Dean, M. (2015). Domestic cooking and food skills: A review. *Critical Reviews* in *Food Science and Nutrition*. doi:10.1080/10408398.2015.1072495
Newton, D. (1990). Does the home economist have a place in the national curriculum technology? *Design and Technology Teaching, 23*(1), 23.
Nuffield Home Economics Project. (1982). London: Hutchinson & Co (Publishers) Ltd. doi:https://doi.org/10.1079/PNS19840051
Ofsted. (2006). *Food technology in secondary schools* (HMI 2633). London: HMSO.
Ofsted. (2008). *Education for a technologically advanced nation design and technology in schools 2004–07* (Reference no. 070224). London: HMSO.
Ofsted. (2011). *Meeting technological challenges? Design and technology in schools 2007–10* (Reference no. 100121). London: HMSO.
Owen-Jackson, G., & Rutland, M. (2016). Food in the school curriculum in England: Its development from cookery to cookery. *Design and Technology Education: An International Journal, 21*(3), 63–73. https://ojs.lboro.ac.uk/ojs/index.php/DATE/issue/view/182/showToc.
Penfold, J. (1988). *Craft, design and technology: Past, present and future*. Stoke-on Trent: Trentham Books.
Rutland, M. (1997). *Teaching food technology in secondary schools*. London: David Fulton Press.
Rutland, M. (2006). The inclusion of food technology as an aspect of technology education in the English school curriculum. In M. J. de Vries & I. Mottier (Eds.), *International handbook of technology education: The state of the art* (pp. 273–284). Rotterdam: Sense.
Rutland, M. (2008, July 2–4). Licence to cook: The death knell for food technology? In E. W.L. Norman & D. Spendlove (Eds.), *The design and technology association international research conference*. Wellesbourne: Design and Technology Association, Loughborough University.
Rutland, M. (2009). *An investigation: Is there a need to modernise the secondary school food technology curriculum?* Report for the Design and Technology Association. Wellesbourne: Design and Technology Association.
Rutland, M. (2010, July 7–9). Food technology in secondary schools in England: Its place in the education of a technological advanced nation. In E. Norman & D. Spendlove (Eds.), *The design and technology association education and international research conference 2010; D&T – Ideas worth sharing* (pp. 103–109). Wellesbourne: Design and Technology Association, Keele University.
Rutland, M., & Barlex, D. (2009, June 30–July 2). The politics of food: Inside and outside school. In E. Norman & D. Spendlove (Eds.), *The design and technology association international research conference*. Wellesbourne: Design and Technology Association, Loughborough University.
Rutland, M., & Owen-Jackson, G. (2015a). Food technology on the school curriculum in England: Is it a curriculum for the twenty-first century? *International Journal of Technology and Design Education, 25*(4), 467–483.

Rutland, M., & Owen-Jackson, G. (2015b). Preparing to teach food technology. In G. Owen-Jackson (Ed.), *Learning to teach design and technology in the secondary school* (3rd ed.). Abingdon: Routledge.

Rutland, M., Barlex, D., & Jepson, M. (2005). Designing in food technology – A curriculum intervention strategy in a one year design & technology postgraduate teacher training course'. In *Inspire and educate DATA International Research Conference* (pp. 153–160). Sheffield: Sheffield Hallam University.

Turner, A. (2013, December 2–6). *The utility of genre theory in technology education: A case study into food technology teaching*. In J. Williams & D. Gedera (Eds.), *Proceedings of Technology Education for the Future – A Play on Sustainability: 27th Annual Pupils Attitude Toward Technology Conference* (pp. 482–490). Christchurch: Southern Cross University.

Textiles, a Dynamic Exchange: Challenges and Opportunities

24

Belinda von Mengersen

Abstract

With its capacity for infinite design adaptation and manifold nonresistant material solutions, the future-focused domain of Textiles has intrinsic value for Design and Technology (D&T) education. Recent technological research, innovation, and development have illustrated its dynamic capacity for cross-disciplinary applications (McQuaid et al. 2005). Far from staid traditional perceptions of Textiles, these iterations, like those showcased in the exhibition Extreme Textiles, include high-performance fabrics in aeronautics, medicine, apparel, sports, agriculture, transportation, and civil engineering (McQuaid et al. 2005). Quinn asserts that Textiles will continue "to transform our world more than any other material" (2010). So how will D&T education be transformed by these new possibilities? This chapter considers Textiles technologies' evolving role within D&T education, alongside relevant sociocultural and educational developments, challenges, and opportunities.

Keywords

Textiles • Design • Complexity • Future • Evolution

Contents

B. von Mengersen (✉)
National School of Arts, Australian Catholic University, Sydney, NSW, Australia
e-mail: Belinda.VonMengersen@acu.edu.au

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_26

Introduction

Internationally, Textiles are usually situated either within the broader domain of Design and Technology education (D&T) or as a discrete specialist subject area within. Recent technological research, innovation, and development has illustrated its dynamic capacity for cross-disciplinary applications (McQuaid et al. 2005). Quinn has described Textiles' potential for connecting "a variety of [design] practices and traditions," redefining Textiles as a "maverick" material where the integration of technology can begin "at a molecular level"(Quinn 2010, 2012). Hughes et al. (2011) discuss new ways for technological textiles to be better integrated into an overall perspective of material and design thinking within D&T education. Far from staid traditional perceptions of Textiles, these iterations, like those showcased in the exhibition Extreme Textiles, include high-performance fabrics in aeronautics, medicine, apparel, sports, agriculture, transportation, and civil engineering (McQuaid et al. 2005). Offering a dynamic, nonresistant, living material register for evolving applications, Textiles is ideally suited to diverse interpretation and adaptation within D&T education, where research and critique inform design development and evaluation. Here, multiple possible solutions are the focus, as opposed to one provided by a single discipline or material. Indeed, Quinn asserts that Textiles will continue "to transform our world more than any other material" (2010). So how will D&T education be transformed by these new possibilities? This chapter considers Textiles technologies' evolving role within D&T education, alongside relevant sociocultural and educational developments such as the urgent need for ethics and sustainability critique. Textiles' offer a diverse range of sophisticated material technologies' that support new design thinking opportunities for D&T education.

Textiles is a fluid and ever-evolving field. Within this dynamic discipline lie opportunities and challenges for increasing integration in Design and Technology education (in secondary and preservice tertiary programs) alongside and in collaboration with specialist Textile subjects. Textiles is currently situated within Design and Technology education as a whole and also, as a specialist subdiscipline subject area. In Australia, for instance, Textiles is taught in Technology Mandatory, Design and Technology, Textiles Technology, and Textiles and Design. The degree of collaboration and role of Textiles as a domain of D&T education varies internationally and will continue to evolve. This chapter indicates opportunities for evolution and collaboration.

Textiles is invariably described by scholars as a "complex" domain (Gale and Kaur 2002; Gordon 2011; Harper 2012; Schoeser 2012). In the words of Gale and Kaur, "within Textiles is art and science, craft, technology and design, industry, history, culture and politics" (2002). There are several reasons: firstly, Textiles draws from the discrete yet intertwined discipline areas of art and science, navigating a path between theory and practice; secondly, Textiles is an inherently broad, dynamic global industry (Gale and Kaur 2002) where new research into fiber, yarn, fabric, and finishes support innovative applications and influence a vast number of fields including medicine, architecture, and engineering; and thirdly, the intriguing set of paradoxes that has emerged from within Textiles, including the rise of diverse applications. "Textiles Theory" is used to describe textile science and theoretical components of textiles and D&T curriculum including the science and technology of fiber, yarn, fabric and finishes, and properties and performance of textiles – however, the term "Textile Theory" also refers to an emerging discipline in tertiary education that draws from the humanities and museology in addition to science and technology (both terms are used within this chapter). Technological textile innovation has also been accompanied by a resurgence in textile-based craft practices in contemporary visual arts and radical social movements like craftivism (Buszek 2011). The fast-fashion phenomenon has resulted in a significant decrease in the perceived value of textiles in society, particularly apparel, and yet the craft movement itself is evidence of society seeking to reconnect with textiles as a material-making practice. Textiles and the role of fashion are questioned in contemporary society on many fronts – social movements, like "Slow Fashion" (Clark 2008; Fletcher 2010), for example, offer alternative perspectives. Textiles' ubiquitous presence in everyday life is being challenged by innovations like the integration of Textiles and electronics. Fashion forecaster Li Edelkoort recently published the "Anti-fashion manifesto" (Edelkoort 2015), and the Rational Dress Society at the SAIC has launched "The Jumpsuit" – a rationalized and unisex alternative approach to dress (SAIC 2016). Visual anthropologists have recently observed the social, collaborative, and political "power of craft" (Felcey et al. 2013). Gale and Kaur asked, "What is Textiles?" (2002), opening their discussion by describing one of these paradoxical concepts – the ever-present nature of Textiles in contemporary society:

> There are perhaps a handful of inventions so central to our being and our ordinary lives that we have almost forgotten how remarkable they are. Cloth is one of these. . .we find its nature so obvious and its presence so universal that we often overlook the genius of its invention. . . [as] an integral part of every cultural nuance (2002, p. 3).

This chapter will outline some of the unique opportunities and challenges of this multifaceted discipline for D&T educators, at a time when Textiles occupies an enigmatic space in contemporary society.

The Textiles Complex

Textiles has a contingent relationship with Technology. Schoeser (2003) describes a unique set of material qualities that Textiles embodies. She considers Textiles to be:

> unique among all artefacts. The fact that their making often involves the creation of the 'ingredients' – unlike working with wood or stone – makes them extremely complex and particularly revealing of human ingenuity. It can be argued that as indicators of cultural mechanisms, textiles offer insights into the greatest range of developments, embracing not only technology, agriculture and trade, but also ritual, tribute, language, art and personal identity (Schoeser 2003).

It is this capacity to design and redesign textiles beyond the basic material level, from finish, fabric structure, yarn structure, fiber, down to molecular level that make it so capable of responding to design challenges and experimental manipulation.

Philosophically, Textiles is equally informed by science (textile chemistry, textile engineering and material science, scientific textile innovation) and art (design and visual arts, humanities including history, cultural studies, and sociology). D&T educators aim to synthesize both the theory and practice based components of Textiles. The global Textiles industry is vast, complex, and diverse, and the place of Textiles in education and academia mirrors that complexity and diversity. Kadolph describes this as "The Global Textile Complex," discussed here in relation to end-use category: "Technical and Industrial Textiles Grouped by End Use Category: Personal Hygiene; Transportation; Environment; Medical; Food; Animal Care; Agriculture; Protective Gear; Sports and Recreation; Manufactured Goods; Miscellaneous Products; Building Materials" (2014).

This diagram (Fig. 1) provides an overview how broad Textile design areas of investigation can be, ranging from traditional to emerging technologies. However, what has become even more apparent recently is that this complex is rapidly expanding in response to intensification of technological research related to engineering, science, and design. Quinn (2002, 2010, 2012) has compiled a set of terms for the integration of technologies' in textile design summarized below (Table 1) that offers some insight into the plethora of potential applications:

Contemporary Textiles' design practices oscillate between traditional craft-based practices and investigative technological applications. As a result, the learning that can be undertaken by Textiles students at this point in time ranges from how to use the simplest historical technological tool, the hand sewing needle, right through to complex ICT applications like 3D printing and knitting methods using natural and synthetic fiber blends. Tortora has traced the relationship between dress, fashion, and technology from prehistory to present (2015). Many D&T students associate the term "Textile" with apparel and garments, but many of them are initially unaware of the diverse arrange of other non-apparel products designed and manufactured using textile materials. These narrow perceptions are redressed in a number of recent textile publications including: Gale and Kaur's *The Textile Book* (2002), Gordon's *Textiles: The Whole Story* (2011), and Schoeser's "*Textiles: The Art of Mankind*"

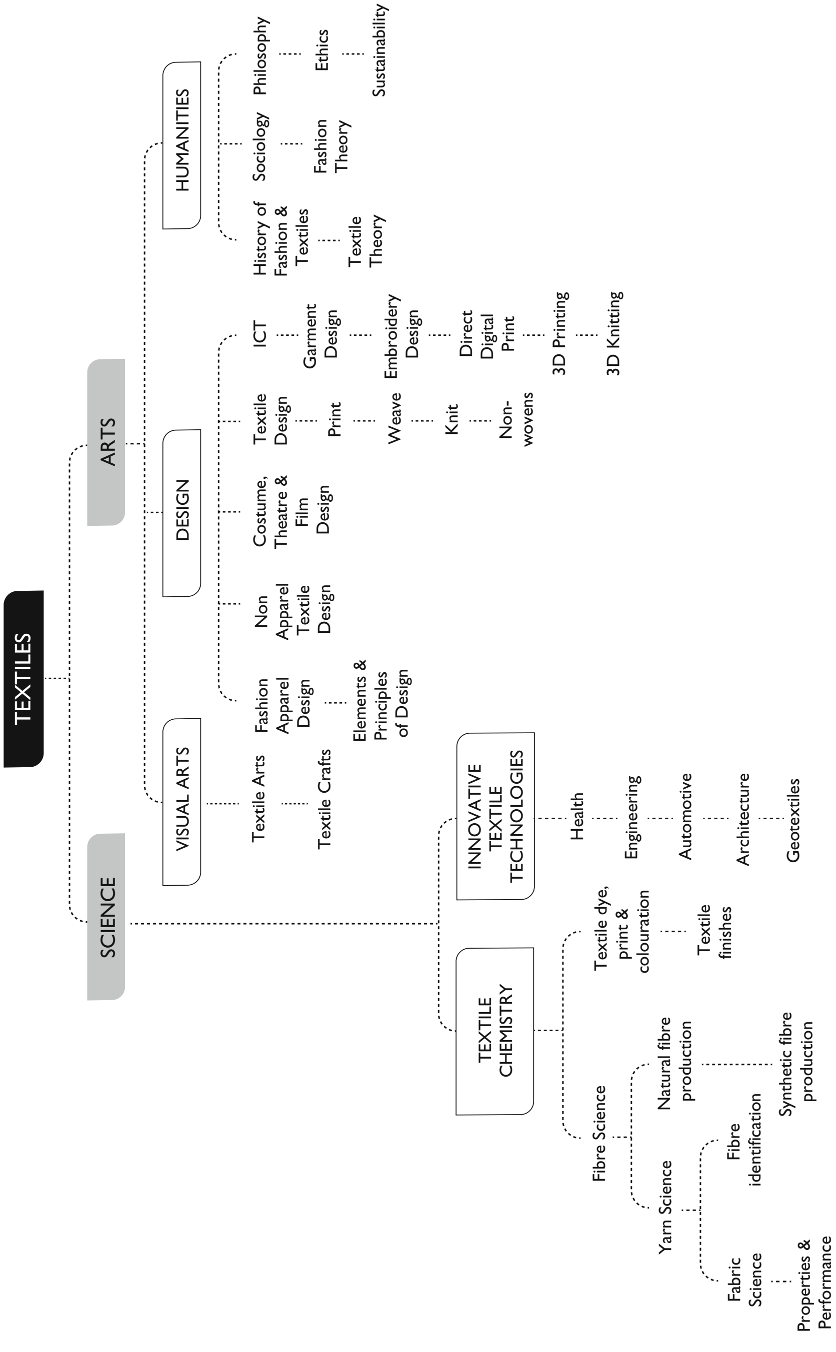


Fig. 1 A "Textiles Complex" diagram

Table 1 Summary of textile technology terminology and applications

Body technology	Synthesized skins	Vital signs
Electronic textiles Illuminating fabric Embedded fibers Subtle surveillance Emotive interfaces	Exoskeletons Robotic textiles Fortified fashion Sensory skins Fluid-based fabrics	Biotextiles Diagnostic textiles Medicating fabrics Smart bandages Well-being
Surfaces	Interior textiles	Extreme interfaces
Perceptual surfaces Invisibility Biomimicry Reactive rugs Thermosensitive materials	Soft walls Fiber furniture Reactive surfaces Sensory membranes Fiber optics	Surface energy Flight Kinetic fabrics Energy absorption Textiles as biological agents

(2012). These publications indicate an ongoing need for the communication and summarization of a discipline overview in Textiles and its increasing significance in D&T education.

History of Textiles Technology Education

Textiles have undergone a phenomenal transformation in society. Historically, textiles were rare and highly valued because they were expensive and labor intensive to produce. The industrial revolution radically changed the landscape of Textiles yarn and fabric production through mechanization, resulting in an increasing trend for textiles production and construction to shift from the home to factories, often in urban areas. A gradual reduction in tariffs and the end of the Multi-Fiber Arrangement (which governed the textile trade from 1974–2004) accelerated the shift of textile production to developing countries where labor was cheaper (Lopez-Acevedo and Robertson 2012). This scenario continued to evolve into the vast textile complex and nontransparent textile global supply chain that has enabled the fast-fashion phenomenon and devaluation of textiles. Since the Rana Plaza disaster in 2011, there has been an increasing awareness of the issue of ethics and sustainability in Textiles and fashion (von Mengersen 2013a, b).

Textiles, in D&T education, mirrors the field's dynamic and complex nature. In Austria and Sweden and other European countries with a textile craft tradition (often described as a precursor to Design and Technology Education) (Jones and De Vries 2009), one challenge is to consider how Textiles are situated; are they being taught in philosophically different ways in both subject areas for instance, or can they be integrated? In Austria, for instance, the syllabus for "Crafts and Technology" instigated in the 1970s and is being revised as part of the UPDATE program (Seiter 2009), poignantly students must choose between "Technical" (Crafts and Technology) or "Textiles" (Textiles Crafts); in Sweden, Textiles are taught as part of a traditional craft skills-based program "Sloyd" (Banks and

Williams 2013); also in these systems, students are often streamed into more vocationally focused (design and technology subjects) or more academically focused schools (more traditional subject choices); this model of streaming is described by Petrina in relation to a US context as “the dichotomy set up between academic and vocational education” (Petrina 1998, p. 104). In the US, technology is focused on engineering; however, educators are successfully integrating Textiles Technology into engineering subjects through electronic textiles (Buechley et al. 2013b).

A comprehensive overview of Textiles in D&T education internationally lies beyond the scope of this chapter; however, a summary of key international perspectives on D&T education (Banks and Williams 2013) supports this picture of diversity in learning focus in D&T internationally. This diversity is duly reflected in Textiles-related offerings (integrated with D&T or otherwise). Further detailed historical perspectives on international developments in technology education can be found in the International Handbook of Research and Development in Technology Education (Jones and De Vries 2009, pp. 1–16).

Textiles Literature Review

The span of Textiles in Design is evidenced by the considerable number of recent publications in Textiles which attempt to offer an overview of the field. Examples of recent publications attempting this overview include but are not limited to “Textile: Critical and Primary Sources” (Harper 2012), “The Textile Reader” (Hemmings 2012), “The Handbook of Textile Culture” (Jefferies et al. 2016), “Textiles: The Art of Mankind” (Schoeser 2012), and “Contemporary Textiles: The Fabric of Fine Art” (Monem 2008). When Harper edited a multivolume reference work titled *Textiles: Critical and Primary Sources* (2012), she described how ordering and arranging the complex and multifaceted contents was challenging: “Textile culture stretches geographic, historical, methodological and disciplinary boundaries, and defies chronological ordering” (Bloomsbury 2016). This design of this reference text is further evidence of the disparate nature of Textiles ability to “draw... on sociology, art/design and cultural history, anthropology, architecture, dress and fashion studies, material culture and science, textile technology, and the rest...” (Harper 2012): Volume One focuses on history and exhibition curation; Volume Two production (including sustainability); Volume Three science and technology; and Volume Four “Identity,” drawing from the arts, sociology, psychology, and the humanities overall. Overall, this increased number of new publications emerging from the field offers an optimistic assessment of the discipline’s vitality and dynamic, evolving trajectory. It reflects a shifting relevance and social realignment. Textiles theory is emerging as a distinct discipline, expanding beyond Textiles Science and Technology into sociocultural explorations. Whist Textiles and D&T curricula have long acknowledged and utilized this field, the recent spate of publications offers an opportunity for that dialogue and the accompanying cultural understanding to be enriched and expanded.

Textiles Technology Educational Research Literature Review

Williams (2013) conducted an analysis of research trends in Technology Education through literature review. Here a similar methodology was used to broadly identify research trends in Textiles as a D&T domain achieving an overall view of research and observing challenges and opportunities that have been identified. This analysis includes three international journals for technology education research (using no specific date range) and one more discipline-specific journal. This table observes the number of articles published that refer to Textiles, Textiles and Design, or Textiles Technology (Table 2):

This table indicates the relatively small scale of Textiles-focused articles as a domain of D&T and clearly suggests an opportunity for more research to be developed. The research topics in Textiles technology education research published within the International Journal of Technology and Design Education vary broadly, ranging from craft, creativity, curriculum, environmental sustainability, student motivation, and gender disparity. Many papers are situated in relation to Textiles, like crafts and technology, 3D simulation technology in apparel design, procedural knowledge in craft, design and technology, design and cultural identity, innovative thinking, evaluating technical solutions, and materials experience. Given the small scale and the diversity of topics, several researchers clearly indicate that Textiles offer many opportunities to the larger discipline of D&T. Hughes, Bell, and Wooff (Hughes and Bell 2011; Hughes and Wooff 2013) suggest that Textiles Technology can be effectively used to support systems-based design approaches like STEM (the integration of Science, Technology, Engineering, and Mathematics). This approach has also been mirrored in Australia where electronic-textiles projects are being integrated into Technology Mandatory (introductory compulsory secondary subject) to support an increasingly STEM-focused curricula.

Hughes, Wooff, and Bell (Hughes and Bell 2011; Hughes et al. 2011; Hughes and Wooff 2013) have published the most comprehensive set of recent research in Textiles specific to Technology education research, clearly illustrating some key contemporary challenges and opportunities outlined within this chapter. Researching the issue from a UK perspective, Hughes, Wooff, and Bell ask a poignant question: “Textiles: design and technology or art?” (2013) – setting out the clear risk for a specialist subject to be subsumed by a larger one and confirming a deep philosophical difference between Visual Art education and D&T education and revealing many limitations for students interested in Textiles as a distinctive

Table 2 The number of Textiles-related articles that appear in each publication

List of technology education journals	No. of Textiles articles
International Journal of Technology and Design Education	**103**
International Journal of Fashion Design, Technology and Education	**60**
Journal of Technology Studies, USA	**9**
Journal of Technology Education, USA	**0**

material science, technology, and complex industry. A shift like this would reduce students' capacity to evaluate the properties and performance material (textile fiber/yarn/fabric/finishes), thus limiting their understanding and ability to develop complex design solutions in Textiles. Hughes and Wooff (2013) clearly outline the many challenges of Textiles remaining within D&T, and these UK-focused findings are equally relevant in other countries. They indicate (a) an already packed curriculum requiring rationalization by schools, compounded by a "return" to focus on reading, writing, and mathematics – classic core subjects that dominate curriculum hours; (b) budgetary constraints on schools, with the less well-resourced unable to provide appropriate facilities, equipment, technical support, or teaching spaces; (c) and the increasing difficulty of recruiting teachers qualified in Textiles – the result of preservice teacher programs focusing on the attainment of a "Technology" major or generic group, rather than specialist areas. In these cases, schools are often forced to choose: in the UK, to offer Textiles only in the visual arts program, and in Australia, to offer Textiles as a materials choice in D&T but not offer the additional enriching elective subjects like Textiles Technology and Design and Technology (Hughes and Wooff 2013). Hughes and Wooff (2013) also outline the textiles industry's significant contribution to the global economy – around 7%. They delineate the industry's evolution from "hand tool and manually operated machines" to "computer-operated machinery such as computer-aided sewing and embroidery machines and laser cutting machines" (Hughes and Wooff 2013). This balance between technologies' continues to develop, with Textiles students in D&T or Textiles labs where students explore DDP – (Direct Digital Print, 3D printing, laser-cutting and CAD-supported yarn and weave design simulation software, pattern modification software, and apparel design simulation). Design with Textiles, materials, and techniques can also include traditional techniques like felting or hand making string or hand-spinning and weaving. It is this cross-pollination, focused on student-centered experiential learning which reflects the complex, evolving nature of the larger industry. One challenge for both education and industry, as presented by Hughes et al., lies in "reducing the practice gap between the design and technology curriculum and the needs of the textile/design manufacturing industry" (Hughes et al. 2011). The push towards real-life design opportunities in education research translates to an "internship" focus in preservice education and linkages with industry partnerships (McLaren 2015). This relationship is a key challenge and opportunity for Textiles in D&T – how and when to link with industry.

Challenges for Textiles Technology

Many challenges for Textiles stem from the field's complexity and diversity and include terminology, a historical gender bias, changing identity, and allocations in curricula. A number of other key challenges outlined by Hughes and Wooff (2013) have already been briefly mentioned.

Terminology

Reduced exposure to Textiles at the domestic level of design, making, or repair has led to an accompanying decrease in commonly known terms. Traditionally, the skills of Textiles construction and repair, present in the everyday home environment, have been passed down through generations. But the fast-fashion phenomenon has undone this process, and quickly, research suggests that in just two generations, our domestically visible skill base has been lost (Fletcher 2014). Consequently, many students no longer have basic understanding of Textiles terminology to bring to D&T – or methods of construction and repair – even for apparel. The TCF (Textiles, Clothing, and Fashion industry) due to the global complex have nontransparent chains. This distancing has created a convoluted, opaque industry supply chain and a lack of experience of textiles-making and repair on a domestic level: though we encounter textiles daily in myriad intimate and practical ways, a critical separation has occurred between these items and the manner of their production.

Historical Gender Bias

This well-acknowledged Textile phenomenon can be easily traced through history. It is profound and remains entrenched even yet: for instance, in Australia, in 2015, there were only 24 males enrolled in Textiles and Design at a senior school level in NSW, equating to a mere 1% of the elective subject's 1,653 enrolments. Awareness is vital, enabling educators to seek opportunities to develop non-gender biased Textiles' material projects in D&T, encourage participation, and acknowledge pre-existing skills that might be applied. Such an approach to non gender-specific project design and assessment has the potential to bring about an incremental shift. Given the opportunity to consider Textiles as materials for design in D&T rather than exclusively for clothing, students can experience the emerging technologies which support valuable links between textiles and fields such as engineering.

Opportunities for Textiles

The philosophy of critique is an emerging signature pedagogy in Technology education (Stables and Williams 2017). D&T educators are finding new ways to focus on integrating a culture of critique, particularly in relation to cultural research, ethics, and sustainability.

This opportunity also extends to design-futures, where speculative thinking and the development of narrative can inform design context.

Narrative

Building a knowledge and skill base in Textiles takes time and practice. Often it is the interrelationship of information or the various properties and performance capabilities of Textile materials in Textile design systems which takes time to comprehend. Delivered in traditional ways, this material can be overwhelming. Gordon offers D&T educators a new framework for dissemination and discussion, based on the narrative capacity of textiles that interlaces textile theory, history, sociology, and cultural examples and also “integrates the fields of art, science, history and anthropology” (2011). This interactive creative approach to learning and teaching in Textiles is supported by evidence of the increasing use of storytelling and narrative in transformative learning (Taylor and Cranton 2012). As Sayer and Studd suggest, one of the ongoing challenges in Textiles in D&T education is to match learning style preferences with suitable delivery methods (2006).

Cultural Research

One key aspect of Textiles theory has been “Textiles and Society” where students study the cultural, historical, and perceived value of textiles. Traditionally this has been interpreted as cultural research into the material, created items of broad cultural groups, and applied to culturally inspired design development. However, this type of research task can become very generic. The emerging dialogue in Textile Theory and Fashion Theory – drawing heavily from sociology and the humanities – has, however, created a new opportunity for educators. Textiles theory as a form of scholarship draws from a wide range of disciplines: sociology, the humanities, technology, museology, and science, among others. Since the launch of Textile: Cloth and Culture (Harper 2003), Jefferies (2016) has described Textiles Theory as an “emerging discipline.” Fashion Theory, too, has become a well-established area of scholarly enquiry clearly linked to Textiles – particularly since the launch of Fashion Theory: the journal of dress, body, and culture (Steel 1997). Both developing disciplines are establishing their reputations through these highly ranked journals and open up opportunities for a far more complex dialogue with students about the diverse sociological aspects of clothing and dress: ideas they can critically engage with on a personal level. Shifting the focus of cultural research increases student engagement because of a sense of connection to the subject material – such as the social psychology of dress. This re-aligns the research task towards a more student-centered approach (Hunt et al. 2012) and links it more clearly to a wider understanding of Textiles design as a form of material culture.

Stem

Textiles are poised to play a far more integrated role in STEM applications. In many D&T programs, this logical integration is already in practice as discussed above. Significantly, as Cowell (citing Quinn 2010) argues, Textile technologies are well-suited integration in these subjects because of their capacity for material design and engineering, “technical textiles are changing the way we think of textiles as a design medium” (Owen-Jackson 2013, p. 142). In particular electronic textiles, where conductive threads, LEDs, sensors, and microprocessors can be integrated into resistant materials substrates and then coded. A rapidly increasing number of resources are available to support the integration of these projects, in particular Leah Buechley's LilyPad Arduino system (Buechley et al. 2013a, b; Kettley 2016).

Ethics and Sustainability in Textiles

In Textiles there is an urgent need for critical engagement with both the philosophy of ethics and its practical application. Such awareness will support student understanding of sustainability as a systems issue in the Textiles industry and enable the practical application of ethics in their learning. Hughes and Wooff have indicated how Textiles and textile items

> are. . .an excellent way to help pupils explore values and ethical issues in design and manufacturing of products. . . examining the way products are manufactured throughout the global supply chain can lead to raising pupils' awareness of ethical issues, (2013).

The Australian Teaching and Learning Council (ALTC 2016) has developed a framework for assessing graduate attributes, including sustainability and ethics, helpful here because such qualities are often considered generic and esoteric. It includes detailed assessment guidelines and descriptive holistic rubrics for educators to use as standards of achievement for teamwork, sustainability, critical thinking, and ethics, providing clear guidelines for D&T educators integrating a critical and practical study of ethics and sustainability into their syllabus. In Textiles-focused D&T research education, there has been a call for a more refined and specific etymology (Davies and Hail 2015; von Mengersen 2013a) around sustainability and ethics, to enable and enrich debates in Textiles. In response, education publisher Bloomsbury has begun to integrate critical ethics sections in each of its publications; in addition, it has developed "a methodology for the consideration of ethical implications of the discipline" (AVA 2016). Recently, a coursework Ethics text book has also been published which, despite its focus on the fashion industry, is a valuable tool for Textiles educators (Paulins and Hillery 2009). The range of publications indicates the emergence of a more clearly defined pedagogy around ethics in Textiles – providing unique teaching and learning opportunities for both the critique of ethics and their practical application.

Design Futures

Constantine and Reuter (1997) describe the inherent paradox of Textiles as both ubiquitous everyday material for clothing mankind and yet capable of complex sociological and cultural communication, and then, they challenged each generation to find a new language for Textiles. For all mankind has an intimate relationship with Textiles and design. Simondon discusses the philosophical notion of the sociological human imperative for expression and nonverbal communication through textiles is a binary between individuation and socialization (Bardin 2015). These ideas are linked to a more critical discussion and understanding and assist in the development of a new technological Textiles language for D&T. One branch of that is speculative design thinking for design futures and as Textile materiality continues to transform in relation to integrated technologies so must our understanding and capacity to adapt and apply those understandings. Speculative design thinking (Ng and Patel 2014) is another emerging pedagogical approach useful for Textiles; in Fashion and/or Textiles Design courses, students are increasingly asked to develop creative narrative-based scenarios design contexts, and develop personas and design in response to these imagined criteria and constraints. Design briefs developed in this way can combine written narrative, design simulations or illustrations, and prototyping in response to both research and speculation.

Conclusion

Textiles is poised for the challenges which lie ahead, well aware that its haecceity offers as many opportunities as it does challenges. An organic outcome of Textiles' situation as an evolving domain of D&T education is an enhanced capacity for critique and reflection. This has enabled a creative, critical, and adaptive pedagogical voice to emerge. Textiles are developing a new language with which to elucidate the value, relevance, and unique philosophy and capacity as "maverick" material – its inherent social, cultural, and ethical concerns, the evolving academic rigor of its scholarship, and above all, its crucial, multidisciplinary role in contemporary Design and Technology education curricula.

References

ALTC. (2016). *Standards of achievement: Framworks for assessing graduate skills.* Retrieved from http://graduateskills.edu.au/project/.

AVA. (2016). *Debating ethics.* Retrieved from http://blog.bloomsburyvisualarts.com/2011/08/16/debating-ethics/.

Bardin, A. (2015). *Epistemology and political philosophy in Gilbert Simondon individuation, technics, social systems philosophy of engineering and technology.* Dordrecht: Springer Netherlands.

Bloomsbury. (2016). *Textiles: Critical and primary sources.* Retrieved from http://www.bloomsbury.com/au/textiles-9780857850355/.

Buechley, L., de Boer, S., Goldfein, J., & Qiu, K. (2013a). *Sew electric: A collection of DIY projects that combine fabric, electronics, and programming*. Cambridge, MA: HLT Press.

Buechley, L., Peppler, K. A., Eisenberg, M., & Kafai, Y. B. (2013b). *Textile messages: Dispatches from the world of e-textiles and education*. New York: Peter Lang.

Buszek, M. E. (2011). *Extra/ordinary: Craft and contemporary art*. Durham: Duke University Press.

Clark, H. (2008). SLOW+ FASHION – An oxymoron – Or a promise for the future...? *Fashion Theory, 12*(4), 427–446.

Constantine, M., & Reuter, L. (1997). *Whole cloth*. New York: Monacelli Press.

Davies, S., & Hail, Y. (2015). *Education for sustainable development within textile technology: A case study of two schools*. Paper presented at the PATT29, Plurality and Complementarity of Approaches in Design and Technology Education, Marseille, France.

Edelkoort, L. (2015). *Anti fashion manifesto*. Published by Lidewij Edelkoort http://www.edelkoort.com/2015/09/anti_fashion-manifesto/

Felcey, H., Ravetz, A., & Kettle, A. (2013). *Collaboration through craft*. London: Bloomsbury Academic.

Fletcher, K. (2010). Slow fashion: An invitation for systems change. *Fashion Practice, 2*(2), 259–265.

Fletcher, K. (2014). *Sustainable fashion and textiles: Design journeys* (2nd ed.). Milton Park, Abingdon, Oxon: Routledge.

Gale, C., & Kaur, J. (2002). *The textile book*. Oxford/New York: Berg.

Gordon, B. (2011). *Textiles: The whole story: Uses, meanings, significance*. London: Thames & Hudson.

Harper, C. (Ed.). (2003). Textile: The Journal of Cloth and Culture.

Harper, C. (2012). *Textiles: Critical and primary sources*. London: Berg.

Hemmings, J. (2012). *The textile reader*. Oxford: Berg.

Hughes, C., & Bell, D. (2011). Underpinning the STEM agenda through technological textiles? An exploration of design technology teachers' attitudes. *Design and Technology Education: An International Journal, 16*(1), 53–61.

Hughes, C., & Wooff, D. (2013). Textiles: Design and technology or art? In G. Owen-Jackson (Ed.), *Debates in design and technology education* (pp. 115–124). Oxon: Routledge.

Hughes, C., Bell, D., & Wooff, D. (2011). *Reducing the practice gap between the design and technology curriculum and the needs of the textile design/manufacturing industry*. Paper presented at the PATT 25: CRIPT8 Perspectives on Learning in Design & Technology Education Goldmsiths University of London.

Hunt, L., Chalmers, D., & Australian Council for Educational Research. (2012). *University teaching in focus: A learning-centred approach*. Camberwell, Victoria: ACER Press.

Jefferies, J., Wood Conroy, D., & Clark, H. (2016). *The handbook of textile culture*. London: Bloomsbury.

Jones, A. T., & De Vries, M. J. (2009). *International handbook of research and development in technology education*. Rotterdam/Boston/Taipei: SENSE Pub.

Kadolph, S. J. (2014). *Textiles* (11th ed.). Harlow: Pearson.

Kettley, S. (2016). *Designing with smart textiles*. London/New York: Fairchild Books, an imprint of Bloomsbury Publishing, Plc.

Lopez-Acevedo, G., & Robertson, R. (2012). *Sewing success? Employment, wages, and poverty following the end of the multi-fibre arrangement sewing successemployment, wages and poverty following the end of the multi-fibre arrangement.* World Bank Publications.

McLaren, S. V. (2015). *It takes a village: The value of partnership working in design & technology teacher education*. Paper presented at the PATT29: Plurality and complementarity of approaches in design and technology education, Marseilles, France.

McQuaid, M., Beesley, P., & Cooper-Hewitt, M. (2005). *Extreme textiles: Designing for high performance*. New York: Princeton Architectural Press in association with Cooper-Hewitt, National Design Museum Smithsonian Institution.

Monem, N. K. (2008). *Contemporary textiles: The fabric of fine art*. London: Black Dog Pub.

Ng, R., & Patel, S. (2014). *Performative materials in architecture and design.* Bristol: Intellect.

Owen-Jackson, G. (2013). *Debates in design and technology education*. Milton Park, Abingdon, Oxon: Routledge.

Paulins, V. A., & Hillery, J. L. (2009). *Ethics in the fashion industry*. New York: Fairchild Books.

Petrina, S. (1998). Multidisciplinary technology education. *International Journal of Technology and Design Education, 8*(2), 103–138. doi:10.1023/a:1008889513151.

Quinn, B. (2002). *Techno Fashion*: Bloomsbury Academic.

Quinn, B. (2010). *Textile futures: Fashion, design and technology* (English ed.). Berg: Oxford.

Quinn, B. (2012). *Fashion futures*. London/New York: Merrell.

SAIC. (2016). *Jumpsuit*. Retrieved from https://www.jumpsu.it/author/admin/.

Sayer, K., & Studd, R. (2006). Matching learning style preferences with suitable delivery methods on textile design programmes. *International Journal of Technology and Design Education, 16*(2), 163–176. doi:10.1007/s10798-005-4327-y.

Schoeser, M. (2003). *World textiles: A concise history*. London: Thames & Hudson.

Schoeser, M. (2012). *Textiles: The art of mankind*. London: Thames & Hudson.

Seiter, J. (2009). "Crafts and technology" and "technical education" in Austria. *International Journal of Technology and Design Education, 19*(4), 419. doi:10.1007/s10798-009-9096-6.

Stables, K., & Williams, P. J. (2017). *Critique in design and technology education.* Springer

Steel, V. (1997) Fashion theory (Online). *Fashion theory: The journal of dress, body & culture*. Oxford: Routledge, Taylor & Francis Group.

Taylor, E. W., & Cranton, P. (2012). *The handbook of transformative learning: Theory, research, and practice*. John Wiley & Sons.

Tortora, P. G. (2015). *Dress, fashion, and technology: From prehistory to the present*. London/New York: Bloomsbury.

von Mengersen, B. (2013a). *Etymology and Ethics: Terms for Sustainability in Textiles*. Paper presented at the PATT27, Technology education for the future: A play on sustainability, Christchurch, NZ.

von Mengersen, B. (2013b). *Sustainability+ Needlecraft= Textiles Technology: Could a Return to 'Needlecraft'Skills Enhance Sustainable Practice in Textiles?* Paper presented at the PATT27, Technology education for the future: A play on sustainability, Christchurch, NZ.

Williams, P. J. (2013). Research in technology education: Looking back to move forward. *International Journal of Technology and Design Education, 23*(1), 1–9. doi:10.1007/s10798-011-9170-8.

25 Resistant Materials in Technology Education

Owain Pedgley and Bahar Sener

Abstract

As the fabric of our natural and manmade worlds, materials take an omnipresent role in everyday experiences. An awareness of the diversity of materials and an appreciation of how they can be put to good use – for technical and experiential purposes – is an essential aspect of much design and technological learning at school. Materials awareness and capability in design and technology is known to be developed most effectively in real-world contexts and in response to real-world problems. It is markedly removed from the study of materials through the lens of the laboratory microscope. This chapter argues for a coherent and modern way that "resistant materials" (traditionally encompassing metals, plastics, woods) can sit within technology and design curricula at primary and secondary schools. Discussions reciprocate between content (what to know and why) and epistemology (ways of knowing and learning). The chapter culminates in a proposal of three pillars for developing students' materials experience, comprising knowledge acquisition, skills, and context. The work is intended to assist all professionals having a stake in technology and design education, by outlining a modern, responsible, and relevant approach to pedagogy for resistant materials.

Keywords

Resistant materials • User experience • Performance • Propositional knowledge • Empirical knowledge

O. Pedgley (✉)
School of Engineering, University of Liverpool, Liverpool, UK
e-mail: pedgley@liverpool.ac.uk

B. Sener
School of Engineering, University of Liverpool, Liverpool, UK

Department of Industrial Design, Middle East Technical University, Ankara, Turkey
e-mail: bsener@liverpool.ac.uk; bsener@metu.edu.tr

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_30

Contents

Introduction

Our world is full with material creations, artifacts, manufactured goods, and infrastructure (from hereon referred to simply as "products"). Products from the smallest to grandest scale are all connected by the principle of harnessing material properties to reach an intended goal. Take a look around you: materials in the bowls you eat from, in the chairs you sit on, in the floors you walk on, in the buildings you live in, and in the vehicles you travel in. Materials not only contribute to the proper functioning of products but also closely define the kinds of product experiences people have through visual or physical contact. Materials are therefore highly influential in decisions made by designers whose work is intended to be physically realized.

Historically, materials are closely tied to the development of civilizations and the technological advancement of products (Doordan 2003). From primitive eras utilizing only wood, stone, leather, and bone, science and engineering have now created around 160,000 materials for potential application in products (Ashby et al. 2013). From among this vast palette, designers are challenged with the task to choose the "right material" for an application at hand (Miodownik 2009). The options are staggering. Designers adopt decision-making processes, often a combination of screening and selection, to propose that "right material." Along the way, designers are also mindful that material choices open doors to new product concepts and new forms. Intellect, ingenuity, and creativity are therefore all important in the designer's consideration of materials.

This chapter argues the ways in which resistant materials should ideally feature within technology and design education at primary and secondary schools. "Resistant" materials are those that require application of substantial force to process, such as metals, plastics, and woods, but also extends into many other material families. The chapter deliberately avoids any inclusion of textiles or food because of their coverage elsewhere in the handbook.

Several questions underpin the discussion in the chapter. How can an enthusiasm for learning about materials be nurtured in youngsters, to fire their curiosity of the world? What needs to be done for students not only to become appreciative of materials but also to become skilled in choosing and using them in appropriate and creative ways? How can schools develop students' "materials experience" (Karana et al. 2014)? Throughout the chapter, discussions reciprocate between content (what to know and why) and epistemology (ways of knowing and learning). Practical matters of *how* to learn and teach materials (regarding planning, content, activities, delivery, and assessment) are avoided, since these are covered in a separate chapter. The chapter culminates in a proposal of three pillars for developing students' materials experience, comprising knowledge acquisition, skills, and context. The work is intended to assist all professionals having a stake in technology and design education, by outlining a modern, responsible, and relevant approach to pedagogy for resistant materials.

The authors' professional expertise is in the education of product and industrial design undergraduate and postgraduate students. One of the opportunities with this chapter has been to place "hot topics" currently affecting materials and design education at university level (Pedgley 2010; Pedgley et al. 2015) into the context of primary and secondary levels.

Use and Appraisal of Materials

Industrial design is a user-centered activity that straddles STEM (science, technology, engineering, and mathematics) and the social sciences. Its outcomes are designs for materialized products, services, and systems, where functionality is an omnipresent requirement. Foremost, materials in technological design activities are harnessed for their utility: the ability to perform and enhance a practical task. Materials are also frequently used for reasons that are independent of, or on top of, utility, which relate to the fulfillment of aesthetic, emotional, or other such human needs. Thus two main dimensions to the use and appraisal of materials in product-related design activities can be identified: (i) a technical/performance dimension and (ii) a human/experiential dimension.

The technical/performance dimension refers to material choices supporting the "proper" functioning of a product. The sheer diversity of products reminds us of the practical adaptability of materials: how they are asked to admirably perform myriad tasks. Materials are selected for their performance against many different criteria such as strength, stiffness, elasticity, piezoelectric effects, antimicrobial protection, low weight, luminescence, energy harvesting, self-healing, self-cleaning, hydrophobic characteristics, biodegradability, and so forth.

The human/experiential dimension refers to material choices that take into account people's appraisal systems. It encompasses historical, cultural, social, and personal implications of materials. These issues were first discussed in Ezio Manzini's seminal book *Material of Invention* (1986), where he laid foundations for what has subsequently developed into a body of work concerned with ways of using materials to positively affect user experiences. Materials usage in products helps define user experiences on multiple levels (Karana et al. 2014), spanning aesthetics, meanings, emotions, and behaviors. A full spectrum of user experiences, from comfort and usability, to pleasure in ownership and use, is implicated in material choices and tied to the qualities of materials that people can sense and perceive.

- **Aesthetics**. How people are (dis)pleased by materials, e.g., enjoying *the smoothness* of polished metal, being put off by *the look* of recycled plastic, being captivated by *the smell* of wood
- **Meanings**. How people label materials by making associations or judgments, e.g., being *traditional*, looking *cozy*, seemingly *high quality*, having a *basic specification*
- **Emotions**. How people feel towards materials, e.g., *surprise* ("oh!"), *disgust* ("urgh!"), *enthrallment* ("amazing!"), *joy* ("fantastic!")
- **Behaviors**. How people act and react because of materials, e.g., *avoiding* products, *spending time* with products, *cautiously approaching* products, *rejecting* products

Some material properties do not have a direct human/experiential dimension (e.g., flammability). But often it is the case that technical/performance and human/experiential dimensions interact, requiring designers to turn material properties to the advantage of utility as well as user experience. For example, translucency in a pen helps to view the ink level but at the same time can contribute to an attractive, frosted, curious product personality. Such dual association of material properties – serving utility as well as user experience – should be a foundational point in technology and design education.

The supply of information for determining material performance and technical accomplishment has a long tradition (Karana et al. 2008). Vast data sets derived from research are available to inform decisions based on metrics such as strength, stiffness, impact resistance, and hardness. In contrast, research into material selections based on intended user experiences is relatively new, undeveloped, and infrequently applied. In essence, it seeks to establish reliable frameworks and data sets on people's experiences arising from person-material-product relations. As the research field matures, it will strengthen the knowledge base for design. The long-term goal is to support decision-making on material sensorial properties, transitioning away from professional intuition towards a knowledge base that can be rationalized in the same way as calculations for performance.

Materials in the National Curriculum of England

Before delving deeper into the specifics of materials within technology and design education, it is helpful at this point to consider the prevalence of materials education across the wider school curriculum. The case of primary and secondary education in

England, within the present (2016) implementation of the National Curriculum, is presented for illustration.

Table 1 describes professional perspectives on materials, spanning disciplines based on scientific activity (chemistry, physics, biology) as well as technological activity (materials engineering, design engineering, industrial design). The science perspectives are covered by the compulsory (core) Program of Study in 'Science'

Table 1 Professional disciplinary perspectives on materials

	Professional Discipline	Focus	Example content		
Science (scientific activity)	**Chemistry**	Investigating and understanding the composition of materials	Periodic table, bonding, crystallinity, polymerization, phase transitions		
	Physics	Investigating and understanding the functioning of materials	Failure modes, crack radiation, magnetism, corrosion, tribology, non-destructive tests		
	Biology	Investigating and understanding the biological composition and functioning of materials	Living tissue, cellular structure, organisms, enzymes		
Technology (technological activity)	**Materials engineering**	Creating and developing advanced materials for applications	Nanomaterials, smart materials, self-cleaning materials, biomaterials, biomimetic materials		
	Design engineering	Using materials to deliver product utility (= functional design)	Selection based on performance criteria: strength, weight, durability, elasticity	**Common factors in selection** Sustainability/ environmental impact, cost-price-value	Area of interest for school-based technology and design education
	Industrial design	Using materials to deliver product experiences (= user-centered design)	Selection based on experiential criteria: aesthetics, meanings, emotions, behaviors		

across Key Stages 1–4 (Years 1–11) of the National Curriculum in England, and extend into Advanced-Level study of subject-specific sciences in Years 12–13 of secondary school. The technology perspectives are covered by the compulsory (foundational) Program of Study in "Design and Technology" across Key Stages 1–3 (Years 1–9) of the National Curriculum in England (optional at Key Stage 4) and continue in Years 12–13 as Advanced Level study in Design and Technology. It will be appreciated that the school subject area of Design and Technology is therefore critical in developing students' knowledge of the applications of materials in products.

Capability for Material Decision-Making

So far this chapter has explained the varied uses of materials in products and provided a brief review of materials teaching in the National Curriculum of England. In this section, the pedagogical challenges for developing materials capability in technology and design students are laid out. Norman's (1998) "technology for design" agenda is used to structure the discussion in this section. He argues that technology (or expertise) for the practice of design can be regarded as an interaction of the notionally separable elements "knowledge," "values," and "skills." Capability for material decision-making should attend to all three, with suggestions provided as follows:

- **Knowledge.** Refers to *knowing* materials (e.g., knowledge of properties, knowledge of applications)
- **Values.** Refers to *valuing* materials (e.g., appreciation, consequences of decisions, conscience to accompany knowledge)
- **Skills.** Refers to *using* materials (e.g., identifying, selecting, fabricating)

Norman's agenda does not explicitly refer to an element of *understanding*, but it is implied that comprehension of the significance of what one knows is a necessary step towards capability.

Material Knowledge

The content of materials knowledge for design may be divided into two main categories:

- **Intrinsic (or innate) aspects of materials.** These can be sensed or tested from samples of matter and comprise what is understood as "engineering material properties."
- **Extrinsic (or immaterial) aspects of materials.** These are labels given by organizations and people onto matter and refer to the "image" or "perception" of what a material is or represents.

The study of ways in which designers generate their knowledge, and in turn the various "forms" of knowledge that they consequently possess and express, is known as "design epistemology." The knowledge base for design and technological decision-making has for a long time been known to be incredibly diverse (Cross 2006), as exemplified by an apt historic quotation from Cross et al. (1981):

> Designers make use of a variety of kinds of knowledge, from scientific knowledge of the properties of materials to the in-effable craft knowledge (derived from apprenticeship, experience, trial and error etc.), which enables a skilled practitioner to say that a given design situation 'feels' right (or wrong). (p24)

It may be justifiably bold to say that successful designers can operate across the sciences and humanities: contrasting views on the world that Snow (1959) regarded within his "two cultures" model of knowledge as irreconcilable. Various commentators uphold the view that for effective decisions on material choices, designers must possess complementary forms of knowledge (Ashby and Johnson 2002; Lefteri 2007; Ward 2008). This materials knowledge may be acquired through several routes, illustrated in Fig. 1.

Of these knowledge acquisition routes, reading, listening, and looking lead to what is termed an explicit "knowing that." In contrast, touching, manipulating, and making lead to a potentially tacit "knowing how" or more simply "know-how" (Ryle 1963). The related concept to grasp here is the distinction between (i) *propositional knowledge* (*knowing-that*), encoded and communicated in numerical or descriptive language, and (ii) *empirical knowledge* (*knowing-how*), experienced as "sense data" (Russell 1929) emanating from a product or the materials of a product and often via exercising some kind of skill. These epistemological contrasts are illustrated in Fig. 2 and visited in more detail later in the chapter. Of course, these two principal knowledge types will inevitably have impact on other knowledge types used in technology and design activities, such as *procedural knowledge* and *conceptual knowledge* (McCormick 1997), though the particular interrelations are beyond the scope of this chapter.

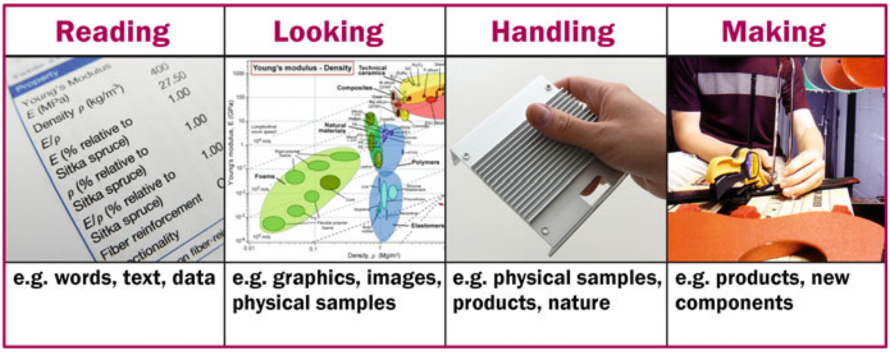
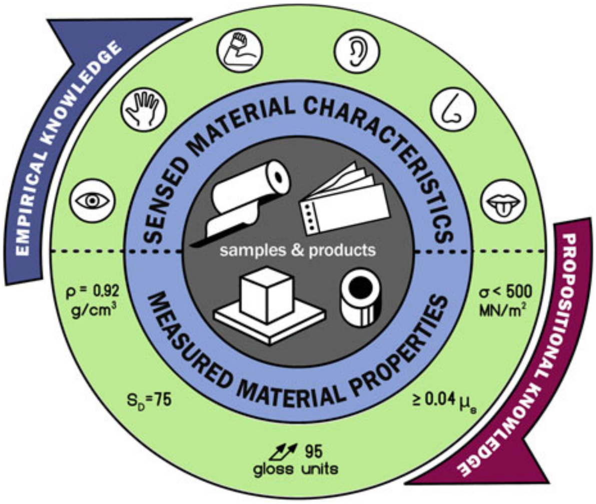


Fig. 1 Routes to acquiring materials knowledge

Fig. 2 Acquisition of empirical and propositional materials knowledge



Material Values

Values give a purpose, justification, and context to knowledge acquisition and expression. The most significant attempts to differentiate and categorize values in relation to design activity have been made by Archer and Roberts (1979), Hicks (1982), Roberts (1993), Norman et al. (2004), and Trimingham (2008). The latter was concerned with values in the specific context of recycled and reclaimed materials. Five categories of values emerge from these studies (technical, economic, aesthetic, moral/ethical, and hedonic), exemplified in Table 2. Values notionally span both “material” and “immaterial” aspects of materials.

It is important to note that a designer’s values and preferences are essentially a part of his/her *modus operandi.* After all, the sense possessed by a designer of what should be achieved and how, given that a multitude of options and directions could all be acceptable, is a strong reason for commissioning design in the first place. For example, how do individual designers feel about the origin of a material or the energy that goes into its reclamation and recycling? Are they driven by a truth to materials maxim? Do they much care for natural materials? Do they possess the same values as the people they are designing for? Explicitly Embedding values into design and technology education is an ideal way for students to appreciate the human/experiential dimension of materials.

Material Skills

Skills in relation to materials and design may be “practical oriented” (e.g. testing materials and making products from materials), or they may be “intellectual oriented” (e.g., identifying materials and selecting materials). Highly skilled

Table 2 Examples of designers' material values

Value category	Example value statement
Technical	"Polypropylene **is acceptable** for use in a musical instrument carry case, but it will be more prone to failure under impact loads than a comparable case manufactured from carbon fiber reinforced plastic." (i.e., values implicating durability)
Economic	"Our new range of music synthesizers have metal casings to achieve a high perceived value, even though plastic alternatives **would be cheaper** to implement." (i.e., values implicating production costs)
Aesthetic	"Shiny plastic looks terrible. Instead, a matted surface was chosen because gloss would **look really messy** and show all finger and smear marks." (i.e., values implicating user experiences)
Moral/ ethical	"We use wood sourced only **from sustainable plantations** and shipped by the most energy conserving means." (i.e., values implicating impact on the environment)
Hedonic	"**I always seek** a highly memorable tactual experience from the plastics I select for products." (i.e., values implicating the designer's personal gratification)

professionals are able to perform some activities without really thinking about them, having internalized the steps and processes of the activity.

Clearly there exists considerable differences and challenges in the learning and teaching of practical-oriented and intellectual-oriented skills, especially considering the developmental capacity of young school children. Practical-oriented and intellectual-oriented skills are notionally associated with the acquisition of empirical knowledge and propositional knowledge, respectively. These matters are discussed in greater detail in the following sections.

Propositional Knowledge of Materials (Knowing That)

Propositional knowledge is explicit (expressed in words, numbers, or other such language), disseminated (and therefore shared), objective and principled (beyond any single individual's claim to know), and proven (in the sense of tested). Acquisition of this form of knowledge dominates later years of formal education. Propositional knowledge of materials is acquired through familiarity with "technical" languages of materials developed by scientists and engineers, usually expressed in SI (Système Internationale) units as illustrated previously in Fig. 2. Such numerical coding of material properties allows universal understanding and adoption (Manzini 1986) and facilitates precise comparison, prediction, and calculation of material functionality and performance.

Information from which propositional knowledge is acquired is recorded external to the human mind (Rodgers and Clarkson 1998). Examples include websites, videos, and books, carrying information in a publicized and impersonal form, such as charts, rules, verified results, diagrams, selection tables, principles of application, data sheets, and catalogue information. It is known that scientific knowledge presented and acquired in such an impersonal state does not facilitate problem-solving, or for our purposes does not support technological decision-making. Scientific knowledge (of materials) instead needs to be learnt in specific contexts, combined with "other knowledge and judgments," (Layton 1993) and undergo conceptual deconstruction and reconstruction to be useful for "practical action" (i.e., to facilitate designing or making something). In other words, materials knowledge acquired propositionally must be placed into a real-world context if students are to make connections to their own design activities. Although such processes of translating or reworking scientific knowledge, illustrated in Fig. 3, exist across technological design activity from engineering (Vincenti 1990) to industrial design (Norman et al. 2004), there is certainly no implication here that it is "superior" to empirically derived materials knowledge.

It is also important to point out that propositional knowledge inherently keeps some "distance" from the subject matter that it refers to, especially in the case of physical phenomena such as materials and products. For example, one can learn about a product – for example, a particular music synthesizer – by reading a press release. One can learn *that* the instrument has 61 keys; *that* the action of the keys is "responsive;" *that* the mass of the instrument is 25 kg; *that* the sounds it produces are 'breathtaking," and *that* the instrument's color is an attractive shade of blue. But from all of this, one still does not really know the product, only *of* or *about* it. Similarly, a student may be instructed *that* to create a quality spray paint finish on a model, the surface must be prepared exquisitely and the paint must be applied in a series of thin layers. But possession of this knowledge is no guarantee that the same student will be able to achieve a high-quality finish on a model. Such reservations reveal the

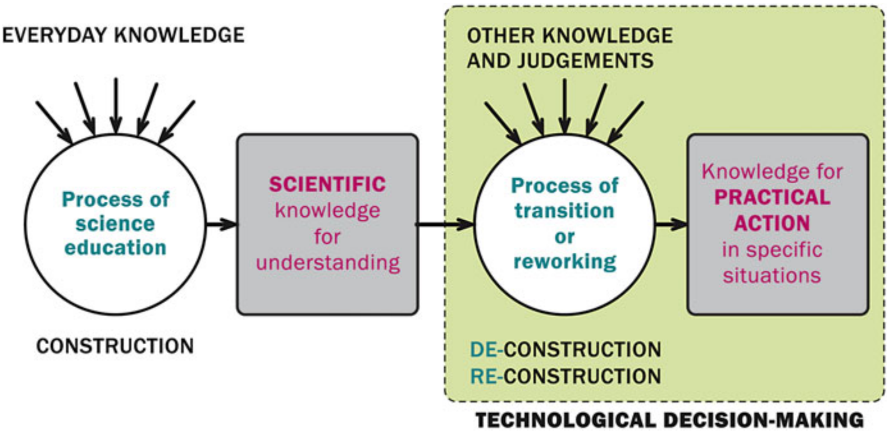


Fig. 3 Representation of Layton's de-/reconstruction of scientific knowledge, emphasizing the connection to technological decision-making

importance of balancing propositional knowledge with an *empirical* knowledge of materials and design.

Empirical Knowledge of Materials (Knowing How)

Engagement in practical activities allied to problem-based learning – variously known as learning-by-doing, vocational, empirical, or active learning (Felder and Brent 2009) – is known to be a major contributor to positive student experiences. It is one of the major traditions and attractions of design and technology education. Vitally, it gives opportunity to enliven potentially dull propositional approaches to learning and teaching of materials and design. Indeed, not all properties of materials can be encoded or verbally expressed, and even if such an attempt is to be made, it is quickly realized that there is no satisfactory replacement for first-hand experience of materials. A useful analogy here is in music: not all properties of music can be expressed through notation. It is only in the playing and listening that full appreciation is gained. From this perspective, direct experience of materials and the acquisition of "personal knowledge" (Polanyi 1983) can contribute to the contextual grounding necessary for practical application of propositional knowledge.

Empirical knowledge is neither codified nor usually amenable to verbal articulation because of the existence of a tacit dimension (Polanyi 1967). In other words, people are unable to say what it is they know or provide reasoned explanation for what they do, only that what they know or do is important to them. As mentioned in the section "Material Skills," the acquisition of empirical knowledge is closely tied to the development and exercising of skills (know-how), in the sense that a skillful hand, eye, ear, etc., will take care to learn and improve.

Design and technology students acquire empirical materials knowledge by touching, manipulating, comparing, evaluating, and fabricating materials. The human experiential dimension of materials is therefore omnipresent: viewing, pressing, flexing, pulling, knocking, smelling, and so forth, to understand not only surface properties but also bulk properties that permeate throughout a material to define its structural performance. Physical encounters facilitate a rich multisensorial appreciation of underlying material properties, known variously as "practical knowledge," "knowledge of the senses," and "knowledge of familiarity" (Dormer 1994). If Itten's thoughtful "theory of contrasts" (Itten 1963) regarding material learning is embraced, then students' sensitivity to sensorial qualities can be developed through exposure to polar opposite material properties (e.g., hard-soft, lightweight-heavy, bendy-rigid, rough-smooth, brittle-tough, strong-weak, shiny-dull). Knowledge generated this way is personally relevant, reflective, associative, and – not in a negative sense – subjective. From an educational viewpoint, there is a need to develop a portfolio of practical activities in which students can carry out and reflect upon task-based material appraisals (see section "Handling Existing Products") or design-and-make projects (see section "Designing and Making New Products"), linked to technical/performance and human/experiential learning objectives.

Handling Existing Products

A child's first experiences of the material world are through play, where personal knowledge is developed by handling and examining existing products without verbal communication (Eggleston 1998). Exploration through sensory interaction is a principle of the Montessori preschool system, where children are encouraged to explore the world of objects through discrimination of sensorial qualities of materials including smell, weight, color, texture, sound, and temperature (Morrison 2007). The most obvious recommendation for primary and secondary design and technology education is to ensure students have plenty of opportunities for physical encounters with materials. One way is to encourage the handling and evaluation of material samples and product exemplars (which may be everyday objects familiar to students) as a vehicle for learning material properties. In the related field of art, Focillon (1934) and Dewey (1980) emphasized the unique role of material engagement in the process of thinking and reflecting. In tertiary education and professional design practice, such engagement is achieved through the use of "material libraries" (Akin and Pedgley 2016).

Schools may invest in their own material libraries, based not on a diversity of material families (which is typically the case to promote creativity amongst professional designers) but instead on communicating a diversity of material properties. One specific route would be a school version of the *Expressive-Sensorial Atlas* created by Rognoli (2004, 2010), shown in Fig. 4. The atlas helps students make connections between sensed and measured material properties, by way of Itten's poles of contrast. For example, correlating "rigid" to a high value of Young's modulus or "non-stick" to a low coefficient of friction. Applied within a class setting, the atlas also helps explain discrepancies between subjectivity (of experience) and objectivity (of SI unit measurements).

It can be appreciated from the "focus" and "example content" columns of Table 1 that significant differences exist between the materials subject matter and materials tests of different disciplines. For materials and design engineering, tests involve taking measurements of performance with relevant equipment, sensors, experiment rigs, etc. For industrial design, tests are performed by observing and questioning people in relation to how satisfactory a material or material-product combination is and why.

Designing and Making New Products

Design and technology education comes to life through the prototyping and evaluation of products that are proposed as new and better. Practical "making activity" is prevalent throughout design and technology education, typically referred to as "design-and-make" (school level), "design-build-test" (tertiary level), and, within this, a specific initiative grown from engineering education known as "conceive-design-implement-operate" (CDIO 2016). Within the Program of Study in "Design and Technology" of the National Curriculum of England, "designing and making" is a recurring theme.

Fig. 4 Rognoli's Expressive-Sensorial Atlas in use © V. Rognoli

The physical modeling or fabrication of a product enables students to appreciate and learn firsthand the technical/performance and human/experiential dimensions of materials when embedded in something they have designed. Taken a step further, we can contemplate the emerging professional design practice of "material tinkering" and creation of DIY (do-it-yourself) materials (Rognoli et al. 2015) being transferred into a school environment. Such practical activities do of course require appropriate workshop facilities to be available within the school and for students to be trained and cleared for workshop activities (see section "Which Materials to Learn?") – which are both space and resource intensive. The main point here is that students would not be expected to assume a role of craftspeople, where there is little or no division between "thought" (intention) and "making" (action) (Glanville 2006). A return to "craft" within the predecessor English curriculum subject of "Craft, Design, Technology" is most definitely not being purported. Instead, firsthand exposure to working of materials should impart a sense of what it takes to turn material into a product, with specific intent to foster mindful connections between the separated professional and industrial activities of designing products and making those products. This is quite aside from prototypical making activities, which will inevitably be led by CAD, CAM, and 3D printing facilities.

Pillars for Student Materials Experience

This penultimate section brings together the work covered in the chapter into a graphical summary comprising three pillars of learning and teaching relevant to developing students' materials experience (Fig. 5). It is not intended to be definitive but rather offered as an opening for debate about how the student experience for materials can be shaped within design and technology education. One source that was influential in devising Fig. 5 was Harrison (2002), concerning the relationship of

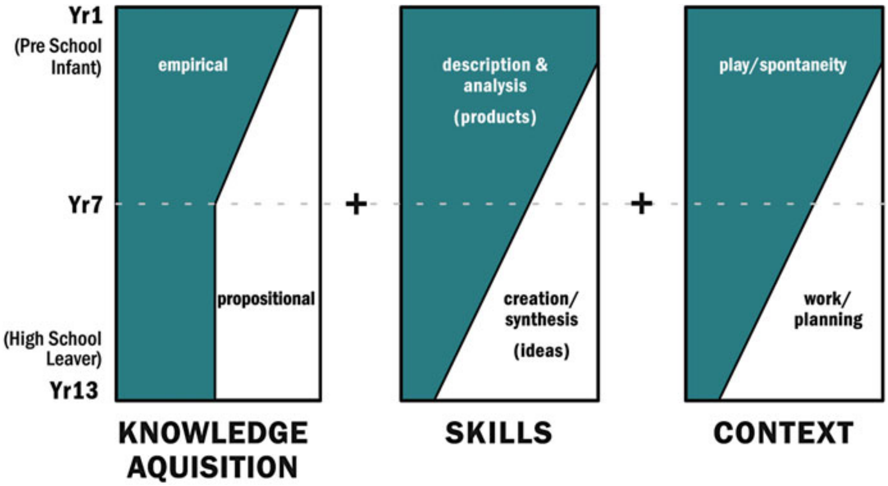


Fig. 5 Pillars for developing student materials experience

technology and designing from young children through to professional designers. What that work shows is technology (and hence technological learning) taking a general progression from the tacit to the articulate or from the experiential to the propositional.

Important work in university-level materials education (Ashby and Johnson 2002; Miodownik 2007) has flagged the need to develop in university students a correspondence between specific material properties and their likely gain – from technical and human dimensions – when used in a product. In professional design, what essentially happens is a cross-referencing of (i) user needs and desires that are (or can be) implicated in materials decisions, (ii) the experiential side of materials (how can materials be experienced?), and (iii) the underlying physical and chemical properties corresponding to those experiences. Imparting this three-way relationship at school level will be challenging and may benefit from cross-curricula initiatives with science lessons. Even in professional practice, integration of materials knowledge learned propositionally and empirically is not straightforward (Wilkes et al. 2016; Schifferstein and Wastiels 2014).

Inherent across the pillars of Fig. 5 is a practical approach to learning. "Play" and "curious exploration" are evidently important in professional designers' work, as Pedgley (1999) compiled from interviews, e.g., "always on the lookout," "constantly . . . cataloguing," asking "I wonder how that works?", "touch products . . . feel it . . . play with it," "you get ideas for materials . . . from seeing their application elsewhere." Accordingly, the "knowledge acquisition" and "context" pillars both give promotion to sensorial exploration of the world during secondary school, just as witnessed in childhood but with a guiding structure in place. The clear message here is to be alarmed if propositional learning is dominant over empirical learning of

Fig. 6 Resistant materials spectrum for design and technology

materials and design and associatively if technical dimensions are institutionally regarded as "more important to solve" than human dimensions.

Which Materials to Learn?

Materials for design and technological decision-making span the more obvious and visible applications (e.g., infrastructure, buildings and product external components) through to less obvious and visible applications (e.g., product internal components and finishes/coatings) – as illustrated in Fig. 6. To the designer-in-training, a wide "vocabulary" in materials is seen as a catalyst for increasing the quantity and diversity of ideas generated to a design brief (Alesina and Lupton 2010). Given the enormous variety of materials, which should be introduced to school students? The answer is usually pragmatic, being dictated by the physical and human resources of individual schools to deliver teaching and learning through "empirical approaches." In other words, with the proper staff expertise, workshop, and "fab-lab" facilities (which could be shared with other technology subjects such as electronics, robotics, ICT, CAD/CAM), it can be possible to offer "making" experiences not only in the core resistant materials of metals, plastics, and woods but also in more diverse families including composites, ceramics, stone, and smart materials. Materials that cannot be introduced through empirical approaches are of course candidates for propositional approaches to learning in the classroom (see section "Propositional Knowledge of Materials (Knowing That)").

Conclusion and Future Directions

Materials are inextricably linked to the success of new products. The study of materials within the frame of technology and design education must provide students with a clear window on the material world, through which they can not only competently appraise materials but crucially make effective connections between materials and new product ideas. One of the contributions of this chapter has been to lay out ways to transition from a culture of "imparting knowledge about materials" to a culture of "generating experience with materials." There exist international initiatives to develop "materials experience" as a formal subject of study at tertiary level, complementary to traditional technical and engineering approaches to materials and design education. These initiatives should be filtered down to secondary and primary levels of education.

One of the main points raised by this chapter is that primary and secondary education should encourage inquisitiveness about materials used in products. Materials can be introduced as a stimulus to learning about complex societal and global challenges requiring technological and designed solutions, such as healthcare, sanitation, housing, environmental preservation, and sustainability. Knowledge that materials perform vital functional tasks in our world should be balanced with an appreciation that a human experiential dimension is also integral to materials adoption and usage. However, separation of the two dimensions is rarely possible or desirable, reflecting the general complexity of design and technological decision-making.

Regarding delivery, computer-, paper-, or classroom-based learning and teaching is insufficient for a comprehensive understanding of materials and design. A substantial quantity of empirical learning is needed, centered on real-world contexts involving "handling existing products" and "designing and making new products." The major educational challenge is to develop bilingualism (and thus personal translations) between empirical and propositional materials knowledge and to complement the knowledge with values and skills. No exclusive connection exists between "what to know" (i.e., technical or human dimensions) and "how to know it" (i.e., propositionally or empirically). However, there is certainly a need to increase the underlying research and supply of quality curriculum resources to learn the human/experiential dimension of materials. Such underlying research will continue to come from the international networks and collaborations of university academics working in the field of materials and design.

Cross-References

► Design and Technology in England: An Ambitious Vision Thwarted by Unintended Consequences

References

Akin, F., & Pedgley, O. (2016). Sample libraries to expedite materials experience for design: A survey of global provision. *Materials and Design, 90*, 1207–1217.

Alesina, I., & Lupton, E. (2010). *Exploring materials: Creative design for everyday objects*. New York: Princeton Architectural Press.

Archer, B., & Roberts, P. (1979). Design and technological awareness in education. *Studies in Design Education Craft and Technology, 12*(1), 55–56.

Ashby, M., & Johnson, K. (2002). *Materials and design: The art and science of materials selection in product design*. Oxford: Butterworth-Heinemann.
Ashby, M., Shercliff, H., & Cebon, D. (2013). *Materials: Engineering, science, processing and design*. Oxford: Butterworth-Heinemann.
CDIO (2016). Retrieved from http://www.cdio.org
Cross, N. (2006). *Designerly ways of knowing*. London: Springer.
Cross, N., Naughton, J., & Walker, D. (1981). Design method and scientific method. In R. Jacques & J. Powell (Eds.), *Design: Science: Method* (pp. 18–29). Guildford: Westbury House.
Dewey, J. (1980). *Arts as experience*. New York: Perige Books.
Doordan, D. (2003). On materials. *Design Issues, 19*(4), 3–8.
Dormer, P. (1994). *The art of the maker: Skill and its meaning in art, craft and design*. London: Thames & Hudson.
Eggleston, J. (Ed.). (1998). *Learning through making: National enquiry into the value of creative practical education in Britain*. London: Crafts Council.
Felder, R., & Brent, R. (2009). Active learning: An introduction. *ASQ Higher Education Brief, 2*(4).
Focillon, H. (1934). *Vie des Formes (life forms)*. Paris: Presses Universitaires de France.
Glanville, R. (2006). My last words for this week. Posting to ahrc-workshop-pl@jiscmail.ac.uk. Retrieved from http://www.jiscmail.co.uk.
Harrison, G. (2002). *The continuum of design education for engineering*. London: The Engineering Council.
Hicks, G. (Ed.). (1982). *Understanding design and technology*. London: APU (Assessment of Performance Unit).
Itten, J. (1963). *Design and form*. New York: Van Nostrand Reinhold.
Karana, E., Hekkert, P., & Kandachar, P. (2008). Materials considerations in product design: A survey of crucial materials aspects used by product designers. *Materials and Design, 29*(6), 1081–1089.
Karana, E., Pedgley, O., & Rognoli, V. (2014). *Materials experience: Fundamentals of materials and design*. Oxford: Butterworth-Heinemann.
Layton, D. (1993). *Technology's challenge to science education: Cathedral, quarry or company store?* Buckingham: Open University Press.
Lefteri, C. (2007). Ingredients no:2 – A materials project. Retrieved from http://moreingredients.com
Manzini, E. (1986). *The material of invention*. Milan: Arcadia Edizioni.
McCormick, R. (1997). Conceptual and procedural knowledge. *International Journal of Technology and Design Education, 7*(*1*), 141–159. doi:10.1023/A:1008819912213.
Miodownik, M. (2007). Toward designing new sensoaesthetic materials. *Pure and Applied Chemistry, 79*(10), 1635–1641.
Miodownik, M. (2009). Materials in the creative industries. Retrieved from http://www.matuk.co.uk/docs/MaterialsUK-CreativeIndustries.pdf
Morrison, G. (2007). *Early childhood education today*. New Jersey: Pearson Prentice-Hall.
Norman, E. (1998). The nature of technology for design. *International Journal of Technology and Design Education, 8*(1), 67–87.
Norman, E., Pedgley, O., & Coles, R. (2004). Design decision-making and materials: Research agendas and gathering evidence. *The Journal of Design and Technology Education, 9*(2), 107–115.
Pedgley, O. (1999). *Industrial designers' attention to materials and manufacturing processes: Analyses at macroscopic and microscopic levels.* Unpublished doctoral thesis, Loughborough University.
Pedgley, O. (2010). Invigorating industrial design materials and manufacturing education. *METU Journal of the Faculty of Architecture, 27*(2), 339–360.
Pedgley, O., Rognoli, V., & Karana, E. (2015). Materials experience as a foundation for materials and design education. *International Journal of Technology and Design Education*. doi:10.1007/s10798-015-9327-y.
Polanyi, M. (1967). *The tacit dimension*. London: Routledge & Kegan Paul.
Polanyi, M. (1983). *Personal knowledge*. London: Routledge.
Roberts, P. (1993). *The Royal College of Art schools technology project: Project paper – the purposes of design and technology in education*. London: Royal College of Art.

Rodgers, P., & Clarkson, P. (1998). Knowledge usage in new product development (NPD). In J. Smith & E. Norman (Eds.), *IDATER98: Proceedings of the international conference on design and technology educational research and curriculum development* (pp. 252–258). Loughborough: Department of Design and Technology, Loughborough University.

Rognoli, V. (2004). *The expressive-sensorial characterization of materials for design.* Unpublished doctoral thesis, Politecnico di Milano, Italy.

Rognoli, V. (2010). A broad survey on expressive-sensorial characterization of materials for design education. *METU Journal of the Faculty of Architecture, 27*(2), 287–300.

Rognoli, V., Bianchini, M., Maffei, S., & Karana, E. (2015). DIY materials. *Materials and Design, 86*, 692–702.

Russell, B. (1929). *Mysticism and logic*. New York: W.W.Norton & Company.

Ryle, G. (1963). *The concept of mind*. Harmondsworth: Penguin. (first published 1949).

Schifferstein, H., & Wastiels, L. (2014). Sensing materials: Exploring the building blocks for experiential design. In E. Karana, O. Pedgley, & V. Rognoli (Eds.), *Materials experience: Fundamentals of materials and design* (pp. 15–26). Oxford: Butterworth-Heinemann.

Snow, C. (1959). *The two cultures*. London: Cambridge University Press.

Trimingham, R. (2008). The role of values in design decision-making in design and technology education. *Design and Technology Education: An International Journal, 13*(2), 37–52.

Vincenti, W. (1990). *What engineers know and how they know it: Analytical studies from aeronautical history*. London: The John Hopkins University Press.

Ward, J. (2008). Materials in art and design education. Retrieved from http://www.iom3.org/fileproxy/37527

Wilkes, S., Wongsriruksa, S., Howes, P., Gamester, R., Witchel, H., Conreen, M., Laughlin, Z., & Miodownik, M. (2016). Design tools for interdisciplinary translation of material experiences. *Materials and Design, 90*, 1228–1237.

26 Teaching Electronics: From Building Circuits to Systems Thinking and Programming

Moshe Barak

Abstract

This chapter addresses a number of reforms in teaching electronics in school to reflect the technological changes and objectives of education in the twenty-first century. One necessary reform in the electronics curriculum is the shift from the traditional teaching of basic components and circuits to teaching electronic systems such as sound, control, and communication systems, with a focus on understanding general technological concepts such as control, feedback, amplification, conversion, modulation, and filtering of electronic signals. A second reform required in teaching electronics relates to highlighting the STEM viewpoint, particularly physics and mathematics, which are an integral part of electronics. A third expected reform in teaching modern electronics is the transition from using conventional electronics hardware to programmable devices such as the field-programmable gate array (FPGA) or the Arduino microcontroller. The use of programmable controllers opens up tremendous possibilities for student projects, such as control systems and robotics, and for STEM-oriented studies, such as computerized physics and chemistry labs. A fourth change in the focus of teaching electronics is placing greater emphasis on project-based learning (PBL) in the electronics class. However, one must take into consideration that the new technologies may also lead to "doing without learning," and students must acquire some basic knowledge and skills before being able to cope with advanced technologies and PB. In summary, electronics offers a rich, flexible, and friendly learning environment for teaching technology and engineering in K-12 education and for fostering students' broad competences such as design, problem solving, creative thinking, and teamwork.

M. Barak (✉)
Department of Science and Technology Education, Ben-Gurion University of the Negev, Beer Sheva, Israel
e-mail: mbarak@bgu.ac.il

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_29

Keywords
System thinking • STEM • Simulation • Embedded engineering • Project-based learning • Task taxonomy • Teachers' professional development

Contents

Introduction

The term electronics has to do with almost every aspect of modern life, such as home instrumentation, communication systems, media, industry, transportation, aviation, medicine, and scientific research. In light of the central role electronics plays in everyone's lives, in the economy, and in society, it is almost unreasonable to talk about technology and technology education without including electronics. But what is electronics? What are the objectives of teaching this subject in K-12 education? How can teaching this subject reflect the electronics that children today encounter in their daily lives? This chapter aims at partially addressing these questions by examining the historical development of electronics and electronics today and suggesting some reforms in teaching this field in the educational system.

A Brief History of Electronics

The history of electronics can be described briefly from a bird's eye view through the following time periods:

600 BC–1900	The investigation of electricity and magnetism and the invention of the first wireless telegraph and radio systems

(*continued*)

1900–1940	The invention of the vacuum tube, triode, and electronic amplifier, which enabled the development of radio, television, and electronic control systems
1940–1960	The invention of the semiconductor diode and transistor, which were the basis for modern analog and digital electronic technologies
1960–1980	The invention of integrated circuits, very-large-scale integration (VLSI) technology, and the microprocessor, which pushed forward the development of microcomputers, communication systems, medical equipment, video cameras, personal computers, and mobile phones
1980–2010	Further development of advanced microprocessors, microcontrollers, field-programmable gate array (FPGA) integrated circuits, and storage technologies, which made digital technology and communication devices available to anyone, anywhere

In view of the rapid development of the electronics world, and digital electronics in particular, some questions arise, for example: How could teaching electronics cope with this rapidly developing field? What are the specific concepts and skills students should gain by learning electronics?

A broader question that arises is to what extent and how could teaching electronics contribute to achieving the objectives of education in general, and technology education in particular, including:

- Developing an individual's personality and capabilities
- Imparting to the school graduate the knowledge, skills, and motivation to integrate into society and support him/herself
- Attracting talented students to choose a career in science and engineering

This paper addresses some of these questions by suggesting innovative approaches for teaching electronics in K-12 education.

From Component to Systems: Fostering Systems Thinking via Electronics Studies

In the past, an electronics course often started out with learning about specific components – the resistor, diode, and transistor. In the lab, students were carrying out "experiments" to check a component's properties or build simple analog and digital circuits, as illustrated in Figs. 1 and 2.

In recent years, however, educators came to understand that teaching electronics in this way is not very attractive to students because it takes months and years before they encounter practical electronic devices they know from their daily lives.

An alternative method is to commence an electronics course by teaching about a familiar electronics system, such as the sound system shown in Fig. 3.

In the lab, the students can deal with assembling a system, checking its properties, or adding connections to listen to music from their smartphone. Later on, the students might learn about and test more closely specific components in the system, such as the microphone or the amplifier. Only students who major in electronics will learn about electronic circuits and components later in detail.

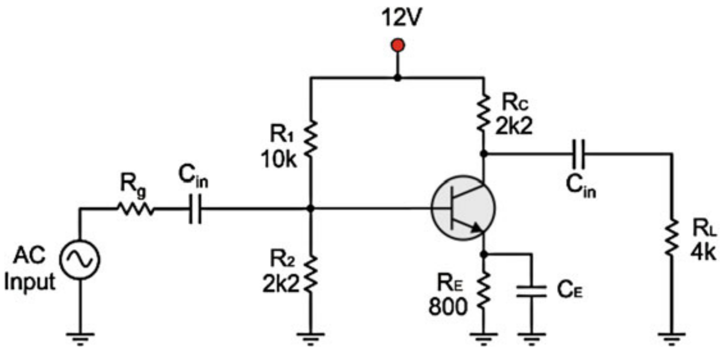


Fig. 1 Basic analog electronic amplifier with discreet components

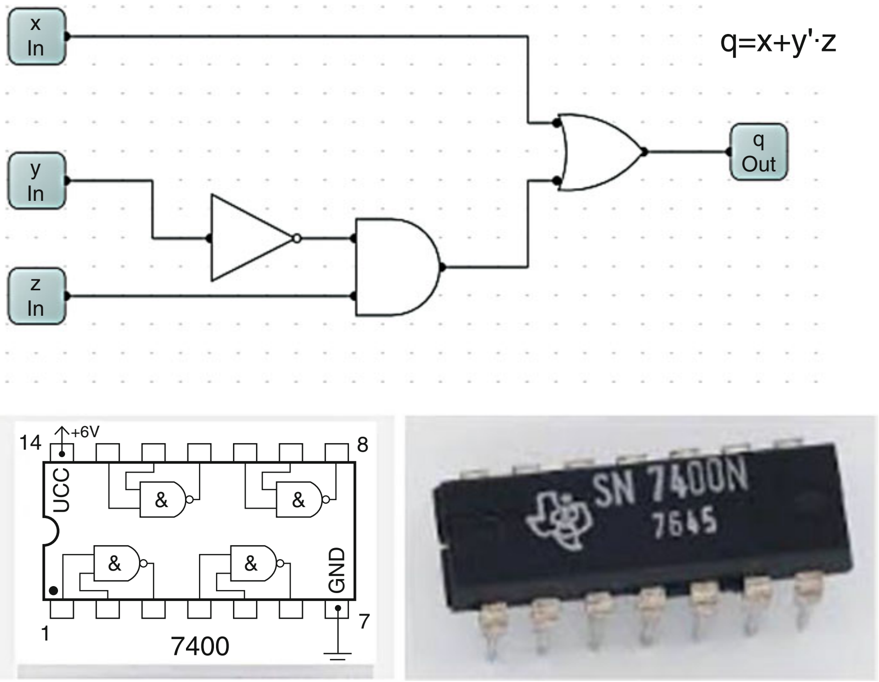


Fig. 2 Basic digital circuit with logic gates (NOT/AND/OR) and integrated circuits

The change in the teaching method of electronics described above could be referred to as adopting the paradigm of "from systems to components" instead of the traditional teaching method of "from components to systems." The "systems" paradigm also includes describing a system using a block diagram, as illustrated in Fig. 4.

Fig. 3 A sound system

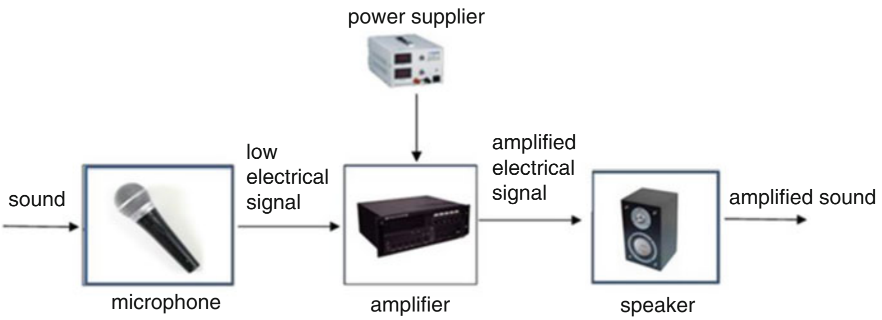


Fig. 4 Block diagram of a sound system

The system approach in teaching electronics described above has to do with **teaching systems thinking** – a central concept in technology and engineering (Frank 2002; Frank and Elata 2005; Rossouw et al. 2010). Barlex and Steeg (2007) described "systems thinking" together with "programmable systems" and "communication technologies" as the core electronics "big ideas" that underpinned the approach taken by Electronics Education in Schools (EEiS) developed in England. Chan (2015) stated that the term "systems" relates not only to man-made systems but also to systems in other areas such natural systems (Tripto et al. 2016) and management systems. Systems created by humans are put together to achieve a purpose, while the purpose imputed to natural systems serves man's view of the world and his relationships with nature.

Systems thinking involves identifying and understanding a number of concepts, such as:

- Parts and structure of a system
- Factors that are important to an outcome
- The big picture or “macro view”
- System boundaries
- Function and behavior
- Feedback in a system
- System dynamics
- Nonfunctional properties, such as safety and reliability, which arise from interactions between parts of a system

According to Chan (2015), systems thinking allows one to comprehend how all pieces of a system fit together to explain a phenomenon, or how all the parts act to produce the intended effect. It is said that the ability of “seeing the forest for the trees” could help an individual solve a problem in a balanced, holistic way, rather than narrowly focusing one only aspect of the problem.

The above examples of systems thinking in electronics demonstrate that teaching electronics could be an effective platform for fostering technological systems thinking, which is an essential factor in fostering design and problem-solving competences.

From Electronics to Science, Technology, Engineering, and Mathematics (STEM) Education

The term STEM education expresses the idea of teaching subjects in science, technology, engineering, and mathematics in an integrated approach, rather than as separate subjects. An increasing number of reports and research papers have been stressing that STEM education is crucial for twenty-first century citizens (National Research Council 2011; Berlin and White 2010). However, as English (2016) points out, the STEM acronym is often used in reference to just one of the disciplines, commonly science. Although the integration of STEM disciplines is being increasingly advocated in the literature, studies that address multiple disciplines appear scant with mixed findings and inadequate directions for STEM advancement, and the method or level of integrating the teaching of S, T, E, and M subjects seems vague to a great extent. English (2016) distinguished between four levels of integrating STEM subjects:

1. **Disciplinary** – Concepts and skills are learned separately in each discipline.
2. **Multidisciplinary** – Concepts and skills are learned separately in each discipline but within a common theme.
3. **Interdisciplinary** – Closely linked concepts and skills are learned from two or more disciplines with the aim of deepening knowledge and skills.
4. **Transdisciplinary** – Knowledge and skills learned from two or more disciplines are applied to real-world problems and projects, thus helping to shape the learning experience.

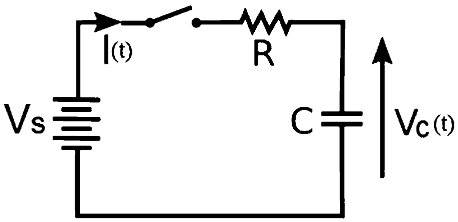


Fig. 5 A typical RC circuit learned both in physics and electronics courses

Electronics is a natural platform for the integration of STEM subjects in levels 3 and 4 mentioned above, for several reasons. First, electronics is strongly based on physics knowledge and concepts, for example, electrical charge, field, current, voltage, electromagnetism, sound waves, and electromagnetic waves. Second, electronics is heavily based on mathematics, for example, algebra, geometry, trigonometry, logarithms, exponential functions, and differential equations. Third, electronics is one of the major engineering fields, which involves using science and mathematical tools for specification-based systems design, optimizing the use of materials and energy, and analyzing products' and systems' safety and reliability. Fourth, electronics relates closely to control systems analysis and design, which is also based comprehensively on mathematics and physics. For example, Barak and Williams (2007) show a case of using mathematics and physics for analyzing dynamic processes in technological systems – temperature change vs. time in heating an object and volume change and flow vs. time in filling water in a tank. These points are often learned in control systems courses and as analogies to electronic circuits.

The following example of analyzing the response of a resistor and capacitor (RC) circuit shown in Fig. 5 demonstrates the integration of physics and mathematics in electronics studies.

Equations 1 and 2 below illustrate the relationship between current I(t) and capacitor voltage Vc(t) in a circuit. Equations 3 and 4 show the circuit response, namely, the change of Vc(t) and I(t) vs. time, as illustrated in Fig. 6.

Eq1: $I(t) = C \cdot dVc(t)/dt$	The relationship between current I(t) and capacitor voltage Vc(t)
Eq2: $Vc(t) + RC \cdot dVc(t)/dt = Vs$	Circuit equation
Eq3: $Vc(t) = Vs(1 - e^{-t/RC})$	Change of capacitor voltage Vc vs. time
Eq4: $I(t) = \left(\frac{Vs}{R}\right)e^{-t/RC}$	Change of the current I vs. time

Students who take courses in both electronics and physics might study this circuit twice, with a different focus and often with different teachers. While physics teachers tend to foster conceptual knowledge, for example, the change in electric field and energy in a capacitor, electronics teachers often stress procedural knowledge, for example, calculating current, voltage, or response time in the circuit and using this circuit for creating a time delay in electronic systems. Mathematics teachers rarely show examples in the class from physics or electronics. However, small

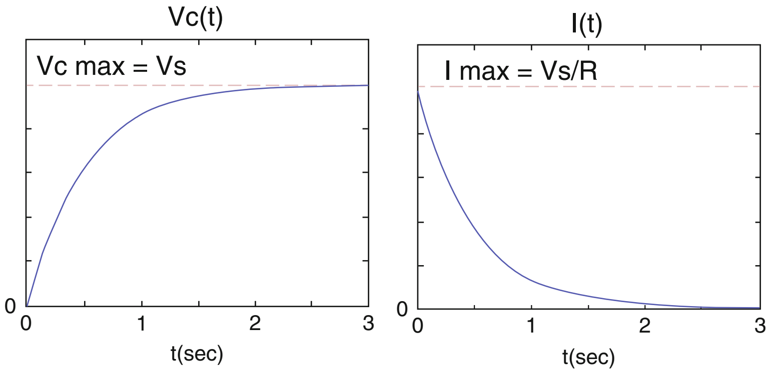


Fig. 6 Response of an RC circuit

modifications in teaching the theory, lab experiments, and students' assignments could reduce this gap and turn this subject into an example of real STEM learning.

While the above example shows how small changes in the traditional electronics, physics, and mathematics curriculum could help in fostering STEM learning, there is also room for developing STEM-oriented programs in the context of science and technology education for primary and middle school levels. Awad and Barak (2014) developed a 30-h course on "sound, waves, and communication systems" (SWCS) aimed at junior high school (middle school) classes. The course was designed to provide junior high school students with scientific concepts such as transitive wave, longitude wave, period (T), frequency (f), wavelength (λ), amplitude (A), sound velocity (v), and sound propagation on different materials or states of matter, as well as technological concepts such as sound system, microphone, speaker, amplifier, analog to digital conversion, and digital sound.

In the lab, the students are engaged in the following activities:

- Testing the effect of air density on sound propagation by a vacuum jar
- Connecting a temperature sensor to a computer and sampling the temperature change versus time using the MultiLab software program
- Constructing a magnetic microphone and lowed speaker
- Connecting a microphone to a computer and measuring sound velocity using the Audacity software program (Fig. 7)
- Constructing and testing an electronic kit of an electronic tweet bell (Fig. 8)

The SWCS course described above presents an example of an integrated program for learning STEM subjects with electronics at its center. Students take great pleasure in assembling a technological system or building small "personal" artefacts, which is done easily in electronics. Using computers for simulation, signal measuring and analysis also helps in learning and promoting students' motivation, as will be discussed in the following sections.

Fig. 7 Connecting a microphone to a computer and analyzing sound waves using the Audacity software program

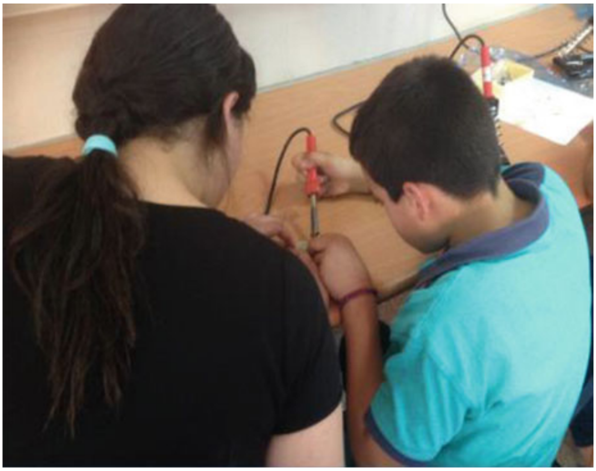


Fig. 8 Students working in the lab

From Hands-on to Computer Interactive Simulation

Promoting the use of information and computer technologies (ICT) for teaching and learning is considered an important objective of education today. Teaching electronics goes hand in hand with using computer technologies because modern electronics is strongly associated with digital technologies. According to Bing et al. (2016), electrical design automation plays an important role in today's electronic industry. Swenson et al. (2016) show that using simulations has become an important tool in technology, engineering, and design education classrooms. Many professional simulation software programs in electronics, suitable for use by students and teachers in K-12 education, are available on the network for free or at a low cost.

Following are some examples of using computer simulation for the design and analysis of electronic circuits. Figure 9 shows an oscillator circuit design using the Micro-Cap simulation software program. The plot of the output signal shows the transient response during which the oscillations are created and the steady-state signal. The learner can easily change the values of the components in the circuit, for example, the coil u or the capacitor c1, and explore the effect of these changes on the output signal.

Figure 10 shows the use of the Electronic Workbench (EWB) software program for the simulation of a circuit including a resistor, coil, and alternating current source. The input and output signals are measured with an oscilloscope.

In the example shown in Figs. 10 and 11, a student can change parameters in a circuit, such as signal frequency or resistor and coil values, and examine how these changes affect signals in the circuit, such as the shift phase of the output voltage in comparison to the input signal.

Figure 12 illustrates a simulation of a logic circuit – one-bit full adders, using the Logicly software program. The software also automatically creates a truth table and Karnaugh map (logic circuit simplification) for the circuit.

Yusof et al. (2012) show the advantages of asking students pre-laboratory questions in the form of computer simulation related to the experiment in order to assist them in their preparation prior to entering the laboratory and to enable them to understand the experiment objectives. In a field study exploring the use of simulation in comprehensive high schools (Barak 2004), electronics teachers mentioned a range of possible applications of computer simulations in electronics studies, including:

- Demonstrating or "verifying" theoretical laws, such as Ohm's law or Kirchhoff's law for solving electrical circuits
- Comparing the response of "practical" versus "ideal" components (which are available only in the simulation)
- Experiencing troubleshooting, such as finding a hidden fault in components or circuit connections
- Investigating advanced electronic circuits or phenomena that are too complex for theoretical analysis in high school, such as unstable circuits, noise effects, response of nonlinear circuits, or spectral analysis of AM and FM radio signals

In the interviews held with the students in the same schools, they were asked how they used the simulation and how the simulation helped them in their electronics studies. The students seldom mentioned the kind of ideas their teachers had suggested but rather raised other points of using the simulation, such as:

- Confirming the results of their solutions for theoretical homework exercises
- Drawing electronic circuits for preparing homework or laboratory reports
- Preparing project portfolios, including circuit design and analysis

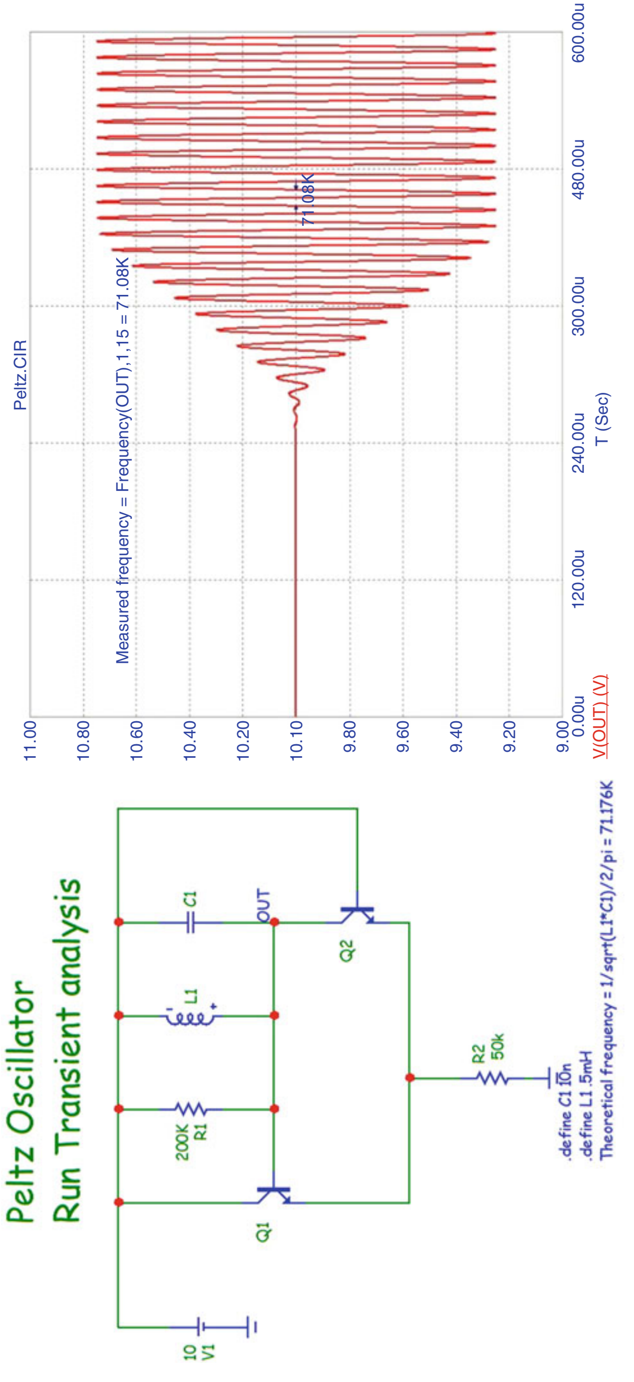


Fig. 9 Simulation on an electronic oscillator using the Micro-Cap software program

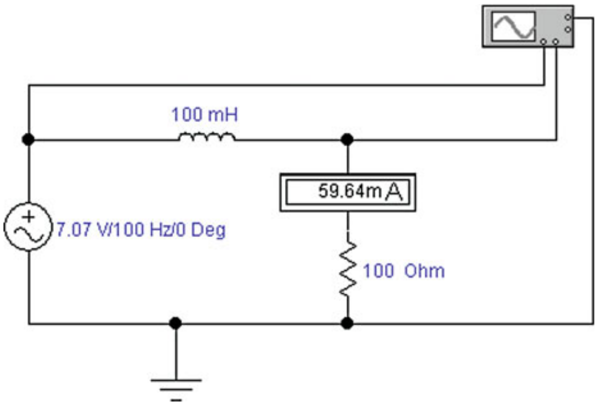


Fig. 10 Simulation of an alternating current circuit using the Electronic Workbench (EWB) software program

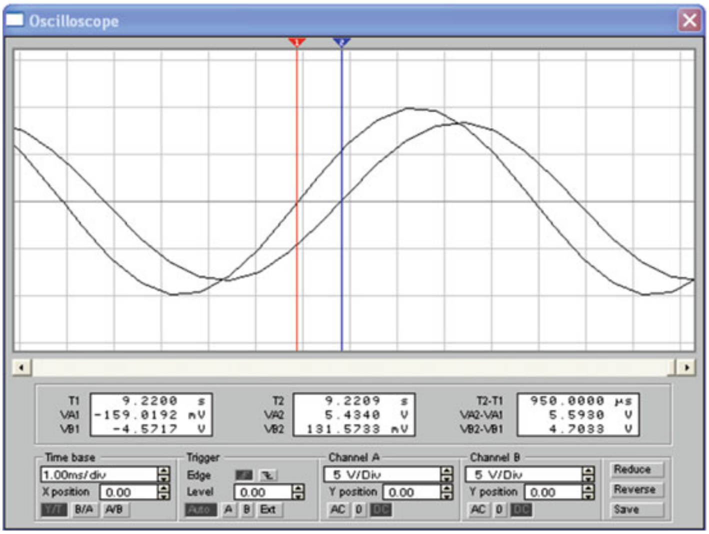


Fig. 11 Simulation of an oscilloscope using the Electronic Workbench (EWB) software program

It is worth mentioning that many sketches of incomplete circuits were found in the students' notebooks, such as circuits missing a connection to a power supply or a "ground" point. This shows that the students often used the simulation just as a drawing tool and did not always test the response of the circuit they had drawn.

A problematic point that came out in the above study was that using simulation gradually became a substitute for practical lab work. In this regard, the teachers had the following comments:

- The simulation draws the students away from the real electronics world.
- The computer cannot replace physical contact with real components.

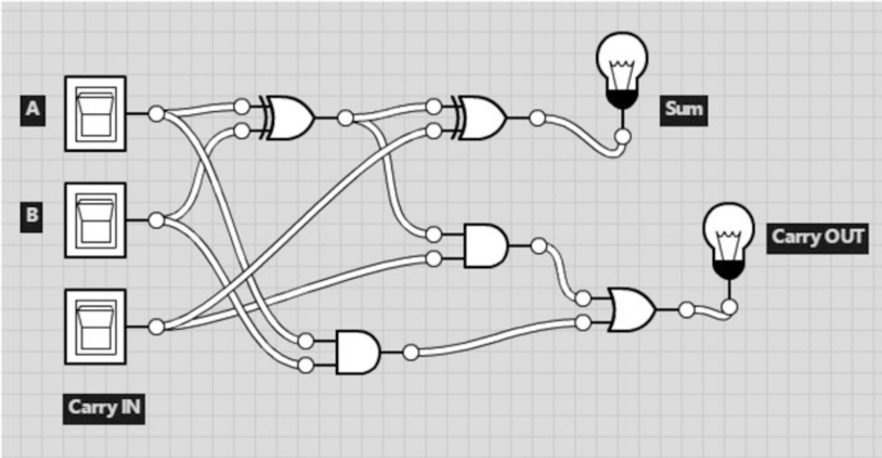


Fig. 12 Simulation of a one-bit full adder using the Logicly software program

- A real technician must from time to time sense the smell of a burnt resistor.
- The electronics laboratory must again take on its central role in the school.

Although the abovementioned study took place more than 10 years before writing this paper, the advantages and limits of using simulations in electronics studies are still relevant today. Moreover, the increased use of programmable devices for electronics applications, discussed in the following section, even worsened the problem of excluding students from the practical side of electronics.

From Dedicated Circuits to Embedded Engineering and Programmable Devices

As mentioned in the brief history of electronics at the beginning of this chapter, among the most important electronics developments since the 1980s were microprocessors, microcontrollers and in-place programmable (field-programmable) devices, and embedded systems. These are digital devices that are installed in systems such as robots or digital cameras that can be programmed or reprogrammed by the customer without disassembling the device or returning it to the manufacturer. This is often a very important feature, as it can reduce the cost of debugging or updating a system. Today, many users are familiar with the process of downloading and installing updates or a brand new operating system on their computers, smartphones, or digital televisions. In the past, in contrast, device firmware was stored permanently in a system's electronic circuit boards and could not be changed in the field. Following are two examples of field-programmable devices used largely in the industry and education.

The Embedded Engineering Learning Platform (E2LP)

Embedded engineering learning platform (E2LP) is a system for learning computer engineering and electronics developed by a consortium of nine partners from academia and industry in a research study supported by the European Commission (Kastelan et al. 2014; Szewczyk et al. 2016; see also "Acknowledgments"). The E2LP system shown in Fig. 13 was designed to enable lab work in learning a wide range of subjects in computer engineering and electronics, such as embedded microprocessors and computer architectures programming, real-time digital signal processing (audio, video, and data), computer networks and interfaces, and system integration.

As seen in Fig. 13, the FPGA device can be programmed by the user via a computer. The user writes the required program and downloads it to the FPGA device, which can run it independently. Programming through the computer can take place using different tools, such as very high-speed integrated circuits hardware description language (VHDL).

The following simple example demonstrates how the logic circuit illustrated in Fig. 14 is created by programming the FPGA device (Fig. 15).

The first part of the program defines two inputs, iA and iB, and internal variable sS and one output, oY.

The second part defines the logical operations.

$$S = \text{iA and iB}.$$

$$\text{oY} = \text{not}\ (S).$$

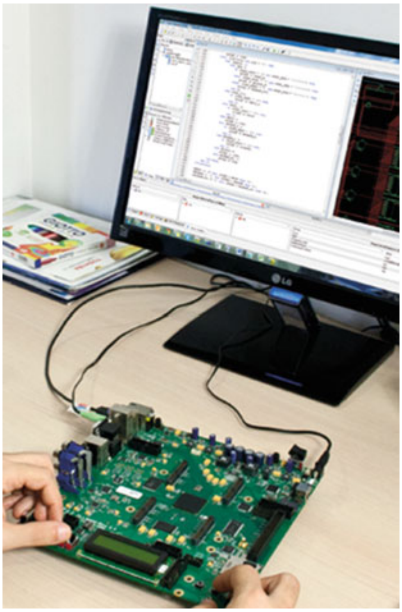


Fig. 13 The embedded engineering learning platform (E2LP)

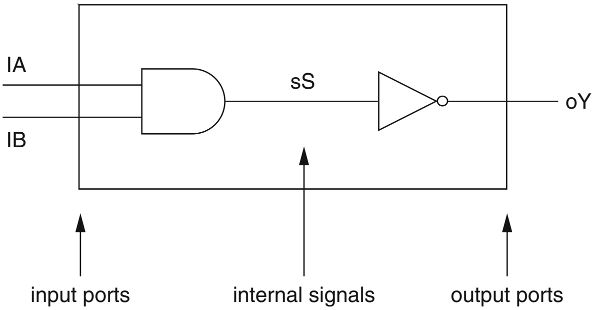


Fig. 14 The logical function oY = not(iA and ib)

Fig. 15 An example of programming the FPGA device

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;


entity lab_1 is
   Port ( iA : in  STD_LOGIC;
          iB : in  STD_LOGIC;
          oY : out  STD_LOGIC);
end lab_1;

architecture Behavioral of lab_1 is
signal S : STD_LOGIC;
begin
S <= iA and iB;
oY <= not(S);
end Behavioral;
```

Since the E2LP system described above might look relatively complicated for use in K-12 education, it is worth showing a simpler option as well, as presented in the following section.

Arduino: A Simple Low-Cost Programmable Device

Arduino is a simple, low-cost programmable microcontroller used increasingly for learning electronics and control application in the tertiary, secondary, and middle schools (D'Ausilio 2012; Lee and Fish 2013).

Arduino boards are able to read digital and analog inputs, for example, from a light sensor, and control a number of outputs, for example, activating on/off a LED, as illustrated in Fig. 16. Programming the controller is done by Arduino programming language and software.

Arduino and similar devices are offering tremendous options for building electronics and control systems at all educational levels. This method is also suitable for learning science, for example, computerized physics and chemistry labs (Mabbott 2014;

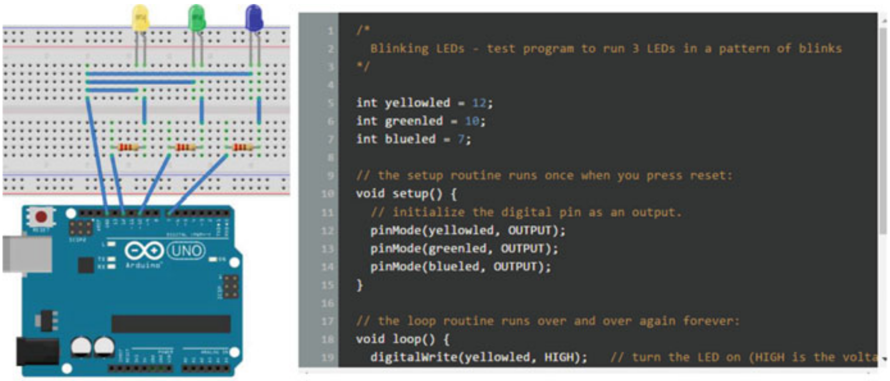


Fig. 16 Using the Arduino programmable device to create a blinking LED application

Kubínová and Šlégr 2015a, b), in STEM learning mentioned earlier in this chapter, as well as project-based learning (PBL) discussed in the following section.

From Traditional Teaching to Project-Based Learning

Over the past few decades, science and technology education has increasingly advocated the advantages of problem-based learning and project-based learning (PBL) over traditional teaching in school (Thomas 2000). PBL is derived from constructivist learning theories emphasizing that learning is a process of knowledge construction, not of passive acquisition of facts and roles (Von Glasersfeld 1988). Learning occurs when students address subjects meaningful for them in a real-world setting. The importance of active experience with objects as a means of developing thinking was stressed by Dewey (1963). Constructionism is a theory that expands on the concept of constructivism by placing critical emphasis on the construction of knowledge through designing and building artifacts and systems that are personally meaningful and that can be shared with others (Papert 1980, 1990). Vygotsky's (1978) sociocultural approach suggested that social and cultural interactions are critical to cognitive functions. A constructivist learning environment engages learners in knowledge construction through collaborative activities that embed learning in a meaningful context and through reflection on what has been learned from conversation with other learners.

Examples of Projects in Electronics

Preparing projects in electronics in general, and computer-based projects in particular, provides learners with endless options for developing new systems in subjects such as robotics and control systems for use at home ("smart home"), industry, agriculture, transportation, or aides for people with special needs. Following is an example of a project prepared by a pair of students at a high school in northern Israel in the summer of 2016. The students developed an alarm for leaving a baby in a car. Figures 17 and 18 show that the system includes an ultrasonic sensor that detects a baby in a car by measuring the distance from the sensor to the baby or the backrest of the empty baby's seat. The system is also connected to the car doors' sensors and the motor computer. The controller is programmed to identify cases in which a baby is sitting in the car seat, the car doors are locked, or the engine is off. The controller sends signals to:

1. The car computer to open the car windows automatically
2. Sound an alarm
3. A local GSM cellular card (with a SIM), which makes a phone call to the car owner

To develop the car alarm system described in Figs. 17 and 18, the students had to learn about the problem the system had to solve, methods of detecting a baby in a car, ultrasonic sensors, the interface with the car computer, Arduino controller inputs and outputs, and programming the device.

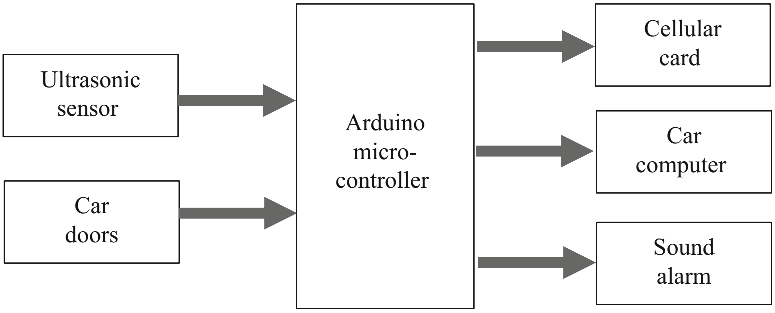
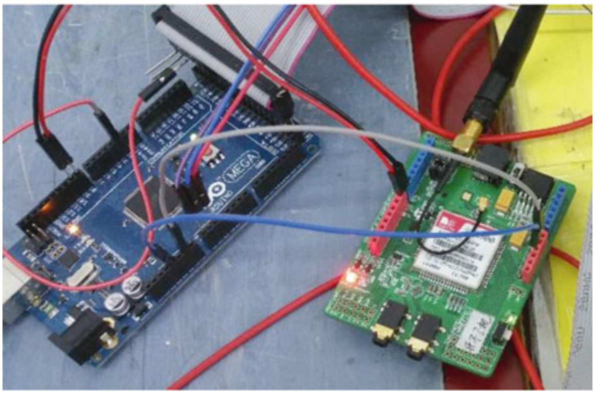


Fig. 17 Block diagram of an alarm for leaving a baby in a car

Fig. 18 Arduino connected to a cellular card to call the car owner in case a baby is left in the car



In the case described above, the students completed only part of the project, but one can see remarkable options for projects that students could develop in such a working environment. Other students in the class also prepared projects using the Arduino microcontroller, for example, a system that controls entering and exiting of car in a parking lot. The students collaborated in learning the Arduino microcontroller with the teacher's help. In the present study, as in a previous study that took place a decade ago (Barak 2005), it was found that students working on computer-based electronics projects tend to:

- Adopt flexible strategies, such as creating new ideas
- Take risks
- Improvise
- Use trial-and-error methods for problem solving
- Move rapidly from one design to another
- Transfer knowledge between students
- Jointly develop ideas

Students working on noncomputerized electronics projects, in contrast, are more likely to progress along a linear path: planning, constructing, troubleshooting, and improving.

Obstacles in Introducing Project-Based Learning in the Electronics Class

Although the literature broadly describes the advantages of PBL over traditional instruction, one must be aware of the difficulties of using this method in technology education and teaching advanced technologies such as robotics in general, and electronics in particular. The rapid development of this field and the appearances of new chips and easy-to-use technologies, devices, and software tools, as described throughout this chapter, are attracting teachers and students to deal with relatively complex projects. However, if the students are not well prepared in using the new technologies, or do not have the time, knowledge, or skills to study these subjects in depth, there is a danger of engaging them in "doing" complex projects while only little significant learning is taking place (Blumenfeld et al. 1991; Barak 2012). Booker (2007) uses the term "a roof without walls" to describe the desire to develop higher-order thinking skills (according to Bloom's taxonomy) of children who have not learned facts and gained substantive knowledge in a certain subject. A number of authors (Kirschner et al. 2006; Hushman and Marley 2015) write about the failure of constructivist-oriented instructional methods such as discovery, problem-based, and inquiry-based teaching because the notion of minimal guidance during learning does not work. Minimal guided instruction is less effective and less efficient than instructional approaches that place strong emphasis on guiding the student learning process. The advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide "internal guidance." Some supporters of PBL (Barak 2002; Hmelo-Silver 2004, Hmelo-Silver et al. 2007; Savery 2006) addressed this issue and mentioned that it is important to tailor the scope and complexity level of the assignments to the students' prior knowledge and skills and provide instruction and scaffolding in order to reduce cognitive load and enable students to learn in a complex domain. Crismond (2011) discusses in detail the constructivist versus the direct instruction dilemma in PBL and suggests using a hybrid method that combines the two instructional methods. The P3 task taxonomy described in the next section can also help in this regard.

The P3 Task Taxonomy

To adapt the level of tasks presented to students in learning advanced technological subjects and prepare students for PBL, it is suggested to distinguish between three levels of student assignments:

- **Practice**: Exercises and closed-ended tasks in which the solution is known in advance and the learners can check if they arrived at the correct answer.
- **Problem solving**: Small-scale, open-ended tasks in which students might use different solution methods and arrive at different answers.
- **Projects**: Challenging tasks in which the problem is ill-defined. Students take part in defining the problem, setting objectives, identifying constraints, and choosing the solution method.

An earlier version of this taxonomy was used for developing instructional materials such as lab experiments and projects in the E2LP projects for learning embedded and computer engineering at the university level (Barak et al. 2016; Kastelan et al. 2014). Barak and Assal (2016) used the P3 taxonomy for designing students' assignments in a robotics course delivered to junior high school students from heterogenic backgrounds in terms of prior learning achievements and motivation. The teacher let each student decide whether he/she would choose to take an "easy-," "medium-," or "high"-level project and determine what these levels meant to them. Consequently, it was found that only some of the students preferred to deal with preparing projects while others completed assignments only at the lower levels.

In summary, it is important to give students the opportunity to gain experience in handling assignments at the "practice" and 'problem-solving" levels ("mini projects") before engaging them in open-ended challenging projects or using the advanced programmable devices mentioned above. It is also suggested to take into account that some of the students need substantial help in coping with project work.

Electronics Teachers: Aspects of Initial Training and Professional Development

Electronics Teachers' Background

Teaching electronics requires a strong background in subjects such as electricity, magnetism, electrical circuits, electric motors, power systems, control systems, sensors, electro-optics, communication systems, analog electronics, digital electronics, microprocessors, digital controllers, programmable devices, and programing. As described by Williams (2009), a significant amount of diversity exists in technology teacher education programs around the world. Still, preservice training of electronics teachers often consists of two parts: (1) 3 or 4 years of studies toward a Bachelor of Science (BSc) in engineering, for example, electricity, electronics, mechanics, or computer engineering; and (2) 1 or 2 years of studies toward a teaching certificate or a Bachelor of Education.

A significant number of electronics teachers have some professional experience from working in industry, either before becoming a teacher or in parallel to teaching in school. An important source of technology teachers, and electronics teachers in particular, includes engineers and researchers retiring from work in advanced industries, or the so-called high-tech industry, after the age of 40 or 50 and who have chosen to become teachers as a second career. On the one hand, these teachers can bring with them the spirit of industry into the schools, serve as role models for the students, and give real-world answers to students' questions such as "why do we need to learn all this?" (Resta et al. 2001; Saltmarsh et al. 2009). On the other hand, these teachers, as well as many of the veteran electronics teachers, lack the knowledge required for introducing progressive teaching and learning pedagogies, as discussed in the following section.

The Need for Developing Teachers' Pedagogical-Content Knowledge

Shulman's (1986) distinction between content knowledge, pedagogical knowledge and pedagogical-content knowledge (PCK) is very helpful in the discussion of electronics teachers' knowledge. In the present case, updating content knowledge has to do with the teachers' need to learn state-of-the-art electronics as a way of life. Pedagogical-content knowledge relates to introducing both new electronics subjects and reform-based instructional methods into the class, such as project-based learning (PBL), and using ICT for teaching and learning. However, our experience shows that preservice and in-service training programs for electronics teachers often focus on updating teachers' content knowledge, while the need to change pedagogy is often left behind. Barak (2010) reported on an effort to cope with this issue by providing an in-service course (seven sessions of 3 h each) to three groups of 45 experienced electronics teachers in the south, center, and north of Israel. The participants learned subjects such as fostering higher-order thinking skills in the technology class, Bloom's taxonomy in the cognitive domain, an engineering-oriented problem-solving taxonomy (PST), types of knowledge in technology (propositional, procedural, conceptual, and qualitative), metacognition, motivation, and self-efficacy beliefs. New criteria for evaluating students' work in the spirit of fostering self-regulated learning (SRL) were also discussed. Of the 135 participants, only a few said that they had been exposed previously to terms such as higher-order thinking, metacognition, or reflection. Some teachers explicitly said that this was the first time they had participated in an in-service course that only dealt with pedagogical issues, instead of routinely learning new subjects in electronics or computers.

Summary and Conclusions

Electronics is definitely one of the central axes of modern technology. This field is unique in that hardware, software, computer simulation, and active real-time control of technological systems are simultaneously part of the technology subject matter learned and are tools for enhancing teaching and learning. The past distinction between "technology education" and "educational technology" is less relevant to teaching and learning electronics. Learning in the ICT environment and using computers to control electromechanical systems such as robots could help in developing students' broad learning skills, attracting them to learn technology, reducing gender or sociocultural gaps, and encouraging excellence among school graduates (Alha and Gibson 2003; Genlott and Grönlund 2016).

Since electronics is not a new subject in the school curriculum, it is important to highlight some reforms required in teaching this subject to reflect both the technological changes and objectives of education in the twenty-first century.

One necessary reform in teaching electronics is the need to stress the study of electronic systems rather than focus on learning basic analog and digital components and circuits, as is often found in schools. Today's curriculum should comprise, for example, learning about sound, control, and communication systems, with a focus on understanding general concepts in electronics and technology, such as control, feedback, amplification, conversion, modulation, and filtering electronics signals. There is still room for teaching specific discreet components such as the transistor, operational amplifier, or logic gates, either to demonstrate the theory or help in understudying the broader concepts mentioned above.

A second reform in teaching electronics is highlighting the STEM viewpoint much more now than in the past. Physics and mathematics have always been an integral part of learning electronics, but teachers emphasized this viewpoint only little. Among the steps that could help in achieving this goal are increasing collaboration between science, mathematics, and electronics teachers and developing an innovative interdisciplinary curriculum oriented to highlight the interaction between STEM subjects in technological class.

A third expected reform in teaching modern electronics is the transition from using conventional electronics hardware or dedicated integrated circuits to using programmable devices such as the field-programmable gate array (FPGA) or the Arduino microcontroller. The new generation of microcontrollers is programmed by universal programming tools such as the very high-speed integrated circuits hardware description language (VHDL) or object-oriented programming languages such as C++. An embedded engineering platform based on programmable microcontrollers often includes a range of digital and analog inputs and outputs for interface with other systems or external components such as sensors. The programmable controllers can be used easily for a wide range of applications, such as real-time control of electronic and mechanical systems, and for STEM-oriented studies such as physics and chemistry labs.

A fourth change in the focus of teaching electronics is placing greater emphasis on project-based learning (PBL) in the electronics class. The new computer-based technologies available today in schools are opening up unlimited possibilities for student projects in electronics and actually all technological areas. However, one must take into consideration that the new technologies may become a cover-up or trap of superficial learning; students still need to acquire some basic knowledge and skills before dealing with the development of advanced technological systems.

In summary, electronics offers a rich, flexible, accessible, safe, and friendly learning environment for teaching technology and engineering in K-12 education. Teaching electronics is not only about attracting talented students to integrate into these areas as a future profession but can also serve as one of the most advantageous learning environments for developing technological and computer literacy and fostering broad competences such as design, problem solving, creative thinking, and teamwork of all school graduates.

Acknowledgments The E2LP research mentioned in this chapter received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 317882.

References

Alha, K., & Gibson, I. S. (2003). Using ICT to improve the gender balance in engineering education. *European Journal of Engineering Education, 28*(2), 215–224.

Awad, N., & Barak, M. (2014). Sound, waves and communication: Students' achievements and motivation in learning a STEM-oriented program. *Creative Education, 5*(23), 1959–1968.

Barak, M. (2002). Learning good electronics, or coping with challenging tasks? Priorities of excellent students. *Journal of Technology Education, 14*(2), 20–34.

Barak, M. (2005). From order to disorder: The role of computer-based electronics projects on fostering of higher-order cognitive skills. *Computers & Education, 45*(2), 231–243.

Barak, M. (2010). Motivating self-regulated learning in technology education. *International Journal of Technology and Design Education, 20*(4), 381–401.

Barak, M. (2012). From 'doing' to 'doing with learning': Reflection on an effort to promote self-regulated learning in technological projects in high school. *European Journal of Engineering Education, 37*(1), 105–116.

Barak, M. (2004). The use of computers in technological studies: Significant learning or superficial activity? *Journal of Computers in Mathematics and Science Teaching, 23*(4), 329–346.

Barak, M., & Assal, M. (2016). Robotics and STEM learning: Students' achievements in assignments according to the P3 task taxonomy – Practice, problem solving, and projects. International Journal of Technology and Design Education.

Barak, M., & Williams, P. (2007). Learning elemental structures and dynamic processes in technological systems: A cognitive framework. *International Journal of Technology and Design Education, 17*(3), 323–340.

Barak, M., Kastelan, I., & Azia, Z. (2016). Exploring aspects of self-regulated learning among engineering students learning digital system design in the FPGA environment – Methodology and findings. In R. Szewczyk, I. Kastelan, M. Temerinac, M. Barak, & V. Sruk (Eds.), *Advances in embedded engineering education*. Heidelberg: Springer.

Barlex, D., & Steeg, T. (2007). *Developing engineers; The case of electronics education in English schools*. Paper for the IEEE International Summit "Meeting the growing demand for engineers and their educators 2010–2020", Munich, November 9–11.

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing With understanding: lessons from research on problem- and project-based learning. *The Journal of the Learning Sciences, 7*(3/4), 271–311.

Berlin, D. F., & White, A. L. (2010). Preservice mathematics and science teachers in an integrated teacher preparation program for grades 7–12: A 3-year study of attitudes and perceptions related to integration. *International Journal of Science and Mathematics Education, 8*(1), 97–115.

Bing, C., Gang, L., & Yuehai, W. (2016). SPICE engine analysis and circuit simulation application development. *Telkomnika, 14*(1), 64–71.

Blumenfeld, P., Soloway, E., Marx, R., Krajcik, J., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3&4), 369–398.

Booker, M. (2007). A roof without walls: Benjamin Bloom's taxonomy and the misdirection of American education. *Academic Questions, 20*(4), 347–355.

Chan, W. T. (2015). The role of systems thinking in systems engineering, design and management. *Civil Engineering Dimension, 17*(3), 126–132.

Crismond, D. (2011). Scaffolding strategies for integrating engineering design and scientific inquiry in project-based learning environments. In M. Barak & M. Hacker (Eds.), *Fostering human development through engineering and technology education* (pp. 235–256). Rotterdam: Sense Publishers.

D'Ausilio, A. (2012). Arduino: A low-cost multipurpose lab equipment. *Behaviour Research Methods, 44*(2), 305–313.

Dewey, J. (1963). *The child and the curriculum*. Chicago: University of Chicago Press.

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of Stem Education, 3*(1), 1–8.

Frank, M. (2002). Characteristics of engineering systems thinking-a 3-d approach for curriculum content. *IEEE Transactions on Systems Man and Cybernetics Part C Applications and Reviews, 32*(3), 203–214.

Frank, M., & Elata, D. (2005). Developing the capacity for engineering systems thinking (CEST) of freshman engineering students. *Systems Engineering, 8*(2), 187–195.

Genlott, A., & Grönlund, Å. (2016). Closing the gaps – Improving literacy and mathematics by ICT-enhanced collaboration. *Computers & Education, 99*(2), 68–80.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark 2006. *Educational Psychologist, 42*(2), 99–107.

Hushman, C. J., & Marley, S. C. (2015). Guided instruction improves elementary student learning and self-efficacy in science. *Journal of Educational Research, 108*(5), 371–381.

Kastelan, I., Lopez Benito, J. R., Artetxe, G. E., Piwinski, J., Barak, M., & Temerinac, M. (2014). E2LP: A unified embedded engineering learning platform. *Microprocessors and Microsystems, 38*(8), 933–946.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.

Kubínová, Š., & Šlégr, J. (2015a). *ChemDuino*: Adapting Arduino for low-cost chemical measurements in lecture and laboratory. *Journal of Chemical Education, 92*(10), 1751–1753.

Kubínová, S., & Šlégr, J. (2015b). Physics demonstrations with the Arduino board. *Physics Education, 50*(4), 472–474.

Lee, K., & Fish, E. (2013). New tools for do-it-yourself projects. *PC World, 31*(1), 18.

Logic.ly. – Software for teaching logic gates and digital systems. Available at http://logic.ly/

Mabbott, G. (2014). Teaching electronics and laboratory automation using microcontroller boards. *Journal of Chemical Education, 91*(9), 1458–1463.

National Research Council (U.S.). (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press.

Papert, S. (1980). *Mindstorms: Children, computers and powerful ideas*. New York: Basic Books.

Papert, S. (1990). Constructionist learning. In I. Harel (Ed.), *Constructionist learning*. Cambridge, MA: MIT Media Laboratory.

Resta, V., Huling, L., & Rainwater, N. (2001). Preparing second-career teachers. *Educational Leadership, 58*(8), 60–63.

Rossouw, A., Hacker, M., & de Vries, M. J. (2010). Concepts and contexts in engineering and technology education (CCETE): An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–423.

Saltmarsh, D., McMaugh, A., Santoro, N., & Reid, J. (2009). Editorial. *Asia-Pacific Journal of Teacher Education, 37*(3), 229–230.

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 9–20.

Shulman, L. S. (1986). Those who understand: Knowledge growth un teaching. *Educational Researcher, 15*(2), 4–14.

Swenson, R., Clark, A., Ernst, J., & Sutton, K. (2016). Design, test, redesign: Simulation in technology, engineering, and design education classrooms. *Technology & Engineering Teacher, 75*(7), 8–12.

Szewczyk, R., KaŠtelan, I., Temerinac, M., Barak, M., & Sruk, V. (Eds.). (2016). *Embedded engineering education*. Switzerland: Springer.

Thomas, J. W. (2000). *A review of research on project-based learning*. San Rafael: Autodesk, National.

Tripto, J., Ben-Zvi Assaraf, O., Snapir, Z., & Amit, M. (2016). The 'what is a system' reflection interview as a knowledge integration activity for high school students' understanding of complex systems in human biology. *International Journal of Science Education, 38*(4), 564–595.

Von Glasersfeld, E. (1988). Cognition, construction of knowledge and teaching. *Synthese, 80*(1), 121–140.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Williams, P. J. (2009). Teacher education. In A. T. Jones & M. J. De Vries (Eds.), *International handbook of research and development in technology education* (pp. 531–540). Rotterdam: Sense Publishers.

Yusof, Y., Sanusi, H., & Mat, K. (2012). Computer simulation as preparation for electronics laboratory. *Procedia – Social and Behavioural Sciences, 60*(2), 397–404.

Robotics in Technology Education

27

Martin Fislake

Abstract

Robotics is one of the most powerful domains in TE. Teaching robotics has to consider the fast loop of innovation and may vary between simple algorithms in primary classes and will not end with the critical engagement with the impact assessment of designing and building robots for the needs of the future world. It connects past, present, and future in many different strands and shows all children the connection between hard- and software. It also helps them to understand and to take part or have insight(s) in this broad field of automation. Despite this it is to take care between general and vocational education.

Keywords

Technology education • Educational robotics • Edutainment robots • Robot competition

Contents

M. Fislake (✉)
Department of Technology Education, University of Koblenz, Koblenz, Rheinland-Pfalz, Germany
e-mail: fislake@uni-koblenz.de

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_28

Introduction

They may fly, crawl, walk, drive, roll, dive, jump, or exist in a virtual world. They have physical structures like wheels, legs, arms, propellers, or wings and are extended by sensors to let them see, feel, and measure their environment. They are empowered by artificial intelligence and energy systems and may move, act, think, and communicate with machines as well as with humans. They are all human made and take part in our everyday life – step by step, more and more.

It is fascinating to observe state-of-the-art robots and the current options of future robotics. But aside this playful and technocratic perspective, the influence and changing of robotics into economics and everyday life has to be respected in technology education. Even though it is a question of continuous curriculum revision, this chapter takes into account some relevant aspects. Starting with a pedagogically extended view at robotics, this chapter embraces teacher's basic handcraft like deciding, reasoning, access into teaching processes, and the contribution of robotics in education. It shows the potential of robotics as a tool and the way how to teach this subject and gives an orientation in the world of educational robots before it ends with an outlined sketch of future technology aspects.

Education and Robotics

Connected to the history of technology, the implications in our everyday life, and the continuous changes in modern industry, robotics is a growing domain in technology education that comes around with different connotations.

Some may understand robotics as something done by engineers designing robots or creating automated systems (Iceaproject 2016). Others call every automated system real or virtual robotics, and children call a lot of different toys robots or robotics (Reynolds et al. 2009). But going this way, it is worthwhile to explain what is meant by robotics! This would only be a repetition of well-known explanations which are easily to find in encyclopedias (Fig. 1).

A pedagogically extended view at robotics takes a look at the chances that are opened by discussing or being engaged with robots and robotics (Bers and Strawhacker 2015; Döbeli Honegger 2013; Schwartz 2014) or even claim "robotics as a learning tool for educational transformation" (Eguchi 2014). What else can be initiated by something that makes progress and automation visible or may be understood as an application of the engineering design process?

Besides this it is to find computational thinking, computational thinking practice (CTP), and information and communication technologies (ICT) and computer sciences principles (CSP) that are involved in robotics (Misirli and Komis 2014; Shoop et al. 2016; The Board of Studies 2016) – sometimes driven by a one-sided view using robotics as a teaching tool in mathematics or informatics settings.

But robotics as a domain in technology education is not only a question of mechanical engineering, mathematical, physics, electronics, computational stuff,

Fig. 1 Robonova. It is a toy everyone calls a robot

and coding. It is also a question of philosophy, ethics, culture (Operto and Veruggio 2008; Sleasman 2015), and the result of the teachers deciding and reasoning process. In this case robotics is to see as a branch whose concept comprehends engineering as a craft, the engineering design process as the way, and robots as the result changing our everyday life.

Thinking robotics this way leads to a deep look for the general aspects of robotics as well as the valuable core of it and should be used as a tool to bring a lot of benefit to the world of teaching technology as a part of general education.

Access into Robotics

With the idea of teaching technology as a part of general education in mind, there are many ways into robotics. Some are more theoretical and some more practical. But they always give a face to the objectives, help to make things concrete, and simplify access into the subject.

One common access into educational processes is to start with previous knowledge collecting terms from the classroom. Terms like cyborg, android, techbots, R2D2, robots, humanoid robots, machines, bots, (tele-)manipulator, and mobile autonomous systems will reflect a wide range of popular and less popular movies as well as an unstructured previous knowledge based on the diversity of technological artifacts. In this case an orientation is announced and may be used as an example for how to handle diffuse and unreflected knowledge as a new starting point into robotics, going to find a useful structure in an unstructured field.

This may lead over to the history-driven access into robotics, which is a useful example for the history of technology in general often tightly connected to options, the spirit of the time, the state of the art, the philosophy, and the inspiration of writers. Things thought by Asimov, Verne, and others have been visionary but are still discussed and valid. Knowing the long history of robotics and respecting it, for example, while building robots, opens the minds and hearts of school students and makes a difference to robotics; it is more than even building.

Close to this access is the etymological way to open the field of robotics and their social impacts. Talking about the meanings and the history of words like “robäter,” “robatter,” or “robota” guides from the idea to build artificial people called robots for a compulsory labor in “Rossum’s Universal Robots” of Karel Čapek in 1921 to Asimov’s short stories from the 1940s where he used the word robotics for the first time. In front of this sometimes profound background, it is hard to explain how to generate up-to-date standard specifications by long counseling in advisory board meetings.

The scope of application is another very useful access into the field of robotics. This is where general education takes a look at the whole world of robotics. While the focus of robotic systems for technology education in a general manner is on edutainment robots (Bilotta et al. 2009) known as small-sized mobile (autonomous) robots, round about 20 cm large, the focus of robotics in vocational education is more concentrated on industrial applications (Fig. 2).

On the one hand, industrial robots foster the internet of things and the industry 4.0. They are a part of flexible manufacturing systems producing consumer stuff like cars and making changes to the workplaces and the kind of working. In this case, vocational robots are typical small or downsized industrial robots – flexible multi-axis robots used as training systems. On the other hand, few industrial robots found their way into medical surgeries, dangerous police tasks, or amusement parks, turning and shaking visitors to their limit (KUKA 2016). Talking about the more and less desired effects of the different applications for the society will be of great value.

The usual use of robotics in natural sciences is not really an access into robotics. Because of the common focus on scientific phenomenons, robotics mostly is used as an(−other) explanation tool in mathematics or in physics. It changes in the moment a constructivist educational approach like problem-based learning (PBL) comes into account. Students then learn science and develop critical thinking skills by solving real-world problems using robotics as an example.

Nevertheless starting building robots in different cases is also a very common access into the technology education process. This is because it is different from “reading books and talking about” based subjects because it allows following a more holistic concepts like Pestalozzi’s approach: “Learning by head, hand and heart.” It opens a way to function driven creativity and self-guided learning. This is supported by most of the educational robotic systems, because they are easy to understand and have a high stimulative nature and a high potential of self-explanatory. The teacher’s role then often changes from the one who simply fills up empty vessels with unrelated knowledge to a mentor as a learning companion.

Apart from that, participating in robotic competitions may be the last and most challenging access into robotics (Miller et al. 2008). The competition itself may motivate and add new aspects to robotics as there are questions of social learning, public relations, finance, funding, and project management. It is a kind of reality in a

Fig. 2 Common edutainment robot on caterpillars. It should be programmed via surface or PC using proprietary (icon-based) or nonproprietary software

sandbox, regarding technology and robotics as a part of a big jigsaw that is based on a copy of real life, business, and industry.

At this point, there is a big matching to the ISTE national education technology standards as there are creativity and innovation; communication and collaboration; research and information fluency; critical thinking, problem-solving, and decision-making; digital citizenship; technology operations; and concepts (ISTE 2016).

Reasoning Robotics

Teaching robotics always has to start with a lot of questions, deciding, and reasoning. As in all other contexts of education, it has to be asked for the learner parameters and conditions. What are the relevant environment and the society they are imbedded in, and what has to come out of the teaching lessons from the administration objectives and standards. Furthermore the idea, the history, the current situation, and the understanding of robotics in different languages and cultures have to be considered.

But this is the teacher's basic handcraft and belongs to his responsibility with the result not to teach robotics in particular cases. For that it is helpful to distinguish between different cases grouped into categories, where robots are useful but not essential and where robots are strongly recommended: No robots are needed while

– Learning about robotics where the focus is on history, philosophy, and social aspects

– Learning of robotics giving attention to the structure, the programming, sensors, and applications of robots

Corresponding to the second category, robots are recommended in the cases of

– Learning by robotics, using robots to teach sciences like mathematics, engineering, and programming
– Fostering individual skills via robotics developing problem solving, creativity, and teamwork

Based on the orientation on learning outcomes, it is the teacher's decision what he wants to do, what he has to do, how he wants to do it, and how he has to do it. What are the main targets, what delta can be reached, and what way is the best for the addressed learning group? For this task exists a lot of different educational accesses into robotics which may be helpful to open ways to technology education as a part of general education.

A Look at the Literature

Regarding the discussion about accesses into robotics and reasoning robotics in education, a review of relevant literature is indicated. While doing so, it is obvious that most research papers may be classified into the second case category (robots are strongly recommended) and are based on descriptive or anecdotic reports of teachers as Gaudiello and Zibetti (2016) actually point out. All papers declare a positive impact of using robotics for higher learning abilities.

But although many robotic programs were designed to teach specific knowledge in mathematics, physics, and programming, only a few examine the impact in detail on the students in this regard. Likewise numerous papers claim that robotics is an evident tool for teaching STEM subjects; only a few studies present specific examples or evidence of achieving this goal.

Church et al. (2010), for example, designed one of these programs and confirm Sullivan's (2008) former perception in this area. They integrated robotic activities in a science curriculum to engage students to develop a conceptual understanding of physics principles through the process of investigation, data analysis, engineering design, and construction. Although they restricted that more formal studies are needed, they concluded that these experiments provide students not only to learn the concepts and the skills of physics. They reported the participants recognized the practical application of their knowledge as there are the opportunities to develop their teamwork and communication skills as well as they become more independent and confident learners.

A robotic-based learning experiment that took place in a school physics class was designed by Alimisis and Boulougaris (2014). They reported that the participants have already been taught kinematics in a traditional lecture-based way before they worked in groups to construct and programmed a robot to move in linear way. Although Alimisis and Boulougaris are cautious to draw any general conclusions from their findings, they emphasize the role of activity. It seemed to have triggered the students' interest and turned, to a certain extent, learning into a game thanks to the invention of the competitive "car racing."

Another educational robotic program was an informal (out-of-school) project developed by Nugent et al. (2014) to implement a comprehensive program for youth ages 9–14. The purpose of the project was to positively impact the youths' science, technology, engineering, and mathematics (STEM) knowledge and attitudes and to foster an interest in STEM careers. The results confirm an earlier informal (out-of-school) project analyzed in 2010 by Nugent, Barker, Grandgenett, and Adamchuk. They summarize that the project promoted STEM learning, particularly in terms of knowledge of engineering, engineering design, and programming, but mathematics knowledge did not show high increases from participation.

The implementation of educational robotic activities in a secondary technical school was reported by Atmatzidou and Demetriadis (2014). Their focus was on the development of computational thinking and problem-solving skills. The results showed that the students developed CT skills specifically, concerning the understanding and assimilation of the CT concepts.

Teachers' perceptions of the effects of robotics on students' personal skills was examined by Khanlari in 2013. The conclusions show that robotics is an effective tool for improving twenty-first-century skills, including students' creativity, collaboration and teamworking, self-direction, communication skills, social and cross-cultural skills, and social responsibilities. They are consistent with the learning by design theory and show that robotics enhances students' skills and abilities.

Kim et al. (2015) used robotics in their research project to promote elementary education preservice teachers' STEM engagement, learning, and teaching. Data were collected and indicated that preservice teacher's engagement improved overall if robotics is used as a technology in activities designed.

After all it is clear that every paper has its own conceptual framework and is always bounded in the "intervention–effect" testing limits at any kind. Therefore it is essential to take into account if the research question is based on old-fashioned educational concept where robotics is only used as a gimmick like an application to make the old learning content sweeter or if they are used to foster new educational concepts and objects. Because of this, it is still an educational question if robotics is only used to teach single aspects or to follow a more holistic approach.

Beside this formal education and short-termed "intervention–effect" – research perspective acatech and others (acatech and VDI 2009; acatech and Körber-Stiftung 2014) studied the long-termed fundamental effects of technology-related environments mostly in informal settings during childhood and youth. They stated robotics and other technology-driven occasions play a formative role on technology socialization and the acquisition of a technology-oriented habitus on the long run.

Robotics as a Teaching Tool

Coming up from an educational perspective, robotics is a big opportunity to do more than building robots or doing things for the sake of doing things. Because the simple use of robotics will not guarantee the gain in learning by students as Gaudiello and Zibetti (2016) disclaimed, robotics has to be comprehended as an educational tool (Chan Lye et al. 2013; Johnson 2003; Miller et al. 2008) not only as a content to teach. To see how to start a robotic program, a helpful guidance is provided by the Carnegie Mellon's Robotics Academy (2016).

In other words, "the pedagogical approach is a key factor" (Gaudiello and Zibetti 2016). Teaching robotics can lead from teaching isolated knowledge of technology rules for stupid knowledge workers to technology literacy, tacit knowledge, and creativity, based on critical-constructive didactic making self-reliant, matured, and emancipated humans with an intellectually engaging kind of manual competencies (Ucgul and Cagiltay 2014).

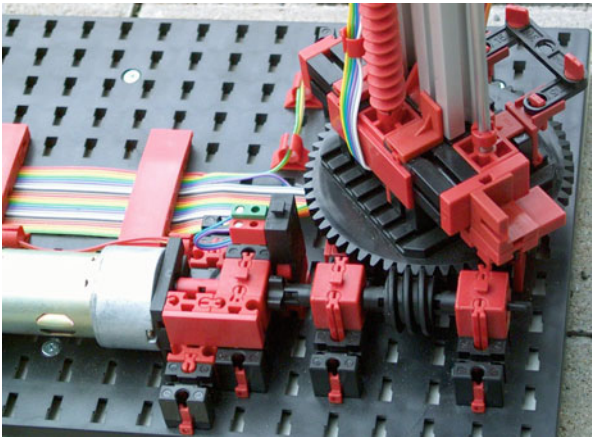
While measuring the impact of teaching technological is leading to literacy based on the part robotics can deliver, teachers are still responsible for the benefit of learning outcomes on their own. They are liable for the right choice of the means, methods, media, and materials as well as for the right selection from the range of possibilities offered in the field of educational, industrial, and entertainment robots (−ics).

But long before the teacher makes a selection of a useful robot or robotic system, he has to comprehend robotics as a powerful teaching tool for general education – the choice of the artifact has to follow the attempt to justify it in educational perspective. That means education comes first, robotics second, and specific learning content like programming third.

In case of the objectives of an educational handbook, robotics has to be enriched by more than the common understanding and perspectives of engineering. This is the moment robotics can show its true diversity and pedagogical potential. Hence this robotics can be understood as:

- A motivational tool. Enthusing students because of working with something new, modern, playful, and connecting tuition to the technology world. Often used in combination with a participation in a robotic competition (Chan Lye et al. 2013; Kraetzschmar 2009).
- A socializational tool. Providing youth the opportunity to acquire a technology-oriented habitus and making them basically interested in technology and related jobs (acatech and VDI 2009).
- A social playground. As to be seen in the "spare parts" movie (based upon a true story). Building robots together needs an ability to work in a team that can be learned in a joint challenge guided by a wise mentor.
- A playground for mathematics and artificial intelligence (AI). It is the place where maths, informatics, and algorithms become visible and alive on screen or as an action-shaped robot (Miller et al. 2008).
- A subject or science itself. This is the tight mechanical engineering way of understanding robotics – concentrating on mechanics, electronics (Taub and Verner 2009), and how to make it move. Far away from user needs, teamwork, and sustainable impact assessments (Fig. 3; Bachmann and Embacher 2016).

Fig. 3 Mechanical drives at the bottom of a half-open construction kit to simulate a 3D robotic system



- A tool to teach the engineering design process in a suitable project. This refers particularly to construction tasks that may come from an "unambitious" robotic competition, solved by self-made robots or educational robotic systems.
- A branch of technology education whose concept understands engineering as a craft, the engineering design process as the way, and robots as a result of teaching processes.
- A domain in technology education. It is a kind of a holistic approach that connects engineering and education with the understanding of history, philosophy, and culture.
- A hobby practiced in out-of-school projects, so as in club houses, maker-spaces, fab labs, summer camps, and other nonformal learning places. This is where robotics makes fun and leads to entertainment and recreation. This is the place where creativity, communities, and contest training teams may grow and find their own way (ElKattan 2015; Fislake and Bogdol 2005; Karp and Maloney 2013; Nugent et al. 2014; Reynolds et al. 2009).
- An example to understand the world of technology. Because robots can show the general spectrum of mechanics and electronics components enhanced by applications of information and communication technologies.
- An example for technology systems (Ropohl 1979). Robots and robotics are good to teach open systems (systems theory) and its in- and external interactions like changing or exchanging information, energy, and/or matter with its environment (Fig. 4).
- An example for socio-technical systems. Broadened to the simple systems theory here is to find an interdisciplinary approach of socio-technical systems in general, showing the difference between designing and systems engineering.
- A showcase. Robotics may be used as a place where the success of learning may become visible for everyone (classmates, parents, colleagues, and others) by the actions of students solving given problems (Miller et al. 2008).

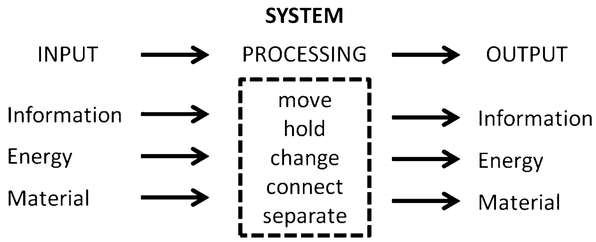


Fig. 4 Technology system, simplified representation

– An assessment subject to measure (soft-)skills, learning competencies, and other outcomes in relevant environments. In contrast to the showcase, it needs a valid, reliable, objective, and transparent measurement.
– A teaching assistance. It is a new kind of robotics which belongs to the growing field of education technology instead of educational robots for the technology education. Like the "cubo" robot, they are tools which are able to read out books or help students to learn in different cases. If and how they take a role in technology education is a question of the evolution in technology, education, and teaching.

Robotics as a Teaching Concept

Based on the authors' reviewed experiences there are three starting points at the end of the deciding process that may be taught stand alone or in any combination. Those are mechanics, informatics and coding. They all gain a profit from pedagogical principles like those of Comenius' pedagogic philosophy. As there are for example: "from the known to the unknown" or "from easy understanding to the complicated at a slow and deliberate pace." They all help to find the right way from simple coding over monitoring sensor data to self learning systems based on artificial intelligence.

Teaching robotics to young children usually starts with creating own robot constructions (Ceceri 2015) or simple coding like "start, go, go, turn right, go, turn left, go and stop." This can be realized on paper, on screen or with robots like Bee-Bot (Cacco and Moro 2014) or Galileo Roboter in real life, Blopp in virtual reality or with pencils on paper. It is followed by the first tasks where the "bot" has to solve easy challenges like "move from the red dot to the blue one" on a prepared field. While the tasks are growing and getting more and more complicated codes like "if. . .then" come into respect using timer for the durance of actions and sensors to trigger a reaction of an actuator (Figs. 5 and 6).

While this is an easy beginning of coding, creating simple robot constructions is the other way into robotics for young children. Working with paper, cardboard and wood connected by glue, wires or adhesive tapes children are able to show what is in their minds when talking about robots. This may be followed by assembly-kits or pre-constructed-kits with electronic components but no real coding functions. At this level children may face playful robots like cubelets or tinkerbots and get in touch

Fig. 5 The Galileo-Roboter as a nice example for a programmable assembly kit. All moves are embedded in not changeable hardware and may be coded via step by step on surface

Fig. 6 Coding Blopp step by step on screen

with factory provided changeable modules or extensions/add-ons to change the (pre-) programmed code that is addicted to the physical structure (Figs. 7 and 11).

Around the age of 8 years children continue or start with tasks that bring coding and mechanical constructions together. In this context the edutainment robotics kits

Fig. 7 Children working with a half open educational robotic system. It comes along with useful assembly instructions, a high stimulative nature and a high potential of self-explanatory

like LEGO Mindstorms and equivalent construction kits are common and well known. They are half open kits and allow different construction solutions. Useful assembly instructions are also available for all first timers. Programming is possible on surface or by proprietary icon based visual programming language via personal computer (Karwall 2010). Changeable actors and sensors like motors, touch- or sound-sensors enhances the constructional freedom and educational value of these kits at last.

This is the main access for many children into real life robotics. It is easy to come in but needs some teacher's assistance to go ahead and not to stop at this level. It is important that they understand that there is a difference between "it's great because it's LEGO" and "it's great although it is LEGO"! In other words: this marks the difference between playground and research.

Those who continue change from graphic based coding to formal constructed programming language and switch to robots ready to use or leave the plastic cover of the prefabricated construction kits aside to use free material instead to build their own robots (Fig. 8).

This is the time when young programmers and young engineers go different ways. Young programmers concentrate on informatics, coding and maths as their main subjects, while young engineers still deal with the whole. Programmers or in this case young software engineers use what is available. They use robots only as a playground to make their code visible, solving all problems, algorithm based as well as mechanical based, preferably by new code.

It seems to be plausible, that these kind of young computer scientists need another educational environment as those who are interested in the whole technology system. They need teachers who are able to find a balance between the three educational approaches of computer sciences as there are coding as a language, informatics as a mathematical application and creating software as an engineering discipline.

In contrast to these concepts the holistic approach uses robotics as a teaching concept in technology education. Based upon the engineering design concept it

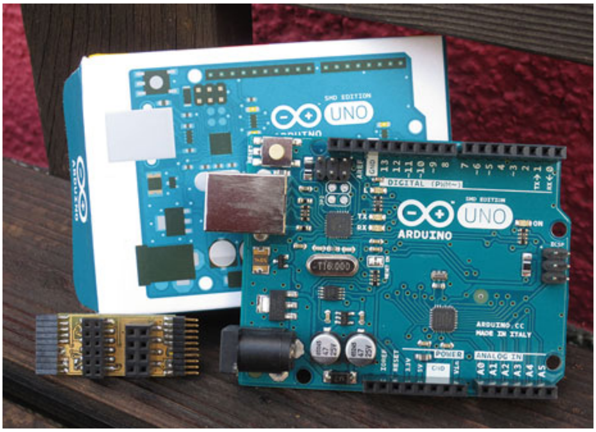


Fig. 8 Integrated circuit and Arduino microcontroller. Hearts and brains of self-made robots

follows the way from the challenge and the problem solving idea to the end. The end means in this case to reflect on learning about what had happened in the meantime, to dismantle the robots and to arrange the parts back into the correct order, while it is disposal, and regarding the environmental impact in real life. For this the teacher's challenges are to guide the processes to responsible reflected actions and to help convert the experiences made into long lasting learning and aspired competencies.

Robots for Robotics

For all this teaching and technology education mentioned above a lot of different robots, materials and robotic kits are available. Some of them are particularly developed for educational use others less. This is the reason why a general overview is necessary. A simple classification for that will help to understand the different kinds of robots for decision making from teaching perspective.

The easiest way to find a first classification relevant to educational tasks is to look for the common application or the chain of distribution of the technical system. This may guide to five classes named industrial robots, vocational robots, research robots, educational robots and entertainment robots. Because this classification is not free of any overlapping it is helpful to ask for the main purpose of the system if orientation is needed.

A widespread multi-axis industrial robot may be a good example for it. While this kind of robot has been designed for manufacturing systems they are also good for entertainment in amusement parks (KUKA 2016) and for vocational training systems in a downsized or original manner. Another example is represented by robots used to simulate processes in teaching causes or designed by little children inspired by robots in a movie, industrial robots or others. They may have a similar structure but are used in different matters (Fig. 9).

Another classification is based on the composition and structure of robots mainly divided into mobile and stationary robots. Every layout is provided by flexible

Fig. 9 Two small and flexible multi-axis robots for educational use. The large one is factory made, the other one a programmable assembly kit

components to make them act in linear or rotating movements up to six degrees of freedom. A coordinate system describes the resulting volume that may be reached particularly by stationary robots while mobile robots are able to compensate their limitations by simple moving.

The kind of moving depends on their physical structures like wheels, legs, arms, propellers and let them fly, crawl, walk, drive, roll, dive or jump. The number of the movement components is varying as there are robots with legs or wheels from two to eight, others with propellers from one up to eight, if drones are enclosed. While two-legged robots are characteristic for humanoid robots, six and eight wheeled or legged robots are typical representatives for all terrain vehicles, as well as those with caterpillars. Some of them are more autonomous like the extraterrestrial research robots some less (Fig. 10).

Even though a good teacher is able to transfer a broad number of robots described above into learning environments, common robots are used as educational robots or as robot systems. They vary from simple tinker-bots to maker-robots and from self-made line-follower and edutainment-robots used in schools as well as at home to (semi-)autonomous programmable robots (Ceceri 2015; Heffernan 2013; Junior et al. 2013; Reynolds 2014).

As seen the teacher has to decide which kind of educational robot will be the best help to reach the aspired objectives in the actual learning setting. Besides the look for support material like curriculum stuff, lessons plans and the quality of hands-on material it is a question of costs, shape and form of appearance as well as a question of functions, structure and the programming complexity. Beside this: if a participation in a competition is aspired all relevant rules have to be regarded.

Because of the variety of educational robots a general orientation is needed to find the right choice between nearly useless (un-)programmable toys and the complexity of free material for self-made robots. Therefore the following table offers a synopsis which spreads the field of educational robots and robotics systems into different

Fig. 10 Older humanoid (released 2005) robot with minor factory provided extensions

Fig. 11 Components of a battery-driven construction kit with cardboard, wood, and electrical motor

clusters. The abscissa of the light gray marked area designates the openness of the structure while the ordinate represents the freedom of programming (Fig. 12).

The openness of hardware leads from a given structure with minor factory provided extensions or add-ons to free material with or without an assembly instruction guide helping to find the way how to build a robot. This is also the strand level of freedom for programming

level of freedom for constructing

programming-modes									
Computer	kind of coding: programming language(pl)	programming how to	code implemented in						
Computer needed	formal constructed pl	Via mouse, keyboard and PC screen	Microcontroller (software/firm ware changeable)	Nao Pololu m3pi	ASURO NIBOBEE	Boe-Bot ActivityBot littleBits			Quickbot diverse electronically, electrically and mechanically components
	Educational pl (non proprietary)					Robot kit	Makeblock robot kits		
	Proprietary pl, (often graphically and proprietary) or (icon based visual programming)			Alpha S1 Dash n Dot The Finch Robotino	Robonova	MA-VIN Robotis Bioloid crash-bobbly KOROBO[MR-9172] Wunderkind CEENBoT	LEGO Mindstorms (RCX, WeDo) fischertechnik (interfaces) VEX robotics Robotics ERP PRO 1.2 KAI Robot iPitara	RiQ (PCS Robotics BRAIN)	Hummingbird Robotics Kit Quirkbot
no Computer needed	no pl, coding via step by step. code (moves, routines or causal chains) embedded in hardware	changeable modules	integrated circuits (software/firm ware not changeable)			Cubelets MOSS			
		read in, teaching		Edison		KIBO (KIWI) TINKERBOTS Cubetto	LEGO Technic 8479		
		on surface or via remote control		Bee-Bot Pro-Bot Roamer Robosapiens	Push-Button programmable Robot Kit Galileo-Roboter		LEGO Mindstorms (NXT, EV3)	LEGO Spybotics	line follower
	no pl or coding, code (moves, routines or causal chains) embedded in hardware	on off, choice between modules/routines not reprogrammable	Electronically, electrically and/or, mechanically controller cylinder, relays, clockworks, punched disks,	Toys		DK Knotbot		LEGO technic fischertechnik	tinkered robots: beetle bots line follower made of paper, card, wood, plastics, wires
		only on off, no choice not reprogrammable		Toys	glued card-robotic kits	DK BounceBot	fischertechnik Mini Bots OWI 14-in-1 Solar Robot		
				Unchangeable (+ minor factory provided extensions, add ons)	Little or no diversity or not reversible (+ minor add-ons, factory provided extensions)	factory provided changeable modules or extensions/add-ons	half open (reversible)	open	free material to construct with (with or without an assembly instruction guide helping to find the way)
				ready to use	*assembly or soldering kits/sets one model*	*assembly kits/sets (one model)*	Construction kits/sets different models possible		self made/constructed
				constructing-modes					

Fig. 12 Synopsis of educational robots and robotics systems

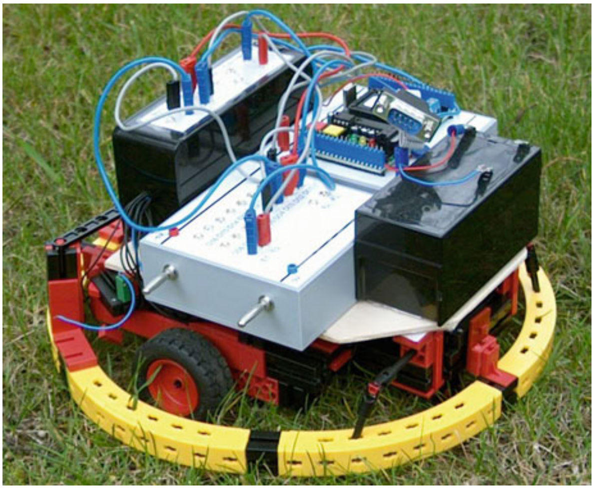


Fig. 13 Half-open construction kit combined with nonproprietary microcontroller and electronic components

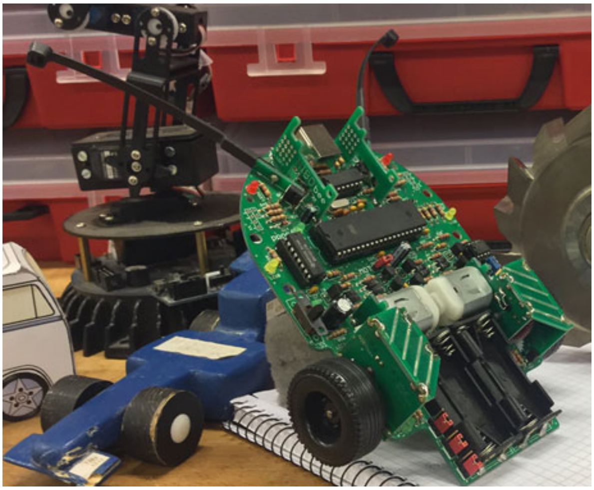


Fig. 14 Assembly and soldering robot kit with minor factory provided extensions

of all kinds of assembly kits and fully open construction-kits made for the free construction and understanding of the mechanical function in a robotic system as well as for half open pre-constructed robotic systems with a reversible but single construction solution (Fig. 13).

The challenge in robotics rises and gets more complicated with the freedom of structure as well as with the freedom of programming. This is the point where a challenge can be adjusted to be stimulating and not boring or overstraining. It is in the nature of learning that the more the learners know how to act and solve problems and the more they know about things like electronic components, the more freedom is announced (Fig. 14).

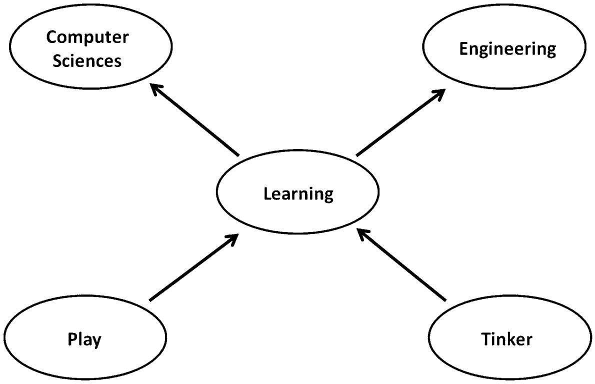


Fig. 15 Robotics as a guiding tool from playground to professional vocation

While the ready-to-use-structure may be represented by robots like Nao and Bee-Bot or different toys, the most open structure is represented by diverse electronic, electric and mechanical components like microcontrollers, resistors, capacitators, wires, motors etc. The programming diversity ranges from embedded not reprogrammable codes selectable via tipping on buttons to teach a simple sequence as the easiest way of coding to the use of formal constructed programming languages.

To summarize what was mentioned before it is to suppose that most children get in contact with robotics in the lower left (toys) or right (tinker) corner moving into the center (educational robots) while growing up and move over to the upper left (given structure/free coding) or right (free structure/free coding) corner at last. It is the way from playground to professional and vocational orientation (Fig. 15).

Because there is a fast loop of innovations and an uncounted number of educational robotics systems in this field only a small number of the full robotics spectrum is regarded. They may be common representatives for the characteristics of the different clusters like: self-made, construction or assembly kits and robots ready to use crossed with different kinds of programming.

If they belong into different clusters they are assigned into the cluster with the lowest freedom. This is typical for a few robotics systems with a main focus an education. Some of these educational kits are combined with an appropriate, usually icon based; visual programming language, but can also be programmed by an educational or a formal constructed language.

Competitions for Robotics

Competitions and contests are very common in the field of robotics. Some have been founded to bring students and researchers together (RoboCup 2016), others to offer a learning supporting area up to K-12 or a playground for vocational orientation (Fislake and Bogdol 2004). While researchers meet to compete for fun (and for

Fig. 16 Programmable robots in a line follower challenge

the sponsors) the exchange of new ideas and research results and the progress in hard- as well as in software is in focus.

RoboCup as one of the famous robotics competitions mainly explains first to be an international scientific initiative with the goal to advance the state of the art of intelligent robots (RoboCup 2016). So the competition is a research and motivation tool for the community and at second glance a marketing tool for young academics. Therefore RoboCup offers a growing number of different cup-classes, as there are soccer, rescue, @home and the junior cups. Except the vocational driven FESTO league they are all divided into different leagues.

The RoboJuniorCup is addressed at the younger ones and separated into soccer, rescue and dance-league to hit the educational driven terms and conditions of schools as well as the FIRST initiative. It is another platform for robotics programs and offers other well known worldwide robotic competitions, as there are the LEGO League, the Tech Challenge League and the Robotics Competition League (FIRST 2016).

Related to the technology education in school contests are the places where robotics comes alive. They are helpful to teach robotics because they motivate students to engage more than in other educational scopes. The more the competition fits to the students' competencies the more benefit. Regarding it the challenge has to be stimulating not boring or overstraining. And sometimes a self made class- or school-wide contest will be the best idea for educational success (Figs. 16 and 17).

This means the teaching success is a question of the competition design and not a self-fulfilling miracle. To make it an effective teaching tool it needs some educational background and guidance. Because a lot of motivation comes from the feeling to be a hero has nothing to do with robotics itself and sometimes the difference is hard to understand for the growing children being admired because the robots are made with LEGO and being admired although (!) they are made with LEGO.

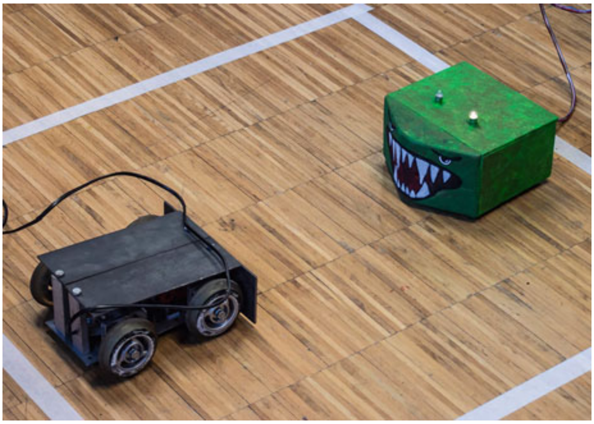


Fig. 17 Self-made sumo bots in a classroom competition

The Look Ahead

A short look into the research laboratories nowadays is very exciting from a technocratic perspective but allows only a vague forecast what will come next into everyday life or industrial applications and has to be respected in technology education. As seen by some technology driven competitions as those from DARPA the development is faster than ever predicted and changes into a technology evolution (DARPA 2016).

Researchers are concerned in the development of new robots for medical or military use, service and social robots for any assistance at home and collaborative robots, so called cobots, as new colleagues (Operto and Veruggio 2008; Timms 2016). Artificial intelligent systems will enhance traditional mechanics, informatics and coding. Future systems will come closer to human beings and will adopt new fields of application like prosthetics, exoskeletons and transhumanism (Cordeiro 2016). Robots will be able to do things, decide and find solutions by themselves, getting more and more autonomous and independent. Like the driving assistance in modern cars few of them will disappear or change their appearance by losing their physical structure and being integrated into other systems.

While the future technology aspects only may be outlined in large sketches, all other and new technological impacts on the environment and social society are not predictable. It is a permanent mission to indentify the curricular challenges for the future and to discuss how to involve school students in understanding the technological, scientific, social, economic and ethical aspects of these developments. It is a continuous challenge in technology education to turn the expected and unexpected advances in robotics into curriculum revisions – more than in other disciplines.

Conclusions and Proposals

At the beginning of the twenty-first century robotics is more than a single branch to explain and to consider in technology education. As seen robotics offers a lot of different educational accesses into the subject itself, but it has to be cleared up what is meant by it from a pedagogical perspective and what is involved. Thereafter a lot of different kinds of robots are available to enhance the teacher's handcraft of decision making, reasoning and teaching, sometimes combined with a participation in a robotics competition to open the technology focus to the environment.

In this Moment robotics may be comprehend as a teaching tool for many teaching cases. This is the place where the future chances of robotics have to be set into a relationship to the future technological impact assessment, the changes to the workplaces and the kind of working. All these changes will bring new challenges for future education and can't disregard philosophical an ethical aspects.

While this has to be respected in future syllabuses of instruction for a general technology education, ethical aspects may help and give answers for it (Hersh and Kopacek 2015). Perhaps someone will then remember the history of technology, and the beginning of robotics and Asimov's "Three Laws of Robotics."

Cross-References

► Teaching Electronics: From Building circuits to Systems Thinking and Programming

References

acatech, & Körber-Stiftung. (2014). MINT Nachwuchsbarometer. München/Hamburg. acatech/Körber-Stiftung. Retrieved 22 Nov 2016, from http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Publikationen/Sonderpublikationen/acatech_MINT_Nachwuchsbarometer_2014.pdf

acatech, & VDI. (2009). Nachwuchsbarometer Technikwissenschaften – Ergebnisbericht. München/Düsseldorf. acatech/VDI. Retrieved 22 Nov 2016, from http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Publikationen/Sonderpublikationen/NaBaTech_Bericht_Final_210709_einzel.pdf

Alimisis, D., & Boulougaris, G. (2014). Robotics in physics education: Fostering graphing abilities in kinematics. In D. Alimisis, G. Granosik, & M. Moro (Eds.), *Proceedings from the 4th international workshop teaching robotics: Teaching with robotics & 5th international conference robotics in education* (pp. 2–10). Padova.

Atmatzidou, S., & Demetriadis, S. (2014). How to support students' computational thinking. Skills in educational robotics activities. In D. Alimisis, G. Granosik, & M. Moro (Eds.), *Proceedings from the 4th international workshop teaching robotics: Teaching with robotics & 5th international conference robotics in education* (pp. 43–50). Padova.

Bachmann, P., & Embacher, M. (2016). Mechanical jigs and fixtures – Solutions for more reliability and accuracy. *Junior Journal of Science and Technology, 3*, 1–6.

Bers, M. U., & Strawhacker, A. (2015). “I want my robot to look for food”: Comparing Kindergartner’s programming comprehension using tangible, graphic, and hybrid user interfaces. *International Journal of Technology and Design Education, 25*, 293–319.
Bilotta, E., Gabriele, L., Servidio, R., & Tavernise, A. (2009). Edutainment robotics as learning tool. In Z. Pan, A. D. Cheok, W. Müller, & M. Chang (Eds.), *Transactions on edutainment III. Lecture notes in computer science* (Vol. 5940, pp. 25–35). New York: Springer.
Cacco, L., & Moro, M. (2014). When a bee meets a sunflower. In D. Alimisis, G. Granosik, & M. Moro (Eds.), *Proceedings from the 4th international workshop teaching robotics: Teaching with Robotics & 5th international conference robotics in education* (pp. 68–75). Padova.
Carnegie Mellon’s Robotics Academy. (2016). Starting a robotics program. Retrieved 19 Nov 2016, from http://education.rec.ri.cmu.edu/educators/getting-started
Ceceri, K. (2015). *Making simple robots: Exploring cutting-edge robotics with everyday stuff.* Sebastopol: O’Reilly and Associates.
Chan Lye, N., Wonga, K. W., & Chiou, A. (2013). Framework for educational robotics: A multiphase approach to enhance user learning in a competitive arena. *Interactive Learning Environments, 21*(2), 142–155.
Church, W., Ford, T., Perova, N., & Rogers, H. (2010, March 23). Physics with robotics using LEGO® MINDSTORMS® in high school education. *AAAI Publications, 2010 AAAI Spring symposium series*. Retrieved 09 Nov 2016, from http://www.aaai.org/ocs/index.php/SSS/SSS10/paper/view/1062
Cordeiro, J. (2016). Technological evolution and transhumanism. In L. Gokhberg, D. Meissner, & A. Sokolov (Eds.), *Deploying foresight for policy and strategy makers. Science, technology and innovation studies* (pp. 81–92). New York: Springer.
DARPA. (2016, July 19). The DARPA urban challenge. Retrieved from http://archive.darpa.mil/grandchallenge/index.html
Döbeli Honegger, B. (2013). Informatik ist mehr als Informatik! – Oder: Warum sich die Informatik mit dem Leitmedienwechsel befassen muss. In N. Breier, P. Stechert, & T. Wilke (Eds.), *Informatik erweitert Horizonte. 15. GI-Fachtagung “Informatik und Schule“* (pp. 11–20). Kiel: Gesellschaft für Informatik.
Eguchi, A. (2014). Robotics as a learning tool for educational transformation. In D. Alimisis, G. Granosik, & M. Moro (Eds.), *Proceedings from the 4th international workshop teaching robotics: Teaching with robotics & 5th international conference robotics in education* (pp. 27–34). Padova.
ElKattan, A. (2015). Learning through making – With relevance to robotics education. *Junior Journal of Science and Technology, 2*, 1–6.
FIRST – For Inspiration and Recognition of Science and Technology. (2016, March 6). Vision and mission. Retrieved from http://www.firstinspires.org/about/vision-and-mission
Fislake, M., & Bogdol, B. (2004). Robonauten-Camp. In Deutsche Gesellschaft für Robotik (DGR) (Ed.), *Robotik 2004. Leistungsstand – Anwendungen – Visionen – Trends.* VDI-Bericht Nr. 1841 (pp. 401–408). Düsseldorf: VDI/VDE-GMA.
Fislake, M., & Bogdol, B. (2005). Das Robonauten-Camp. In A. B. Cremers, R. Manthey, P. Martini, & V. Steinhage (Eds.), *Lecture notes in informatics. INFORMATIK 2005 Informatik LIVE!* (Vol. 1, pp. 183–187). Bonn: Gesellschaft für Informatik e.V. (GI).
Gaudiello, I., & Zibetti, E. (2016). *Learning robotics, with robotics, by robotics: Educational robotics*. London: Wiley-ISTE.
Heffernan, J. S. (2013). *Elementary robotics: Sustaining the natural engineering instincts of children*. North Charleston: CreateSpace Independent Publishing Platform.
Hersh, M., & Kopacek, P. (2015). Roboethics. In M. Hersh (Ed.), *Ethical engineering for international development and environmental sustainability* (pp. 65–102). New York: Springer.
Iceaproject. (2016, April 7). Robotik. Retrieved from http://www.iceaproject.eu
ISTE. (2016, June 6). ISTE –Standards students. Retrieved from: http://www.iste.org/standards/iste-standards/standards-for-students
Johnson, J. (2003). Children, robotics, and education. *Artificial Life and Robotics, 7*, 16–21.

Junior, L. A., Neto, O. T., Hernandez, M. F., Martins, P. S., Roger, L. L., & Guerra, F. A. (2013). A low-cost and simple arduino-based educational robotics kit. Journal of Selected Areas in Robotics and Control. 3(12). Availabble from: http://www.cyberjournals.com/Papers/Dec2013/01.pdf

Karp, T., & Maloney, P. (2013). Exciting young students in grades K-8 about STEM through an afterschool robotics challenge. *American Journal of Engineering Education – Special Edition, 4*(1), 39–54.

Karwall, N. (2010). Visual programming application for children to program robotic toys. *Conference paper. International conference on 'Designing for children' with focus on 'play + learn'*. Available from http://www.designingforchildren.net/2010/papers/nikhil-karwall-designingforchildren.pdf

Khanlari, A. (2013). Effects of robotics on 21st century skills. *European Scientific Journal, 9*(27), 26–36.

Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education, 91*(C), 14–31.

Kraetzschmar, G. K. (2009). Educational robotics: On the role of robotics in learning and education. In C. Zacharias, K. W. ter Horst, K.-U. Witt, V. Sommer, M. Ant, U. Essmann, & L. Mülheims (Eds.), *Forschungsspitzen und Spitzenforschung* (pp. 83–90). New York: Springer.

KUKA. (2016, June 20). Robot based ride: The new KUKA Coaster. Available from http://www.kuka-robotics.com/NR/exeres/895CF070-5E8C-49A4-8A4F-745AF46BE8A3

Miller, D. P., Nourbakhsh, I. R., & Roland, S. (2008). Robots for education. In B. Siciliano, O. Khatib. (Ed.). Springer handbook of robotics. (pp. 1283–1301). Berlin/Heidelberg: Springer.

Misirli, A., & Komis, V. (2014). Robotics and programming concepts in early childhood education a conceptual framework for designing educational scenarios. In C. Karagiannidis, P. Politis, & I. Karasavvidis (Eds.), *Research on e-learning and ICT in education: Technological, pedagogical and instructional perspectives* (pp. 99–118). New York: Springer.

Nugent, G., Barker, B., Grandgenett, N., & Adamchuk, V. I. (2010). Impact of robotics and geospatial technology interventions on youth STEM learning and attitudes. *Journal of Research on Technology in Education, 42*(4), 391–408.

Nugent, G., Barker, B., Grandgenett, N., & Welch, G. (2014). Robotics camps, clubs, and competitions: Results from a U.S. robotics project. In D. Alimisis, G. Granosik, & M. Moro (Eds.), *Proceedings from the 4th international workshop teaching robotics: Teaching with robotics & 5th international conference robotics in education* (pp. 11–18). Padova.

Operto, F., & Veruggio, G. (2008). Roboethics: Social and ethical implications of robotics. In B. Siciliano & O. Khatib (Eds.), *Springer handbook of robotics* (pp. 1499–1524). New York: Springer.

Reynolds, L. (2014). Workshops with little equipment and one computer – Tips and hints. *Proceedings from the GCER. Global conference on educational robotics*. KISS Institute for Practical Robotics, Norman.

Reynolds, L., Clark, R., & Reynolds, J. (2009). Inspire students with robotic toys. *Proceedings from the GCER. Global conference on educational robotics*. KISS Institute for Practical Robotics, Norman.

Robocup. (2016, June 14). Retrieved from http://www.robocup.org

Ropohl, G. (1979). *Eine Systemtheorie der Technik: Zur Grundlegung der Allgemeinen Technologie*. München: Hanser.

Schwartz. (2014, June 15). Robots in the classroom: What are they good for? *Mind/Shift. How we will learn.* Retrieved from https://ww2.kqed.org/mindshift/2014/05/27/robots-in-the-classroom-what-are-they-good-for/

Shoop, R., Flot, J., Friez, T., & Schunn, C. (2016). Can computational thinking practices be taught in robotics classrooms? *Presented at the international technology and engineering education conference.* Washington, DC: National Harbor.

Sleasman, M. (2015). Robots. In H. ten Have (Ed.), *Encyclopedia of global bioethics* (pp. 1–14). New York: Springer.

Sullivan, F. R. (2008). Robotics and science literacy: Thinking skills, science process skills and systems understanding. *Journal of Research in Science Teaching, 45*(3), 373–394.
Taub, H., & Verner, I. (2009). Teaching electronics through constructing sensors and operating robots. In J.-H. Kim, S. S. Ge, P. Vadakkepat, N. Jesse, A. Al Mamun, S. Puthusserypady, et al. (Eds.), *Progress in robotics, communications in computer and information science* (Vol. 44, pp. 255–261). New York: Springer.
The Board of Studies, Teaching and Educational Standards NSW (BOSTES). (2016). A guide to coding and computational thinking across the curriculum. Retrieved 19 July 2016, from https://k6.boardofstudies.nsw.edu.au/wps/portal/go/science-and-technology/statement-on-coding
Timms, M. (2016). Letting artificial intelligence in education out of the box: Educational cobots and smart classrooms. *International Journal of Artificial Intelligence in Education, 26*(2), 701–712.
Ucgul, M., & Cagiltay, K. (2014). Design and development issues for educational robotics training camps. *Int J Technol Des Educ, 24*, 203. doi:10.1007/s10798-013-9253-9

Further Readings

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education, 72*, 145–157.
Birk, A., Poppinga, J., & Pfingsthorn, M. (2009). Using different humanoid robots for science edutainment of secondary school pupils. In L. Iocchi, H. Matsubara, A. Weitzenfeld, & C. Zhou (Eds.), *RoboCup 2008: Robot Soccer World Cup XII, lecture notes in computer science* (Vol. 5399, pp. 451–462). New York: Springer.
Chiou, A. (2010). Multiple format search and rescue robot as a competitive arena. In R. Nakatsu, T. Naoko, F. Naghdy, W. Wong Kok, & P. Codognet (Eds.), *Cultural computing. Advances in information and communication technology* (Vol. 333, pp. 1–8). New York: Springer.
Gallenbacher, J. (2015). Vorwort zur 10,000. Infos Informatik allgemeinbildend begreifen. In J. Gallenbacher (Ed.), *Proceedings from the Gesellschaft für Informatik (GI)*, (Vol. P-249). *INFOS 2015 – Informatik allgemeinbildend begreifen. Lecture Notes in Informatics (LNI)* (pp. 5–7). Gesellschaft für Informatik.
Karna-Lin E., Pihlainen-Bednarik K., Sutinen E., & Virnes M. (2006). Can robots teach? Preliminary results on educational robotics in special education. *Proceedings from the ICALT '06. Sixth IEEE International Conference on Advanced Learning Technologies* (pp. 319–321). IEEE.
Pfadenhauer, M., & Dukat, C. (2016). Zur Wirkung von Technik. Ethnographisch gestützte Überlegungen am Beispiel der Social Robotics in der Demenzbetreuung. In N. Burzan, R. Hitzler, & H. Kirschner (Eds.), *Materiale Analysen. Methodenfragen in Projekten* (Vol. Erlebniswelten, pp. 33–52). New York: Springer.
Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–424.
Spyros, G. T. (2016). *Roboethics. Intelligent systems, control and automation: Science and engineering. A navigating overview.* New York: Springer.
Weiß, K., Volkmann, T., & Herczeg, M. (2015). Das Kreativlabor als generationsverbindendes Angebot im Bereich der praktischen Informatik. In J. Gallenbacher (Ed.), *Proceedings from the Gesellschaft für Informatik (GI)*, (Vol. P-249). *INFOS 2015 – Informatik allgemeinbildend begreifen. Lecture Notes in Informatics (LNI)* (pp. 301–307). Gesellschaft für Informatik.

28 Drawing and Sketching: Understanding the Complexity of Paper–Pencil Interactions Within Technology Education

Diarmaid Lane

Abstract

The emergence of sophisticated digital systems that support the generation of complex graphical models has changed how people use freehand sketching as a tool in designing and problem solving. While digital technologies offer exciting alternatives for expressing design ideas and communicating visually, the ability to create visual images using freehand interactions remains a fundamental skill that has central importance in design and technology classrooms. The value in a sketch is much more than the generated visual image. *Sketching* is a tool that supports the tacit, complex cognitive processes involved in sense-making, creative discovery, and problem solving.

Through an analysis of contemporary literature, this chapter examines the nature of sketching through both visual cognition and skills building lenses. Firstly, a foundation is outlined in relation to the nature of visual mental images and how these are generated and externalized during *drawing* and *sketching*. Secondly, *drawing* and *sketching* are defined and the pedagogical considerations for developing these skills are described using a theoretical model for developing expertise.

Keywords

Sketching • Drawing • Interventions • Visual mental imagery • Memory • Visual perception

D. Lane (✉)
School of Education, University of Limerick, Limerick, Ireland
e-mail: diarmaid.lane@ul.ie

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_32

Contents

Introduction

The ability to communicate visually through the medium of *sketching* is an important skill that involves both cognitive and physiological processes (Frith and Law 1995). Even with the advent of sophisticated digital graphics software, *sketching* remains a fundamental skill that supports higher-order cognitive processes such as creative problem-solving and innovative critical-thinking.

Sketching is a tacit, complex skill that can be developed with appropriate intervention. While there are many textbooks detailing activities that attempt to promote the development of *sketching* skills, there are few interventions that validate the effectiveness of these with empirical evidence (Verstijnen et al. 1998). The lack of contemporary research focused on the effectiveness of *sketching* interventions may be due to difficulties that arise when attempting to measure the development of *sketching* expertise and sketch quality. Instead, contemporary research in the area of *freehand sketching* is largely focused on examining factors such as behavior during *sketching* episodes (Middleton 2008) and attitudes towards *sketching* (Alias et al. 2002).

Some of the most significant research that has contributed towards a more comprehensive understanding of *sketching* expertise has been conducted in the area of human memory systems and visual image processing. To this end, the first section of this chapter deals with the nature of visual mental images and how these are generated and externalized during *drawing* and *sketching* episodes.

Visual Perception and Visual Mental Imagery

It is important to understand how human beings perceive the visual world and how this can help us better understand the complexity of visual communication. Visual thinking and spatial reasoning are critical skills that contribute to *freehand sketching*. During *sketching*, students need to be able to think visually in order to understand what an object looks like and spatially reason in order to know where an object is located relative to other objects in a scene (Glasgow and Papadias 1992). *Visual Perception* and V*isual Mental Imagery* have often been regarded as cognitive functions driven by common mechanisms.

Visual Perception is the process through which information from a visual stimulus is received through the eye (sensory input) and transmitted through the visual pathways to the visual cortex. This is the basis through which human beings interpret the visual world. Visual information can be forgotten immediately or can be stored in memory as a chunk of information. Visual perception is a "*bottom-up process*" (Borst and Kosslyn 2008) that occurs when a physical stimulus is being viewed, resulting in the creation of "*modality specific internal representations*" (Kosslyn et al. 1993).

Visual Mental Imagery is a unique, "*top-down*" (Borst and Kosslyn 2008) "*graphics processor*" like component of the cognitive architecture (Stillings et al. 1995). It can also be defined as "*experience resembling perceptual or motor activity*" influenced by nonpictorial, "*propositional schematic representations*" that occur when the relevant external perceptual stimuli or motor actions are absent (Bergena et al. 2007; Ranganath 2006). *Visual Mental Imagery* is utilized during *freehand sketching* where the maker reactivates propositional information in long-term memory in order to reorganize and synthesize the information in short-term working memory. The images generated during the retrieval of information from long-term memory correspond to representations of real physical scenes or to abstract concepts that are manipulated in ways similar to physical forms (Glasgow and Papadias 1992).

Numerous researchers have shown that many of the same processes used in *Visual Perception* are the same as those used in *Visual Mental Imagery* (Finke 1990; Kosslyn 2005). Therefore, it can be assumed that many of the same processes used in *Freehand Drawing* and *Freehand Sketching* are similar.

Memory Systems

The completion of complex cognitive tasks such as idea generation and problem solving through *sketching* is based on the retrieval of large amounts of information from memory (Ericsson and Kintsch 1995).

The classical theory of the cognitive architecture (Stillings et al. 1995) includes three types of memory: working memory (short-term), declarative and procedural (both long term). *Short term (working) memory* has particular importance in both *drawing* and *sketching*. It is a complex system that involves a range of interacting subcomponents that provide an interface between memory, attention, and perception (Baddeley 1998; Stillings et al. 1995). Integral to the model of working memory proposed by Baddeley (1998) is a central executive and two subsystems (Fig. 1), specifically, the "*phonological loop*" and the "*visuospatial sketchpad*" (Baddeley 1998; Bruyer and Scailquin 1998) that function independently of each other. The "*phonological loop*" controls the storage of new sounds or words. The

Fig. 1 Model of working memory proposed by Baddeley (1998)

"*visuospatial sketchpad*" stores visual nonverbal information (e.g., the orientation of an observed cube in space before being drawn) (Baddeley 1998; Bruyer and Scailquin 1998).

The "*visuospatial sketchpad*" plays a significant role in both *drawing* and *sketching*. It is activated during the stage where an image is created in "*the mind's eye*" (Fish and Scrivener 1990). It is then stored for a short period of time before being externalized on paper or a digital screen. The limitation of working memory has a significant effect on human cognition. It constrains the ability to comprehend information (Adam-Just and Carpenter 1992) and it determines how complex cognitive tasks are solved (Stillings et al. 1995). Research has found that working memory can only store three or four pieces of information at any one time (Broadbent 1975; Cowan 2001) and this further highlights its limitations. This has particular importance in relation to freehand sketching where the externalization of visual imagery assists in reducing the "*cognitive load*" (Pass et al. 2003) experienced during visual problem solving and exploration.

Drawing, Sketching, and Visual Processing Theory

The creation of images through freehand interactions is a complex cognitive process. Based on the literature presented in the previous sections, a theoretical model representing the relationship between both is presented in Fig. 2. The purposeful mark-making using paper and pencil interaction is primarily driven by the capacity of the working-memory system to generate visual mental images. During *freehand drawing*, a visual metal image is *encoded* in working memory when a visual stimulus is perceived. During *freehand sketching,* propositional information in long-term memory is used to *generate* a visual mental image.

It is important that educators, who are interested in developing students freehand sketching skills, understand the theory associated with visual perception, visual mental imagery, and working memory. Additionally, it is important to understand the principles of geometry with particular reference to orthogonal projection and perspective. In a broad sense, the maker creates a visual mental image in their imagination and communicates this using a range of graphical symbols. The clarity of the visual mental image depends on many variables including the presence or absence of a visual stimulus, the complexity of the image to be externalized, and the ability of the maker to visualize spatial information.

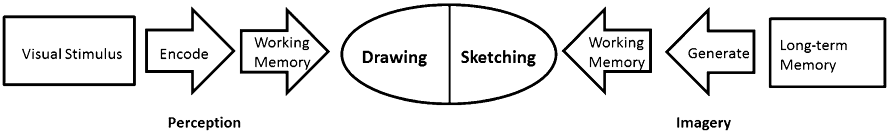


Fig. 2 Mapping Visual Processing Theory with *Drawing* and *Sketching*

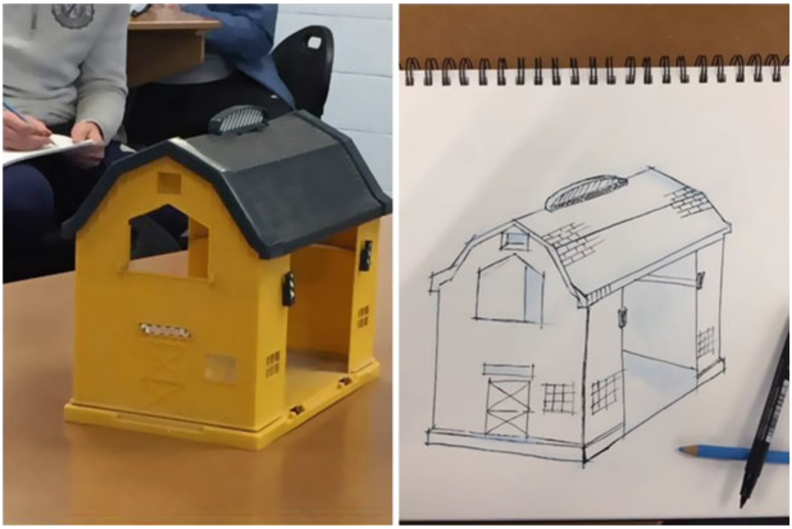


Fig. 3 The presence of a visual stimulus in Freehand Drawing

Sketching and *Drawing*

There are ambiguities within the literature in relation to definitions for *drawing* and *sketching*. Both *drawing* and *sketching* involve the purposeful mark-making on a flat, 2D surface using a medium such as a pen or pencil or in the case of digital sketching, a stylus on a touch screen. The marks that are produced on paper or on a digital touchscreen are symbolic in nature and lie somewhere between purely depictive representation and purely descriptive representation (Fish and Scrivener 2004; Palmer 1978).

Freehand Drawing is the communication of an observable object or scene using detailed and purposeful methods of projection. It does not involve any mental manipulation of visual mental imagery and is primarily driven by visual perception. During *freehand drawing*, the maker has the benefit of using visual perception to help refresh these internal representations in short-term working memory. *Freehand drawing* is a slow, controlled, and reflective process through which a detailed externalization such as a painting is produced. During this process, the creator can constantly refresh the image in their mind's eye by reverting attention back to the visual stimulus or object (Fig. 3).

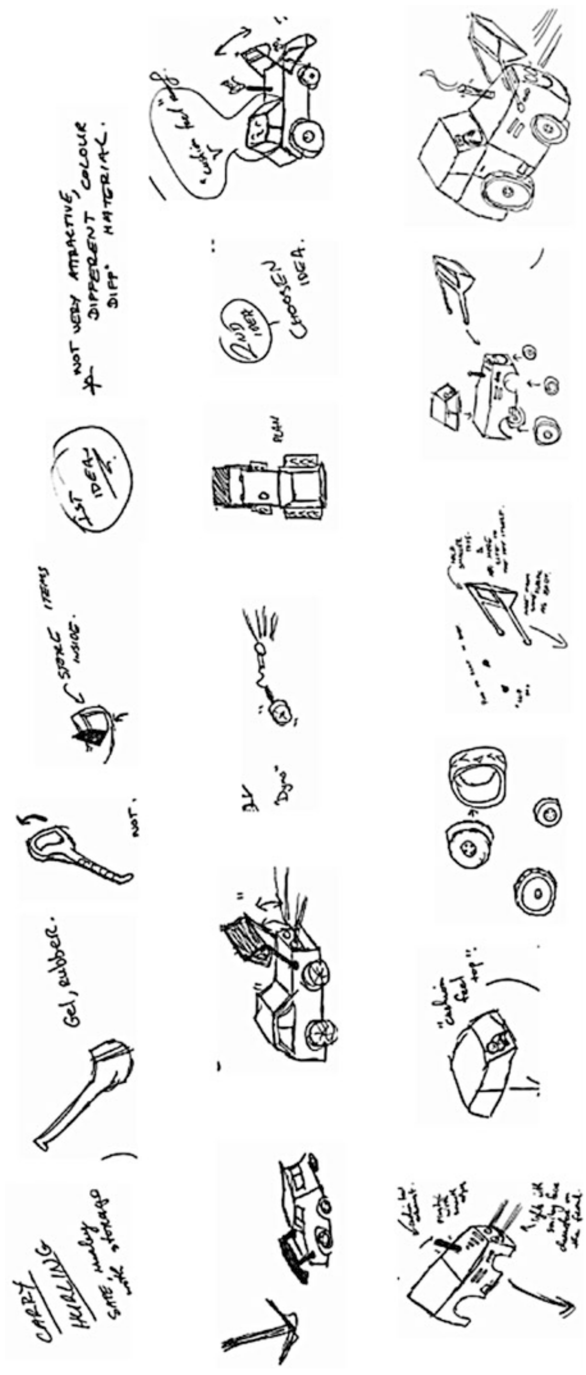


Fig. 4 Sense-making and problem solving through freehand *sketching*

Freehand Sketching on the other hand is the communication of a visual mental image with no reference to any supporting visual stimulus. *Sketching* plays an important role in supporting the synthesis of fragmentary information stored in long-term memory. *Freehand Sketching* is a tool that supports sense-making and creative discovery during design based tasks (Fig. 4). New information can be extracted from sketches by manipulating and synthesizing visual images in new ways. *Freehand sketching* is considered a fluid, automatic, and reflexive process in which externalizations are communicated. With the absence of a visual stimulus, the creator needs to be able to retrieve imagery from long-term memory and visualize this in their "*mind's eye.*"

Goldschmidt (2003) describes two essential components of *drawing*. She firstly describes it as a fluid activity, which does not give spare attention to the production process. The second component concerns the command of orthogonal projection, which enables the precise communication of an object based on geometric rules. On the other hand, *sketching* is a "*systematic dialectic*" between seeing and imagining (Goldschmidt 1991) where the ability to manipulate and synthesize visual mental imagery is fundamental. Fish and Scrivener (1990) consider *sketching* as a support tool for the synthesis of visual mental imagery. The demand for *sketching* is stimulated by the need to foresee the results of manipulation and synthesis of objects without actually seeing or executing such operations. The utilization of scaffolds such as words, pictures, and models as imitations of objects, scenes, or events not physically present significantly increases the ability to engage in mental visualization (Fish and Scrivener 1990).

Fundamental to creative expression and designing, *sketching* offers a medium to problem solve, record ideas for later use, and explore design modifications and alternatives (Prats et al. 2009). It is a low cost, fast, and flexible tool (Prats et al. 2009) that allows people such as designers, problem solvers, and geometricians to generate external representations or early sketches that can be utilized as a medium in reflexive conversation between the sketcher and the brief (Kim et al. 2009) as a "*sense making activity*" (Kimbell 2004, p.137).

Sketching is the ability to produce a snapshot image of cognitive activities (Schutze 2003) during the development of visual, creative ideas, and hypotheses (Fish and Scrivener 1990; Suwa et al. 1998). Initial "*study sketches*" are completed in the early stages of design activities and are of particular interest in design and technology education. Sketches can often be so idiosyncratic that they are only comprehendible by their maker (Fig. 5) (Goldschmidt 1991).

Special Attributes of Sketches

Sketching has experienced little change since Leonardo da Vinci (1452–1519). The uniqueness of hurried and untidy sketches incorporating rough hatching and linetypes using mediums such as crayon, pencil, or watercolor on scrap pieces of paper remains unchanged. Examination of these unique attributes gives an insight into the underlying cognitive processes that occur during the production of external

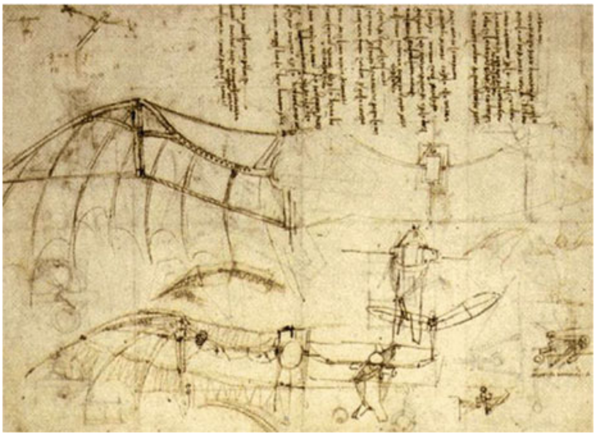


Fig. 5 Combination of sketches and notes in one of Da Vinci's idiosyncratic invention sketches

representations (Fish and Scrivener 1990). The attributes of sketches can be outlined as follows:

- Sketches use two dimensional sign systems that include descriptive linetypes as well as written notes to represent three dimensional visual information (Deregowski 1970; Fish and Scrivener 1990).
- Linetypes and sign systems that are communicated in sketches are descriptive and depictive in nature and assist in the mental gymnastics between two modes of visual representation.
- Sketches contain both selective and disjointed information. They are records of a sequence of acts that combine visual perceptual information with images generated from memory (Fish and Scrivener 1990).
- Sketches contain deliberate or accidental indeterminacies to help rouse the mind to creative thought processes and invention. Indeterminacies include scribbles, smudges, rough cross hatching, dark mysterious areas of shadow, and shade as well as empty or negative space.

Sketching and Drawing as tools to augment CAD

It is important to consider the merits of freehand sketching bearing in mind the wide range of digital software available through which designs can be virtually realized and animated. It could possibly be argued that freehand sketching is now redundant; however, it could be also argued that freehand sketching is an even more critical skill in the current technological age.

"*Do I have to sketch first or do I model on CAD first?*" Sketching can be used as a tool to augment CAD models. Software such as GoogleSketchup, SolidWorks, and Fusion360 can easily be used to generate sophisticated CAD models. Quick modifications and representations of alternatives to these CAD models can sometimes be tedious and problematic. A CAD image can sometimes be used as an underlay to explore possible design modifications using freehand sketching (Fig. 6).

Alternatively sketching can be used as a developmental and iterative tool to facilitate the sense-making process in developing an idea. Final iteration sketches can easily be imported to CAD software and used as a reference to build well-proportioned models (Fig. 7).

Sketching can be either analogue or digital. Analogue sketching is typically carried out through paper and pencil interactions. Carbon and tracing paper can also be very effectively used in quickly copying and modifying geometry in sketches (Fig. 8).

Digital sketching has come to prominence over recent years with the increasing popularity of tablet devices. Apps such as Sketchbook by Autodesk and Adobe Illustrator Draw allow designers to express ideas and concepts through intuitive interfaces with a range of perspective tools. Files of sketches are typically compatible with other software through which parametric and free-form models can be generated by referencing the sketch (Fig. 9).

Interventions: *Freehand Drawing* and Visual Perception

Across the domains of design, technology, and engineering education, *sketching* interventions focus on developing self-confidence and reducing inhibition (Booth et al. 2016; Edwards 1989; van Passel and Eggink 2013), developing technical representation skills within engineering education (Jacobs and Brown 2004), and developing visual thinking and creative discovery (Lane et al. 2010; van der Lugt 2002).

Fig. 6 Augmenting a CAD model using sketching (Smith 2016)

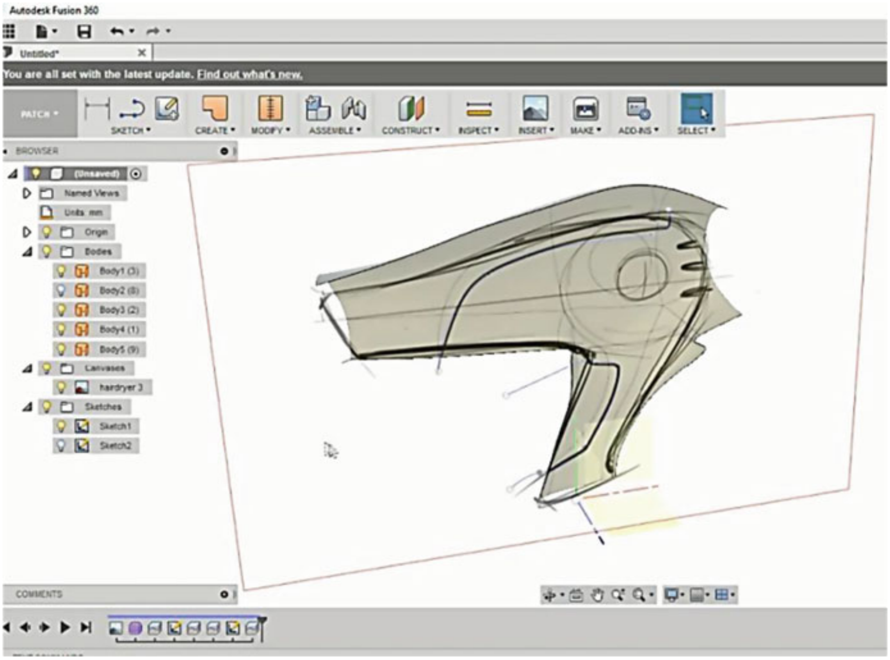


Fig. 7 Sketching as an iterative tool using Autodesk Fusion360 (Smith 2016)

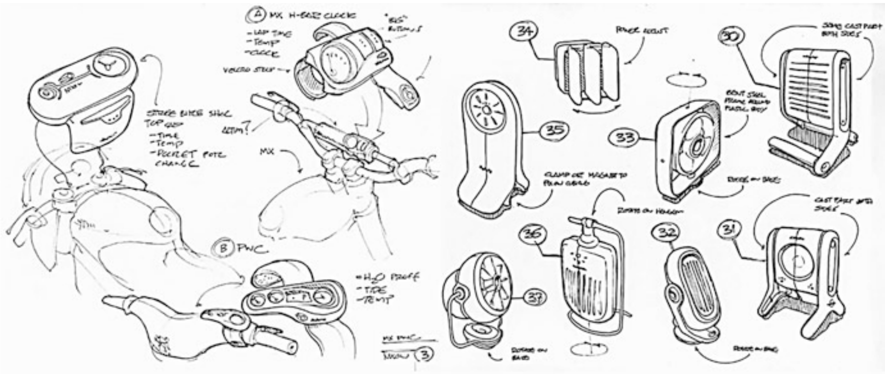


Fig. 8 Analogue sketching as an iterative tool (Smith 2016)

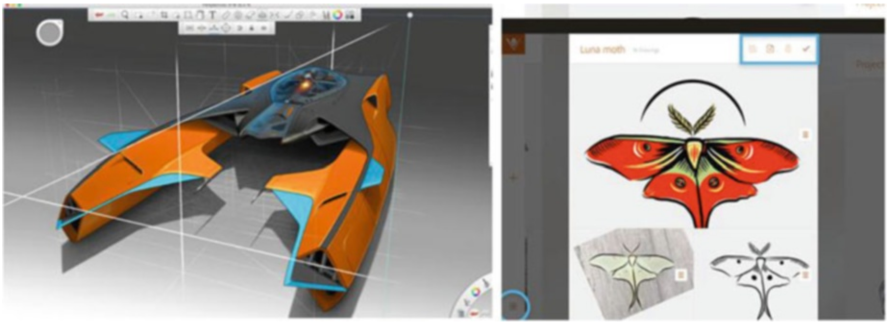


Fig. 9 Sketchbook (*left*) (Autodesk 2016) & Adobe Illustrator Draw (*right*) (Adobe Systems 2015)

The command of orthogonal projection and fluidity are the two key components of *drawing* described by Goldschmidt (2003). These provide a logical starting point for examining interventions associated with developing expertise in *drawing* and *sketching*.

Command of Orthogonal Projection

The precise communication of an object based on geometric rules is particularly important in *drawing* and *sketching*, particularly when the visual representation is to be interpreted by somebody other than the maker. The ability to *freehand draw* should be considered as the first building block towards developing *sketching* expertise within design and technology education. Interventions focused on *free-hand drawing* help develop confidence, accuracy, and an appreciation of the principles of the picture plane. Encoding and refreshing small chunks of information in short-term memory is made easier when attention can be reverted to a visual stimulus at any time.

Edwards (1989) and Lane et al. (2012) describe the use of techniques such as upside-down *drawing* to help students in turning off the verbal left hemisphere and switching on the visual, more holistic right hemisphere. These techniques initially focus on the communication of 2D line *drawing*s where the original *drawing* is inverted in order to activate right hemisphere actions in the brain (Fig. 10). The challenge is in helping students to "see" the visual information and create that image in short-term memory and communicate it. Small chunks of visual information can be processed and communicated as the student has the benefit of reverting attention back to the visual stimulus in order to refresh their short-term memory.

Progressing from 2D "*copying*" activities, the ability to draw 3D physical objects is the next phase of development. Objects can be selected that vary in complexity from regular geometries to complex objects with varying textures (Fig. 11).

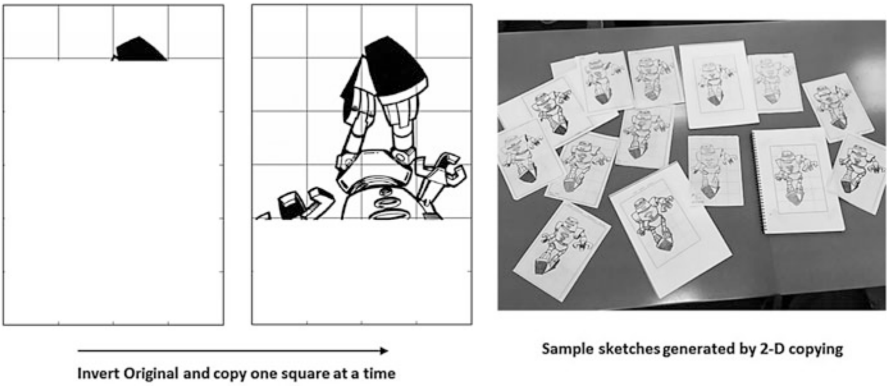


Fig. 10 Example of a 2-D copying activity

Fig. 11 Sketching complex objects

The use of a picture plane helps students to understand the rules of orthogonal projection as a clear interpretative process (Kavakli and Gero 2001). The principles associated with the picture plane date as far back as 1423_{AD} when Filippo di Ser Brunellescho developed an algorithm for making pictures. Through the use of a picture plane (Fig. 12), points on a sketched image correlate with points in a represented setting. This is done by repeatedly connecting the point of view to points in the scene using a transparent plane of glass and ensuring that the spectator is a fixed distance from the plane. Lines constructed will intersect the picture plane at a point that represents the corresponding point in the world (Binkley 1989).

The goal for teachers teaching perception-based *freehand drawing* skills is to eliminate the need for the physical picture plane and develop students' ability to imagine it instead. Subsequent to this stage, students should have the confidence, precision, and command of orthogonal projection to create *drawing*s with the support of a visual stimulus using a range of media.

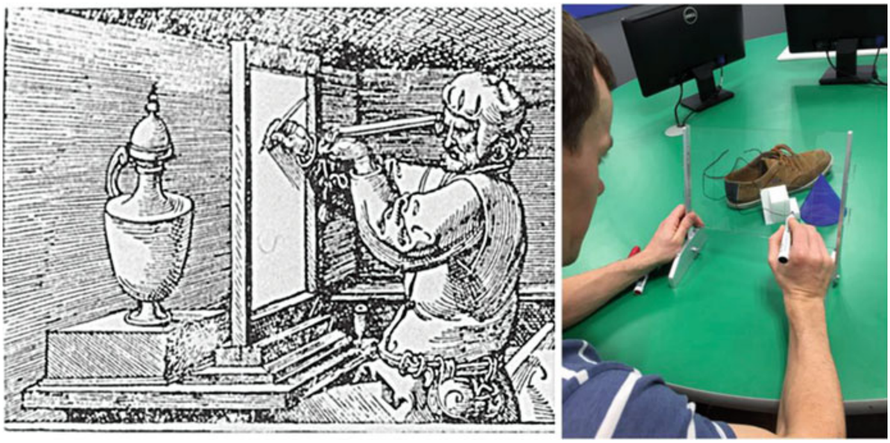


Fig. 12 Artist *drawing* directly on the picture plane (left, taken from (Binkley 1989) and adaption of the same concept for in an intervention to develop sketching expertise (Lane et al. 2012)

Fluidity

Building on the skills developed in *freehand drawing*, *freehand sketching* is a more complex process. With the absence of a visual stimulus, students need to retrieve "*graphical libraries*" from long-term memory and generate visual mental imagery in working memory. Sketches provide an external memory aid (Simon 1973) and reduce cognitive load of working-memory during conceptual design tasks. The communication of these visual mental images through paper and pencil interactions is necessary for a range of activities in design and technology education including idea generation, product *sketching*, and problem-solving. Many research studies have investigated the nuances of *sketching* skill and behavior in different disciplines such as Engineering Design (Yang and Cham 2007), Fashion Design, Architecture, Graphic Design, Product Design (Jonson 2005), and Automotive Design (Tovey et al. 2002). However, there are limited studies that validate the effectiveness of interventions in improving *sketching* expertise.

The process of creating images through paper and pencil interactions should be automatic and reflexive in nature. Research in behaviors and attitudes towards *sketching* reveals more information in relation to expertise and the concept of fluidity during *sketching* episodes that require generation of visual mental imagery without the scaffold of a visual stimulus.

- Experts tend to use *freehand sketching* more effectively as a "*sense-making tool*" (Jonson 2005).
- Expertise in *freehand sketching* is associated with high levels of creativity (Verstijnen et al. 1998).
- Expert sketchers tend to perform better in mental "*restructuring*" tasks (Verstijnen et al. 1998).

- Expert sketchers tend to communicate significantly more detail in their sketches (Kavakli et al. 1999; Yang and Cham 2007).
- Experts tend to engage in significant exploration at the beginning of design-based *sketching* tasks while the rate of generating actions tends to increase as the activity progresses (Middleton 2008).

While these behaviors are associated with expertise in *freehand sketching*, it is difficult to translate these into a ready-made intervention for classroom use. Controlling the rate of information processing especially for those with who are inexperienced in sketch production and sketch recognition (Kavakli and Gero 2001) is important in the early stages of skill development. Much early focus is put into reducing inhibition and increasing self-confidence in the students own ability. Ensuring that student's complete tasks similar to those described earlier for perception-based *freehand drawing* will help increase self-confidence and reduce inhibition.

Within design and technology education, *sketching* is widely considered as a medium for recording the journey through iterations and communicating solutions to problems (Hope 2008; Schutze 2003; Storer 2008). For example, in Fig. 13, it can be seen how tracing paper can be used effectively to copy and modify design ideas during the exploration process.

Storer (2008) considers the importance of industrial designers becoming experts in *sketching* despite the emergence of sophisticated CAD software. Various *sketching* techniques such as crating, primitives, and Boolean operations (Fig. 14)

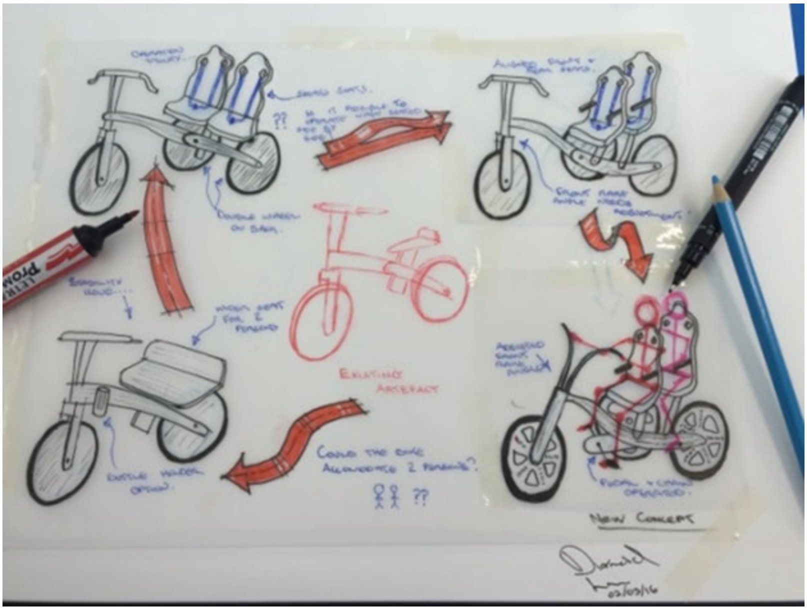


Fig. 13 Using tracing paper to copy and modify sketches

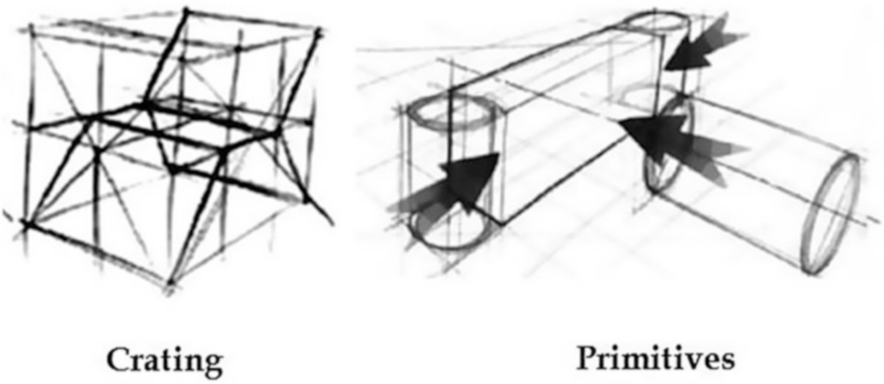


Fig. 14 Sketching techniques applied by Storer (2008)

that are utilized by industrial designers are presented by Storer (2008) and the importance of building a "*graphical library*" of products and images that can be accessed during design activities is also considered.

Conclusions and Future Directions

While the theory and research presented in this chapter describes the cognitive processes and techniques involved in developing the ability to draw and sketch using freehand interactions, it must be considered that there are numerous other factors that contribute to *sketching* expertise. While expertise in *freehand sketching* involves skills such as fluency, command of orthogonal projection, and an understanding of the picture plane (Goldschmidt 2003), there are other aspects to *freehand sketching* skill that may need to be developed without freehand analogue or digital interactions. These include creative and innovative skills (Frith and Law 1995). However, these are things that come from within, rather than being a routine response to something in the outside world. A student might be able to produce high quality sketches with the aid of a visual stimulus but might struggle to generate ideas when attempting to solve conceptual problems.

The need for *freehand sketching* has been questioned across design and technology domains (Jonson 2005) with the emergence of sophisticated ideation software. Client expectations for photo-realistic images at the ideation stage of projects gives rise to the popularization of computer software. However, *sketching* still has a very important role to play in terms of self-dialogue, re-interpretation of ideas (Schon and Wiggins 1992), sense-making, and the rough restructuring of ideas during initial problem-solving, exploration, and ideation (Tovey et al. 2003).

In conclusion, it is important that educators and curriculum developers understand the basis of the theoretical literature that informs the development of *sketching* expertise. Rather than solely implementing activities in the classroom, an understanding of the theory presented will help teachers in developing custom pedagogies and interventions to support the development of *sketching* expertise.

References

Adam-Just, M., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*(1), 122–149.

Adobe Systems, I. (2015). Illustrator Draw. Retrieved 02 Dec 2016, from https://helpx.adobe.com/mobile-apps/how-to/illustrator-draw-get-started.html

Alias, M., Gray, D. E., & Black, T. R. (2002). Attitudes towards sketching and drawing and the relationship with spatial visualisation ability in engineering students. *International Education Journal, 3*(3), 11.

Autodesk, I. (2016). Sketchbook Retrieved 02 Dec 2016, from http://www.autodesk.com/products/sketchbook-pro/features/all/gallery-view

Baddeley, A. (1998). Recent developments in working memory. *Current Opinion in Neurobiology, 8*, 234–238.

Bergena, B. K., Lindsayb, S., Matlockc, T., & Narayanand, S. (2007). Spatial and linguistic aspects of visual imagery in sentence comprehension. *Cognitive Science, 31*, 733–764.

Binkley, T. (1989). The wizard of ethereal pictures and virtual places. *Leonardo*. Computer Arts in Context Supplemental Issue, 13–20.

Booth, J. W., Taborda, E. A., Ramani, K., & Reid, T. (2016). Interventions for teaching sketching skills and reducing inhibition for novice engineering designers. *Design Studies, 43*, 1–23.

Borst, G., & Kosslyn, S. M. (2008). Visual mental imagery and visual perception: Structural equivalence revealed by scanning processes. *Memory & Cognition, 36*(4), 849–862.

Broadbent, D. A. (1975). The magical number seven after fifteen years. In A. Kennedy & A. Wilkes (Eds.), *Studies in long-term memory*. New York: Wiley.

Bruyer, R., & Scailquin, J. (1998). The visuospatial sketchpad for mental images: Testing the multicomponent model of working memory. *Acta Psychologica, 98*, 17–36.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioural and Brain Sciences, 24*(1), 87–114.

Deregowski, J. B. (1970). *Illusions, patterns and pictures*. New York: Academic Press.

Edwards, B. (1989). *Drawing on the right side of the Brian*. New York: Putnam Publishing Group.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102*(2), 211–245.

Finke, R. (1990). *Creative imagery: Discoveries and inventions in visualisation*. East Sussex: Psychology Press.

Fish, J., & Scrivener, S. (1990). Amplifying the Mind's eye: Sketching and visual cognition. *Leonardo, 23*(1), 117–126.

Fish, J., & Scrivener, S. (2004). Cognitive catalysis: Sketches for a time-lagged brain. In G. Goldschmidt & W. L. Porter (Eds.), *Design Representation*. London: Springer.

Frith, C., & Law, J. (1995). Cognitive and physiological processes underlying drawing skills. *Leonardo, 28*(3), 203–205.

Glasgow, J., & Papadias, D. (1992). Computational Inagery. *Cognitive Science, 16*(3), 355–394.

Goldschmidt, G. (1991). The dialectics of sketching. *Creativity Research Journal, 4*(2), 123–143.

Goldschmidt, G. (2003). The backtalk of self-generated sketches. *Design Issues, 19*(1), 17.

Hope, G. (2008). *Thinking and learning through drawing*. London: Sage Publications Limited.

Jacobs, B. J., & Brown, T.A. (2004). *Addressing Inequities in Engineering Sketching Skills*. Paper presented at the creating flexible learning environments: Proceedings of the 15th Australasian Conference for the Australasian Association for Engineering Education and the 10th Australasian Women in Engineering Forum Toowoomba, Queensland.

Jonson, B. (2005). Design Ideation: The conceptual sketch in the digital age. *Design Studies, 26*, 12.

Kavakli, M., & Gero, J. S. (2001). Sketching as mental imagery processing. *Design Studies, 22*, 18.

Kavakli, M., Suwa, M., Gero, J., & Purcell, T. (1999). Sketching interpretation in novice and expert designers. In J. S. Gero & B. Tversky (Eds.), *Visual Reasoning in Design* (pp. 209–219). Sydney: Key Centre of Design Computing and Cognition, University of Sydney.

Kim, J., Bouchard, C., Omhover, J.F., Aoussat, A., Moscardini, L., Chevalier, A., Tijus, C., & Buron, F. (2009). *A Study on Designer's Mental Process of Information Categorization in the Early Stages of Design*. Generation of new image-based and user-centered solutions for design. University Paris 8. Paris.

Kimbell, R. (2004). Ideas and ideation. *The Journal of Design and Technology Education, 9*(3), 3.

Kosslyn, S. M. (2005). Mental images and the brain. *Cognitive Neuropsychology, 22*(3/4), 333–347.

Kosslyn, S. M., Alpert, N. M., Thompson, W. L., Maljkovic, V., Weise, S. B., Chabris, C. F., Hamilton, S. E., Rauch, S. L., & Buonanno, F. S. (1993). Visual Mental Imagery Activates. Topographically Organized Visual Cortex: PET Investigations. *Journal of Cognitive Neuroscience 5*(3), 263–287.

Lane, D., Hamlin, A. J., Veurink, N., & Seery, N. (2012). *The role of observational sketching in forming and manipulating graphical libraries*. Paper presented at the ASEE annual Conference, San Antonio.

Lane, D., Seery, N., & Gordon, S. (2010). Promoting creative discovery and mental synthesis through freehand sketching. Paper presented at the visualizing change: Graphics on the horizon, Houghton, Michigan.

Middleton, H. (2008). Examining design thinking. In H. Middleton (Ed.), *Researching technology education – Methods and techniques*. Rotterdam: Sense Publications.

Palmer, S. (1978). Fundamental aspects of cognitive representation. In E. Rosch & B. Lloyd (Eds.), *Cognition and Categorization*. Hillside: Lawrence Erlbaum Associates.

Pass, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1–4.

Prats, M., Lim, S., Jowers, L., Garner, S. W., & Chase, S. (2009). Transforming shape in design: Observations from studies of sketching. *Design Studies, 30*(5), 503–520.

Ranganath, C. (2006). Working memory for visual objects: Complementary roles of inferior temporal, medial temporal, and prefrontal cortex. *Neuroscience, 139*(1), 277–289.

Schon, D. A., & Wiggins, G. (1992). Kinds of seeing and their functions in designing. *Design Studies, 13*(2), 135–156.

Schutze, M., Sachse, P., & Romer, A. (2003). Support value of sketching in the design process. *Research in Engineering Design, 14*(2), 89–97.

Simon, H. A. (1973). The structure of ill structured problems. *Artificial Intelligence, 4*(3–4), 181–201.

Smith, J. (2016). DV20455: Fusion 360 and SketchBook as Teammates. Retrieved 02 Dec 2016, from http://au.autodesk.com/au-online/classes-on-demand/class-catalog/2016/fusion-360/dv20455#chapter=0

Stillings, N. A., et al. (1995). *Cognitive Science: An introduction*. London: MIT Press.

Storer, I. (2008). Reflecting on professional practice: Capturing an industrial designer's expertise to support the development of the sketching capabilities of novices. *Design and Technology Education: An International Journal, 10*(1), 19.

Suwa, M., Gero, J., & Purcell, T. (1998). *The roles of sketches in early conceptual design processes.* Paper presented at the proceedings of 20th annual meeting of the cognitive Science society, Madison, Wisconsin.

Tovey, M., Porter, S., & Newman, R. (2002). Sketching, concept development and automotive design. *Design Studies, 24*(2), 19.

Tovey, M., Porter, S., & Newman, R. (2003). Sketching, concept development and automotive design. *Design Studies, 24*(2), 135–153.

van der Lugt, R. (2002). Brainsketching and how it differs from brainstorming. *Creativity and Innovation Management, 11*(1), 12.

van Passel, P., & Eggink, W. (2013). *Exploring the influence of selfconfidence in product sketching*. Paper presented at the International Conference on Engineering and Product Design Education, Dublin Institute of Technology, Dublin, Ireland.

Verstijnen, I., Hennessey, J. M., van Leeuwen, C., Hamel, R., & Goldschmidt, G. (1998). Sketching and creative discovery. *Design Studies, 19*, 28.

Yang, M. C., & Cham, J. G. (2007). An analysis of sketching skill and its role in early stage engineering design. *Journal of Mechanical Design, 129*(5), 7.

Using Computer Technologies in Design and Technology Education: Teaching-Learning Process

29

Jacques Ginestié

Abstract

Design and technology education has a long tradition of using ICT applications. The development of digital technologies amplifies this use and opens many new pedagogical plans. In this chapter, we study this particular domain through, on one hand, an analysis and the design of controlled or automated systems and, on the other hand, the use of computer-aided design and computer-aided manufacturing in pedagogical situations. Both of these domains are plentiful for meaningful situations related to the modern environment – for the students' familiar environment and also for discovering and knowing the world of contemporary industry. Thus, we discuss, with the aim of understanding in design and technology education, examining what the use of these digital technologies introduce to and modify in students' learning. This paper is based on two studies: (1) the first one concerns the understanding developed by students of a complex automated system in the aim to program its different controls and (2) the second one is based on the use of CAD software. We examine the learning process in the framework of the theory of activity and the anthropological analysis, based on the individuation and socialization processes.

Keywords

Design and technology education • Individuation • Socialization • Digital technologies • Complex systems • Computer-aided design • Computer-aided manufacturing

Contents

J. Ginestié (✉)
Aix-Marseille Université, EA 4671 ADEF, Marseille, France
e-mail: jacques.ginestie@univ-amu.fr

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_31

Introduction

Historically, design and technology education (DTE) has dealt with information and communication technology (ICT) since the first implementations of curricula, for some countries (i.e., France, Germany, the UK) in the mid-1980s. These curricula follow, more or less, the evolution of these technologies and the impact of ICT on the teaching-learning process. We can make distinctions between different kinds of ICT uses, for different purposes and different kinds of applications. Because DTE must be relevant to high-tech, the use of ICT is central if we consider that its aim is to develop an understanding of the contemporary world of objects. Because DTE must be relevant to the social world of work, the use of ICT is also central if we consider the placement of these tools in a large part of professional activities.

These two axes define a large part of DTE's curricula around the world. The first axis is mainly centered on the understanding of the world of objects – mainly the world of automated or controlled systems. The second axis is organized around the development of the ability to produce solutions to a problem. Both axes are closely linked, and there is a long tradition for this link, going back long before the existence of DTE and long before ICT-based education; DTE is deeply inscribed in this double, very old pedagogical current of learning by doing and of understanding the world (Cygnaeus 1910; Dewey 1916; Freinet 1946; Montessori 1912), reinforced by the development of cognitive psychology (Piaget 1947; Vygotski 1962, 1998; Vygotski and Piaget 1997).

The introduction of ICT in DTE opens many pedagogical opportunities, widely supported by the development of digital technologies. Let us look at what has happened over the last 30 years. The 1980s saw the arrival of the personal computer with about 64 KB of RAM and 8 bit processors, while today the ordinary smartphone includes 64 GB of RAM and 64 bit quad-core processors. This massive increase in performance and miniaturization (screens, processors, memory) is accompanied by a rapid development of connections between personal terminals and text, audio, and audiovisual databases. Big data centers collect everything about anything, and everyone can easily access this information, wherever he or she has access to a connection, such as in a classroom. Beyond this increase in performance, what is the impact of actual digital technologies on DTE? What are their pedagogical uses? Do we have an idea about what they are changing in the teaching-learning processes?

Understanding the World of Automated or Controlled Systems

Understanding the World of Complex Systems

The great majority of the DTE curricula, in the framework of education for all, aims to develop an understanding of the technical world, which constitutes a familiar context for the students. But what does it mean to understand complex systems that we use every day? According with Wallon (1956, re-ed. 2007), personal development is inseparable from cultural mediation between the subject and his/her social environment: "Everyone undergoes the footprint of civilization which rules his/her existence and is necessary to his/her activity." Simondon (1989) discusses these social and cultural mediations in his book, *Du mode d'existence des objets techniques*. For him, what is essential for human activities involves establishing relationships with our technical environment to act with it. These relationships result from two indivisible and distinct processes: the process of individuation by which the subject develops his/her potentiality of action with and on his/her environment and the process of socialization by which the subject fits in his/her social and cultural environment.

With this perspective, understanding means the development of a level of awareness of the technical objects that occupy the environment. For Bruner (1997), awareness is at the center of learning. He defines three kinds of properties for awareness: (1) socialization, to be aware is to interact with others; (2) systematicity, the ability to extract relationships between events and to progress over the given information; and (3) instrumentality, the ability to identify relationships between means and goals present in the environment and to impose these relationships. Understanding, awareness, individuation, socialization – these key concepts are involved in the processes of teaching and learning in DTE. But what do we know about these processes in the specific case of understanding automated and controlled systems?

About Complex Systems

The complexity of systems does not mean that studying them is complicated. There are several ways to analyze them at different level of complexity, from a general view up to a specific and restricted view (Cannon et al. 2007; Goldberg et al. 2012; Liu et al. 2013, 2015; McCartney and Sanders 1998; Mioduser and Levin 1996; Shafat et al. 2014). Many technical languages support these analyses, and this richness provides excellent support for educational situations, adapted to the different levels of education, from early primary school up to higher education. Overall, a system is characterized by a function of who transforms the input for producing output by adding some value (Fig. 1).

The function characterizes the aim of the system and why this system exists. For example, the function of an elevator is to move people from one floor to another, the function of a power plant is to produce electric energy, and the function of a

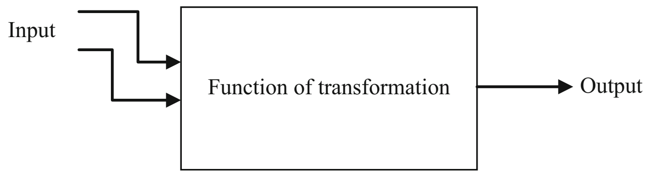


Fig. 1 General description of a system

smartphone is to connect people. Inputs can be matter, energy, or information. The output is a result of the transformation of the inputs according to the process controlled by a processor; the difference between output and inputs defines the added value brought by the system.

From this first level of description, there are several ways of description; we privilege two: the structural approach and the functional approach. The first one is based on the arrangement of devices for fulfilling the function of the system, while the second describes how the system fulfils the function. Both work together to design new systems as well as to describe existing systems. Many pedagogical situations deal with these two approaches (Akın et al. 2013; Gini 1996; Kantor et al. 1996; McCartney 1996; McCartney and Sanders 1998).

Some Examples of Students' Activity

Understanding is based on the use of languages that can be informal or formal. In the area of DTE, the languages are technical languages. The first description is generally with an informal language by which students at any level of education describe the system; the formalization of these first descriptions by using a formal language is the basis of learning (Ginestié 2011; Hérold and Ginestié 2011). To illustrate this approach, we refer to an example using Legos®. Students (12 years old) must describe a computer-controlled model of the automated transport of bricks; this system is based on a forklift truck. The system can move (forward and backward), can turn (left and right), and can move a brick up or down. It has to move bricks, one by one, from one defined place to another (Fig. 2).

Let us look of some examples of the informal description of the system by students (Fig. 3).

These first descriptions are significant for the students' level of precision. The first group of two students wrote only one sentence, focusing on the logical continuity of the movement of the forklift truck; they do not speak about the action of the conveyor belt. The description by the second group is also a one-sentence description, but they introduce more precision and include the actions of the conveyor belt. The third group describes the system in the first sentence, but the description is focused on the forklift truck; then, the students present a five-stage description including the conveyor belt. The aim of the task is to program the robot. We can follow the development of the reasoning with a few other students (Fig. 4).

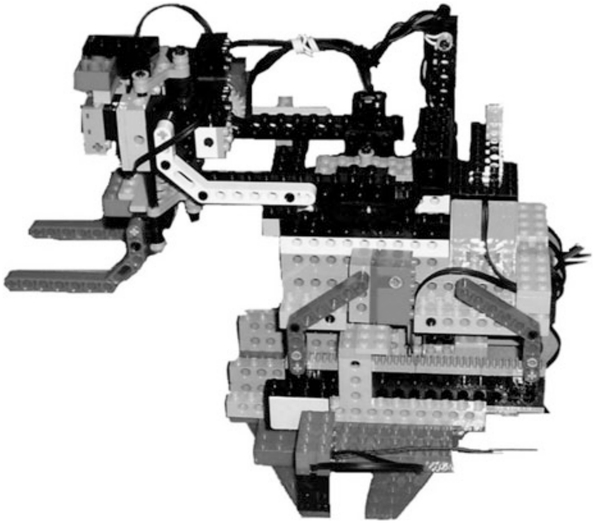


Fig. 2 Forklift truck robot

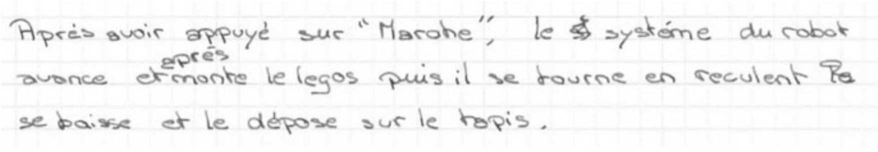
This description is interesting because students mix different components, such as the elements of functioning and the structure of the system. After much discussion, they produce this second description (Fig. 5).

This description is very interesting because the group introduces the idea of actions, as do the others, but also introduces the idea of detection, not only the position of the piece or the robot. They recognize the outputs but also the inputs. In the end, after three more stages, they produce a diagram in a formal technical language (GRAFCET) (Fig. 6).

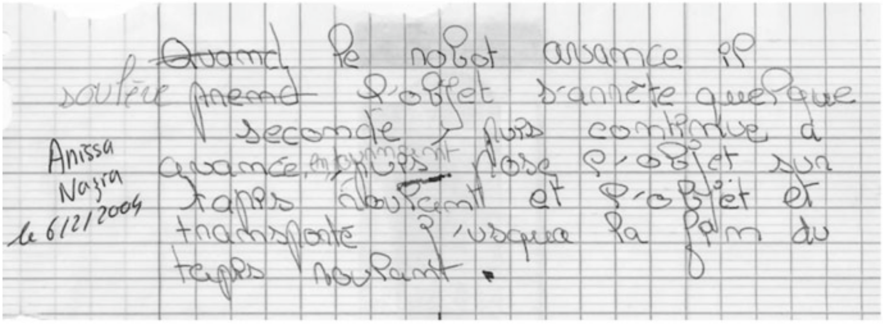
This description is insufficient for programing the system, but we can see the major principles of the description of the system. After much manipulation and trial and error, they produce a program. The interface is based on symbols for actions (outputs) and for detections (inputs) and arranges them into sequences of actions and detections; it provides strong guidance for elaborating the functional program of the system. In the end, they understood many major concepts about complex systems, such as differences between action and detection (input-output), the role of the program, and the control of the system. Through this example, we can see how students build their knowledge and the role of language in this construction; the literature relates many other example as well (Balat et al. 2015; Furat and Eker 2014; Goldberg et al. 2012; Gregson and Little 1999; Hamrita et al. 2005; Hussain et al. 2006; Klement and Klementova 2016; Lindh and Holgersson 2007; McCartney and Sanders 1998; McNair et al. 2015; Ozbek and Eker 2015; Sobiesk et al. 2007; Somyurek 2015).

Languages for Learning

The role of the language is primordial because languages help make links between the thought and actions of a person. This example illustrates the process of

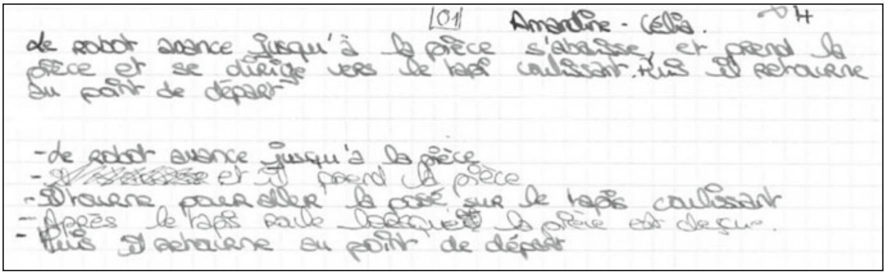

Après avoir appuyé sur "Marche", le système du robot avance et après monte le legos puis il se tourne en reculent la se baisse et le dépose sur le tapis.

After switch on, the system of robot goes forward and after lift up the legos then it turns while going backward here drops and leave it on the conveyor belt.


~~Quand~~ le robot avance il soulève ~~prend~~ l'objet s'arrête quelque seconde puis continue à avance en tournant pose l'objet sur tapis roulant et l'objet et transporte jusqu'à la fin du tapis roulant.

Anissa
Nazra
le 6/12/2004

~~When~~ the robot goes forward. It lifts up ~~takes~~ the object waits few seconds then continues going forward while turning then drops the object on the conveyor belt and the object moves at the end of the conveyor belt.


101 Amandine - Célia. 4

Le robot avance jusqu'à la pièce s'abaisse, et prend la pièce et se dirige vers le tapis roulant. Puis il retourne au point de départ

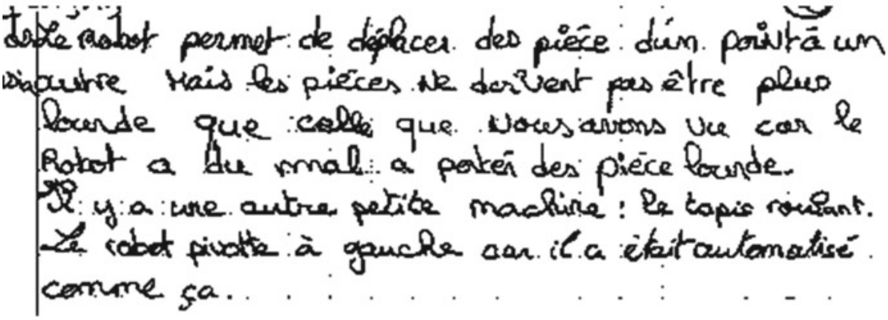
- Le robot avance jusqu'à la pièce
- ~~il s'abaisse~~ et il prend la pièce
- il tourne pour aller la poser sur le tapis roulant
- Après le tapis roule lorsque la pièce est déposée.
- Puis il retourne au point de départ

The robot moves forward to the piece, goes down and takes the piece and goes toward the conveyor belt. Then it goes back to the starting point

- The robot moves forward to the piece
- ~~It goes down~~ and it takes the piece
- It turns to put it on the conveyor belt
- After, the conveyor rolls when the piece is received
- Then it goes back to the starting points

Fig. 3 First descriptions with an informal language

individuation and socialization as Simondon (2005) describes it. Students aim to solve a problem: elaborating the program to control the complex system; this problem is open, and the pedagogical approach does not guide students toward a

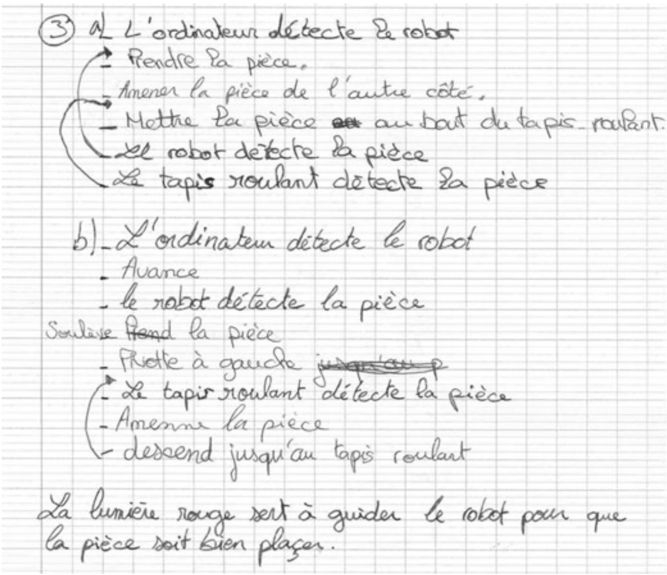


The robot enables to move some pieces from one point to another. But the pieces must not be heavier than ones we saw because the robot has difficulty bringing heavy pieces.
There is another small machine: the conveyor belt.
The robot turns left because it has been automated for that.

Fig. 4 First description of the group

predetermined solution. The different stages and interaction with peers show interesting traces of the construction of understanding. The subject develops ideas and then improves them through discussions with his/her partner. There is a double construction: procedures for acting and meanings for understanding. As do many psychologists, Rabardel and Bourmaud (2003) contribute to the exploration of this human activity of learning. Based on an instrumental genesis (Rabardel 2000), they show that human activity is a result of two different schemes: the procedural (how to do) and the semiotic schemes (why do it and why do it like this). Step by step, we can follow the long construction of meanings and procedures for understanding and acting. In this context, the study of complex systems and project-based approaches by problem-solving makes sense. Different levels of understanding can be approached at different levels of education, in general education, with the aim to develop the students' interrelationships with their technical environment, and in specialized courses for developing specific competencies. We can easily find many pedagogical applications as resources for organizing pedagogical situations in the schools.

Learning something new is easier if the learning is based on prior knowledge, sometimes called precursors, and if the pupil understands the meaning (Cook et al. 2008; Ginestié 2011; Hérold and Ginestié 2011; Mayer 2008). We identify two main ways to acquire knowledge: learning by discovering through action and learning by instruction. Learning supposes building the procedural schemes and the semiotic schemes. This articulation between procedural and semiotic schemes defines new knowledge and its functionality (Ginestié 2008b; Ginestié 2009, 2010). The first form of acquisition, learning by discovering through action, is well adapted for learning procedures and giving meaning to the situation. For these complex tasks, the success involves the mobilization of different registers of activities; some of them are the aim of the teaching-learning process, but others are only necessary to achieve



③ a) L'ordinateur détecte le robot
- Prendre la pièce.
- Amener la pièce de l'autre côté.
- Mettre la pièce au bout du tapis roulant.
- Le robot détecte la pièce
- Le tapis roulant détecte la pièce

b) - L'ordinateur détecte le robot
- Avance
- le robot détecte la pièce
Soulève ~~Prend~~ la pièce
- Pivote à gauche
- Le tapis roulant détecte la pièce
- Amenne la pièce
- descend jusqu'au tapis roulant

La lumière rouge sert à guider le robot pour que la pièce soit bien plaçer.

a- The computer detects the robot
- Take the piece
- Bring the piece on the other side.
- Put the piece at the tip of the conveyor belt
- The robot detects the piece
- The conveyor belt detects the piece

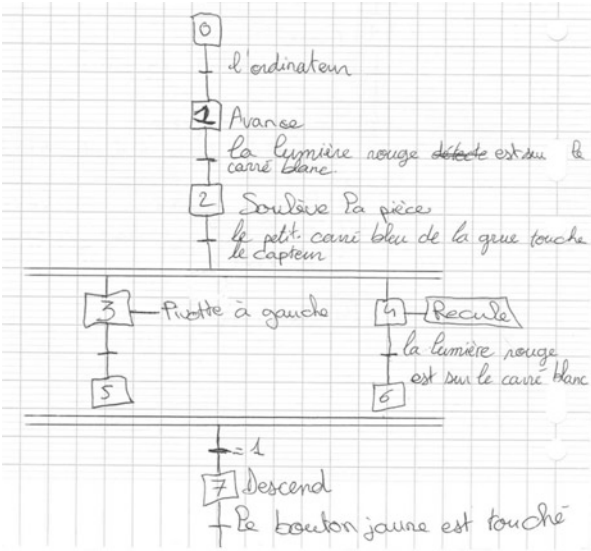
b- The computer detects the robot
- Goes forward
- The robot detects the piece
- Lifts up the piece
- Turns left
- The conveyor belt detects the piece
- Brings the piece
- Lifts down to the conveyor belt

The red light is used for guiding the robot in order that the piece is well positioned

Fig. 5 Second description

the task, without any particular learning's goals. It is necessary to reduce the cognitive load linked to the situation by providing some guidance to achieve the task (Chanquoy et al. 2007). This guidance is aimed at reducing the cognitive load induced by the situation and releasing sufficient cognitive resources for performing the task and for learning (Musial and Tricot 2008). This debate between learning by discovering and learning by instruction is at the center of the process of teaching-learning when using computer-based applications.

Fig. 6 Last description



Using a Computer for Designing and Realizing

Learning About Digital Technologies or with Digital Technologies

In our previous examples, students used an interface for programing a system. We saw that there are many computer-based applications for that. Another domain concerns the use of computer-aided design (CAD), which has been associated with DTE for a long time. CAD applications drastically changed the world of industrial production about 30–40 years ago; they also changed DTE. Up to the late 1990s, CAD applications were based on the 2D-projection draft, issued from the traditional industrial draft approach. Their use supposed a high level of competence of the draughtsman. The introduction of these applications in education mainly concerns higher technological education, even if we find many attempts to introduce it at the junior high school level, i.e., the software Sketch® which was very successful in DTE, with many interesting experiences.

A slight change appeared in the early 2000s with 3D modelers; this new generation of CAD applications broke with the 2D references and integrates many innovations such as piloting digital-control machines for computer-aided manufacturing (CAM), libraries of shapes, assemblies, machining, existing modular elements, and more or less complex functions. (Abouelala et al. 2013). The continual development of computer capacity (processor speed, memory size, ergonomic interfaces) and the decrease in price of the CAM systems have popularized the integration of complete systems in the classroom. The recent development of the 3D printer facilitates this, and we can find more experiences at junior high schools as well as at primary schools. It is easy to link design and manufacturing. It is very interesting, for example, to see how questions of creativity have shifted from art and craft to DTE (Bonnardel and Zenasni 2010).

Historically, DTE refers to the world of industry and, for general education, more specifically, to the professionals' practices. These references have two main goals. The first one concerns the development of knowledge about the evolution of industry and the new jobs that are created by this evolution. The second one promotes high-tech innovations and creativity supported by new technologies. Evidently, it is important that the students have a positive attitude toward the technological evolution, and the use of these modern tools (CAD, CAM, 3D–modellers, 3D–printers) marks this strong orientation, which we can observe in many curricula (Fidan and Baker 2013; Johnson et al. 2012; Khoroshko and Sukhova 2013; Kurak Acici and Sonmez 2014; Moseley and Broiles 2012; Nicholas and Ng 2012; Rivera-Solorio et al. 2013; Zeid et al. 2014).

Some Example of CAD/CAM's Educational Uses

Despite the apparent user-friendliness of these systems based on attractive interfaces, the main issue is what students learn. In other words, the CAD or CAM systems are tools, as we said previously, but the question becomes how students use these tools to produce solutions. We know that tools are social objects that bring a capacity of action to the environment (Simondon 2014). For the subject, the recognition of an object as a tool supposes the recognition of this potentiality of action for solving a problem, problem he/she cannot solve with the tools he/she usually use.

In his PhD thesis, Laisney (2012) experimented with the use of a 3D modeler with students in junior high school. He observed activities of students in two different pedagogical situations – open or closed problem-solving. The closed situation is based on learning by instruction in which the teacher (through documents) details the basic procedures for guiding students toward his/her solution; in this situation, all the difficulties are ironed out, and students only need to execute the actions planned by the teacher. The open situation, however, is based on learning by discovering where the teacher (through documents) details the problem, the context, and the aim of the task, but lets the students face the problem. There is no solution provided by the teacher, nor procedures to guide the students toward this solution. Students have to think about the best way to come up with a solution. The thesis shows the importance of the exploration phase of the problem. This phase is spontaneously present for the students in the open problem situation; during this phase, they think about their solution, and they are involved in many discussions and exchanges about their points of view. During this phase, students are invited to produce drawings. Supporting one's thinking by using drawings seems to be very effective. The following figures show the evolution of the design of a token for trolleys' lock (Fig. 7).

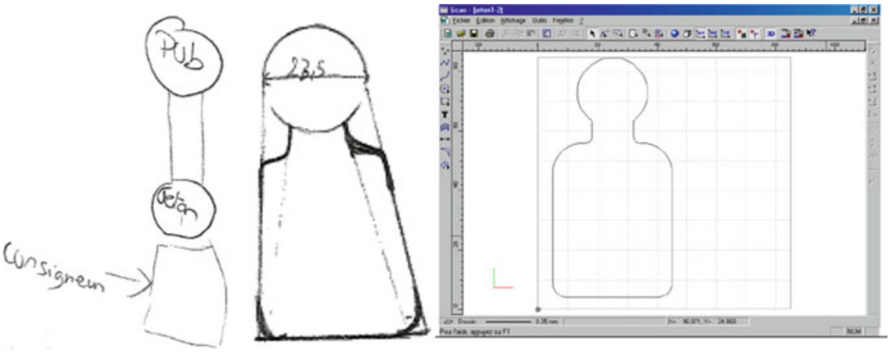
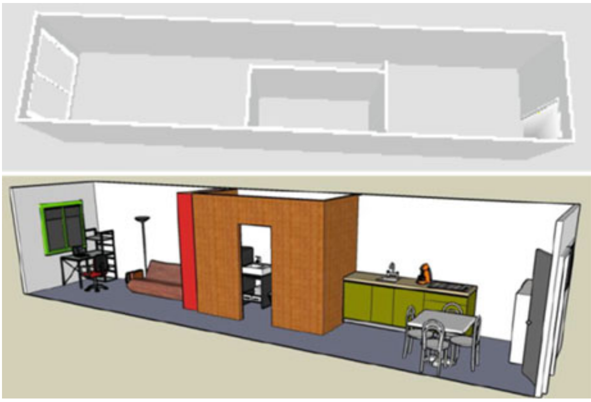


Fig. 7 From drawings to CAD

Fig. 8 Layout of a container for housing



From the first drawing, we can observe the evolution of the design; it is interesting to see how students assume the shape's evolution. During interviews with the students after each stage, they justify this evolution by integrating the constraints. For example, after the second drawing, they say that in the first drawing, the link between the two parts is too much breakable. The following figure shows another work but with a 3D modeler (Fig. 8).

In both situations, students had previously used CAD software. In both solutions, we can observe the double process of individuation and socialization. The elaborated solutions are original, and they are a result of personal construction; they mark the identity of each author. The socialization is present in the both cases; the solutions are socially registered. An analysis of these activities shows the evolution of the status of the tool to the instrument. In conformity with the instrumental genesis, for reaching these solutions, students recognize the tools (here, the drawing, the software, etc.) as social objects that have the potential to solve their problem; the integration of the tools in their activity (and the mastery they have of them) confirms their ability to use them as an instrument for acting. During their learning, they develop their procedural abilities and the meaning they give to the task. In the same study, the author shows a notable difference between students according to whether they had previous familiarity with the software or not (Laisney and Brandt-Pomares 2015). For the group of students who did not use the software previously, he notes the impact of the software's manipulation on their performance. This limitation impacts the learning-teaching processes; sophisticated tools, like CAD or CAM software, can be a help or a handicap for students. Helping students during their activities supposes shifting tools to the status of an instrument, and this shift largely depends on the teaching situation established by the teachers.

Conclusion and Discussion

The different examples in this chapter show that learning about ICT applications in the practice of DTE is possible. In some particular situations, the students' elaborations are very interesting and demonstrate their ability to use sophisticated tools, to produce innovative solutions, and to give meaning to their school activities. They develop their own reasoning; they are able to anticipate and to plan their activities to reach a goal and to solve a problem. They integrate the major functions of sophisticated tools, and they make the most of their potential. In the end, in both situations, analyzing a complex system to program it and designing an object with CAD software, they produced interesting solutions, increased their ability to act, and developed new knowledge. At the same time, we can observe some conditions that limit the significance of these outcomes.

The first limitation concerns the conditions of the learning process. In this paper, we based our study on the students who succeeded in the task, but some students did not succeed. In both situations, as is also the case in many other situations described in other publications, these tasks bring into play many combinations of sophisticated devices, i.e., computers robots, software, and connections. In these situations, the mobilization of the students' cognitive attention becomes a central question. Several works treat the cognitive load in a learning situation (Hérold 2014; Sweller 2010; Sweller and van Merriënboer 2005; Tricot et al. 2000). Evidently, taking charge of the cognitive load depends typically on the design of the tasks proposed to the students, within the framework of the pedagogical engineering. In many cases, we can observe strong procedural guidance of the students' activity. This kind of guidance reduces the students' cognitive load; at the same time, these situations lead the students to the expected solution for solving the problem. In terms of learning, this kind of situation is poor, specifically for building meaning and understanding.

The second limit is a result of the previous one. We can see the important role played by experimental situations driven by researchers. The question is about the dissemination of these experiments' outcomes. Some works, which focus on the teachers' activities, show that they spontaneously privilege procedural guidance (Ginestié 2008a, b), although researchers show that these situations are not efficient. The transfer of researches' outcomes toward the teachers' practices and, also, the fundament of research questions based on the teachers' practices constitute a very large field of development. The development of digital technologies provides many ways to think about the evolution of the teachers' role and of their practices. In fact, that can change the model for linking research, training, and practices. This is probably the central goal for the coming years and is a huge challenge for thinking about the future of DTE in education, specifically in general education for all.

References

Abouelala, M., Taha Janan, M., & Brandt-Pomares, P. (2013, November 4–6). *CAMs learning modeling in education towards a methodology for software choice*. Paper presented at the London International Conference on Education (LICE-2013), London.

Akın, H. L., Meriçli, Ç., & Meriçli, T. (2013). Introduction to autonomous mobile robotics using Lego Mindstorms NXT. *Computer Science Education, 23*(4), 368–386. doi:10.1080/08993408.2013.838066.

Balat, G. U., Dagal, A. B., & Kanburoglu, V. (2015). The effect of computer aided education program on the development of concept in 48–60 months children. In A. Isman (Ed.), *International educational technology conference, IETC 2014* (Vol. 176, pp. 20–26). (Coll. Procedia Social and Behavioral Sciences).

Bonnardel, N., & Zenasni, F. (2010). The impact of technology on creativity in design: An enhancement? *Creativity and Innovation Management, 19*(2), 180–191. doi:10.1111/j.1467-8691.2010.00560.x. URL: <Go to ISI>://WOS:000208219900010.

Bruner, J. S. (1997). *Car la culture donne forme à l'esprit. De la révolution cognitive à la psychologie culturelle* (173 p). Genève: Georges Eshel.

Cannon, K., Lapoint, M. A., Bird, N., Panciera, K., Veeraraghavan, H., Papanikolopoulos, N., & Gini, M. (2007). Using robots to raise interest in technology among underrepresented groups – A technology day camp for women, African Americans, and Hispanics. *IEEE Robotics & Automation Magazine, 14*(2), 73–81. doi:10.1109/mra.2007.380640. URL: <Go to ISI>://WOS:000247833500011.

Chanquoy, L., Tricot, A., & Sweller, J. (2007). *La charge cognitive, théorie et applications* (293 pp). Paris: A. Colin.

Cook, M., Wiebe, E. N., & Carter, G. (2008). The influence of prior knowledge on viewing and interpreting graphics with macroscopic and molecular representations. *Science Education, 92*(5), 848–867.

Cygnaeus, U. (1910). *Kirjoytukset*. Helsinki: Kansanvalistusseura.

Dewey, J. (1916). *Democracy and education: An introduction to the philosophy of education (French traduction; (1990); Deledalle, G.; Démocratie et Éducation : introduction à la philosophie de l'éducation)*. Paris: Armand Colin.

Fidan, I., & Baker, J. C. (2013, June 23–26). *Designing the future: Integrating cutting-edge design and manufacturing tools into 9th and 10th grade STEM education*. Paper presented at the Asee Annual Conference, Atlanta. *ASEE Annual Conference & Exposition* (pp. 1–10). Washington: ASEE. Retrieved from <Go to ISI>://WOS:000367454805034.

Freinet, C. (1946). *L'école moderne française*. Paris: Editions Ophrys.

Furat, M., & Eker, I. (2014). Computer-aided experimental modeling of a real system using graphical analysis of a step response data. *Computer Applications in Engineering Education, 22*(4), 571–582. doi:10.1002/cae.20482. URL: <Go to ISI>://WOS:000344185700001.

Ginestié, J. (2008a). From task to activity, a re-distribution of the roles between the teacher and the pupils. In J. Ginestié (Ed.), *The cultural transmission of artefacts, skills and knowledge: Eleven studies in technology education* (pp. 225–256). Rotterdam: Sense Publishers.

Ginestié, J. (2008b). Konzepte einer Technischen Bildung in Frankreich (C. Vitale, Trans.) In E. Hartmann & W. Theuerkauf (Eds.), *Allgemeine Technologie und Technische Bildung* (pp. 107–125). Frankfurt am Main: Peter Lang.

Ginestié, J. (2009). Thinking about technology education in France: A brief overview and some aspects of investigations (R. Watson, Trans.) In J. T. Alister & M. De Vries (Eds.), *International handbook of research and development in technology Éducation* (pp. 31–40). Rotterdam: Sense Publisher.

Ginestié, J. (2010). From art and craft Éducation to design and technology Éducation: A thirty year story (R. Watson, Trans.) In A. Rasinen & T. Rissanen (Eds.), *In the spirit of Uno Cygnaeus, pedagogical questions of today and tomorow* (pp. 169–182). Jyväskylä: University of Jyväskylä.

Ginestié, J. (2011). How pupils solve problems in technology Éducation and what they learn. In M. Barak & M. Hacker (Eds.), *Fostering human development through engineering and technology education* (pp. 171–190). Rotterdam: Sense publisher.

Gini, M. (1996). Designing and building autonomous minirobots. *Computer Science Education, 7*(2), 223–237. doi:10.1080/0899340960070207.

Goldberg, N., Aizikovitsh-Udi, E., & Levin, I. (2012). Children's concept learning in solving logic problems. In L. G. Chova, I. C. Torres, & A. L. Martinez (Eds.), *Edulearn12: 4th international conference on education and new learning technologies* (pp. 6656–6661). Valenica: Iated-Int Assoc Technology Education a & Development. (Coll. EDULEARN Proceedings).

Gregson, P. H., & Little, T. A. (1999). Using contests to teach design to EE juniors. *IEEE Transactions on Education, 42*(3), 229–232. doi:10.1109/13.779906. URL: <Go to ISI>://WOS:000081935700014.

Hamrita, T. K., Potter, W. D., & Bishop, B. (2005). Robotics, microcontroller and embedded systems education initiatives: An interdisciplinary approach. *International Journal of Engineering Education, 21*(4), 730–738. URL: <Go to ISI>://WOS:000232008100022.

Hérold, J.-F. (2014). A cognitive analysis of students' activity: An example in mathematics. *Australian Journal of Teacher Education, 39*(1), 137–158.

Hérold, J.-F., & Ginestié, J. (2011). Help with solving technological problems in project activities. *International Journal of Technology and Design Education, 21*, 55–70. doi:10.1007/s1007/s10798-009-9106-8. URL: http://rdcu.be/mIwj.

Hussain, S., Lindh, J., & Shukur, G. (2006). The effect of LEGO training on pupils' school performance in mathematics, problem solving ability and attitude: Swedish data. *Educational Technology & Society, 9*(3), 182–194. URL: <Go to ISI>://WOS:000239556500016.

Johnson, M., Ozturk, E., Johnson, J., Yalvac, B., Peng, X. B., & Asee. (2012). AC 2012–3927: Assessing an adaptive expertise instrument in computer-aided design (cad) courses at two campuses *2012 Asee Annual Conference*. (Coll. ASEE Annual Conference & Exposition).

Kantor, G., Manikonda, V., Newman, A., & Tsakiris, D. P. (1996). Robotics for high school students in a university enviroment. *Computer Science Education, 7*(2), 257–278. doi:10.1080/0899340960070210. URL: http://dx.doi.org/10.1080/0899340960070210.

Khoroshko, L. L., & Sukhova, T. S. (2013, March 13–15). *Application of computer aided design (CAD) systems for development of electronic educational courses for engineering disciplines in engineering higher educational institution*. Paper presented at the IEEE Global Engineering Education Conference, Berlin. *Educon: Proceedings of the IEEE Global Engineering Education Conference* (pp. 644–647). Berlin: Tech Univ Berlin. Retrieved from <Go to ISI>://WOS:000327180400088.

Klement, M., & Klementova, S. (2016). Benefits of the support of polytechnic education for non-technical schools students. In M. Minas (Ed.), *Future academy multidisciplinary conference Iceepsy & Cpsyc & Icpsirs & Be-Ci* (Vol. 217, pp. 149–159). (Coll. Procedia Social and Behavioral Sciences).

Kurak Acici, F., & Sonmez, E. (2014). The place of hand drawing and computer aided design in interior design education. In H. Uzunboylu (Ed.), *3rd Cyprus international conference on educational research* (Vol. 143, pp. 716–720). (Coll. Procedia Social and Behavioral Sciences).

Laisney, P. (2012, Octobre 17). *Conditions d'études en éducation technologique : l'usage de la CFAO avec des classes de collège.* Doctorat, Under the direction of J. Ginestié & P. Brandt-Pomares, Document imprimé, Aix-Marseille Université, Marseille. Retrieved from http://www.theses.fr/2012AIXM3049

Laisney, P., & Brandt-Pomares, P. (2015). Role of graphics tools in the learning design process. *International Journal of Technology and Design Education, 25*(1), 109–119. doi:10.1007/s10798-014-9267-y. URL: http://dx.doi.org/10.1007/s10798-014-9267-y.

Lindh, J., & Holgersson, T. (2007). Does lego training stimulate pupils' ability to solve logical problems? *Computers & Education, 49*(4), 1097–1111. doi:10.1016/j.compedu.2005.12.008. URL: <Go to ISI>://WOS:000250024100009.

Liu, A. S., Kallai, A. Y., Schunn, C. D., & Fiez, J. A. (2015). Using mental computation training to improve complex mathematical performance. *Instructional Science, 43*(4), 463–485. doi:10.1007/s11251-015-9350-0. URL: <Go to ISI>://WOS:000355144600002.

Liu, A. S., Schunn, C. D., Flot, J., & Shoop, R. (2013). The role of physicality in rich programming environments. *Computer Science Education, 23*(4), 315–331. doi:10.1080/08993408.2013.847165. URL: http://dx.doi.org/10.1080/08993408.2013.847165.

Mayer, R. E. (2008). *Learning and instruction*. Upper Saddle River: Prentice Hall.

McCartney, R. (1996). Introduction to robotics in computer science and engineering education. *Computer Science Education, 7*(2), 135–137. doi:10.1080/0899340960070201. URL: http://dx.doi.org/10.1080/0899340960070201.

McCartney, R., & Sanders, K. E. (1998). Small robot projects: Before you start. *Computer Science Education, 8*(1), 56–63. doi:10.1076/csed.8.1.56.3821. URL: http://www.tandfonline.com/doi/abs/10.1076/csed.8.1.56.3821.

McNair, L. D., Davitt, M., & Batten, G. P. (2015). Outside the 'comfort zone': Impacts of interdisciplinary research collaboration on research, pedagogy, and disciplinary knowledge production. *Engineering Studies, 7*(1), 47–79. doi:10.1080/19378629.2015.1014817. URL: <Go to ISI>://WOS:000353013500003.

Mioduser, D., & Levin, I. (1996). Cognitive-conceptual model for integrating robotics and control into the curriculum. *Computer Science Education, 7*(2), 199–210. doi:10.1080/0899340960070205. URL: http://dx.doi.org/10.1080/0899340960070205.

Montessori, M. (1912). *Scientific pedagogy as applied to child education in the chlidren's houses* (A. E. George, Trans.). New-York: Frederick A. Stokes Company.

Moseley, B., & Broiles, K. (2012). Automation strategies and project life cycle documentation in the instructional system design process. *5th International Conference of Education, Research and Innovation (Iceri 2012)* (pp. 5210–5216). URL: <Go to ISI>://WOS:000318422205034.

Musial, M., & Tricot, A. (2008). Enseigner pour que les élèves apprennent. 2) le modèle « Enseigner pour que les élèves apprennent ». *Technologie STI, 158*, 22–33.

Nicholas, H., & Ng, W. (2012). Factors influencing the uptake of a mechatronics curriculum initiative in five Australian secondary schools. *International Journal of Technology and Design Education, 22*(1), 65–90. doi:10.1007/s10798-010-9138-0. URL: <Go to ISI>://WOS:000298810500005.

Ozbek, N. S., & Eker, I. (2015). An interactive computer-aided instructional strategy and assessment methods for system identification and adaptive control laboratory. *IEEE Transactions on Education, 58*(4), 297–302. doi:10.1109/te.2015.2412512. URL: <Go to ISI>://WOS:000369513400012.

Piaget, J. (1947). *La Représentation du monde chez l'enfant* (Nouvelle ed.,Vol. XLIV, 425 p). Paris: Presses universitaires de France.

Rabardel, P. (2000). Influence of the development of knowledge systems and technological systems on cognition. *International Journal of Psychology, 35*(3–4), 274–274. URL: <Go to ISI>://WOS:000088388802683.

Rabardel, P., & Bourmaud, G. (2003). From computer to instrument system: A developmental perspective. *Interacting with Computers, 15*(5), 665–691. doi:10.1016/s0953-5438(03)00058-4. URL: <Go to ISI>://WOS:000186220800003.

Rivera-Solorio, C., Garcia-Cuellar, A. J., & Flores, A. (2013). Design and construction of a boat powered by solar energy with the aid of computational tools. *International Journal of Engineering Education, 29*(2), 380–387. URL: <Go to ISI>://WOS:000329810700011.

Shafat, G., Levin, I., & Ieee. (2014). Recognition, reconstruction and fault identification problems in Boolean concepts learning. In *10th European workshop on microelectronics education (Ewme)* (pp. 155–160). URL: <Go to ISI>://WOS:000345757100034.

Simondon, G. (1989). *Du mode d'existence des objets techniques* (Réédition ed.). Paris: Aubier, (Coll. Collection l'invention philosophique).

Simondon, G. (2005). *L'individuation à la lumière des notions de forme et d'information* (571 p). Grenoble: J. Millon, (Coll. Collection Krisis).

Simondon, G. (2014). *Sur la technique*. Paris: PUF.

Sobiesk, E., Gini, M., & Marin, J. A. (2007). *Using group knowledge for multitarget terrain-based state estimation* (117–126 p), (Coll. Distributed Autonomous Robotic Systems 6, Directed by *R. alami*, R. Chatila & H. Asama).

Somyurek, S. (2015). An effective educational tool: Construction kits for fun and meaningful learning. *International Journal of Technology and Design Education, 25*(1), 25–41. doi:10.1007/s10798-014-9272-1. URL: <Go to ISI>://WOS:000348118900002

Sweller, J. (2010). Element interactivity and intrinsic, extraneous and germane cognitive load. *Educational Psychological Review, 22*, 123–138.

Sweller, J., & van Merriënboer, J. (2005). Cognitive load theory and complex learning: Recent developments and future direction. *Educational Psychology Review, 17*(2), 147–177.

Tricot, A., Pierre-Demarcy, C., & El Boussarghini, R. (2000). Specific help devices for educational hypermedia. *Journal of Computer Assisted Learning, 16*, 102–113.

Vygotski, L. S. (1962). *Thought and language* (Vol. xxi, 168 p). New York: Wiley.

Vygotski, L. S. (1998). *Child psychology* (xv–359 pp). New York/Dordrecht/London: Kluwer Academic/Plenum publishers.

Vygotski, L. S., & Piaget, J. (1997). *Pensée et langage* (536 p). Paris: la Dispute.

Wallon, H. (1956, re-ed. 2007). Levels of ego fluctuation. *Evolution Psychiatrique, 72*(4), 607–617. doi:10.1016/j.evopsy.2007.10.012. URL: <Go to ISI>://WOS:000251928600006

Zeid, I., Chin, J., Duggan, C., & Kamarthi, S. (2014). Engineering based learning: A paradigm shift for high school STEM teaching. *International Journal of Engineering Education, 30*(4), 876–887. URL: <Go to ISI>://WOS:000347457200011.

Maker Movement in Education: History and Prospects

30

Paulo Blikstein

Abstract

The maker movement in education has been a revolution in waiting for a century. It rests on conceptual and technological pillars that have been engendered in schools and research labs for decades, such as project-based learning, constructivism, and technological tools for "making things," such as physical computing kits, programming languages for novices, and inexpensive digital fabrication equipment. This chapter reconstructs the history of the maker movement in education analyzing five societal trends that made it come to life and reach widespread acceptance: (1) greater social acceptance of the ideas and tenets of progressive education, (2) countries vying to have an innovation-based economy, (3) growth of the mindshare and popularity of coding and making, (4) sharp reduction in cost of digital fabrication and physical computing technologies, and (5) development of more powerful, easier-to-use tools for learners, and more rigorous academic research about learning in makerspaces. The chapter also explicates the differences and historical origins of diverse types of spaces, such as Hackerspaces, FabLabs, Makerspaces, and commercial facilities such as the Techshop, and discusses educationally sound design principles for these spaces and their tools. Finally, strategies for adoption in large educational systems are suggested, such as the inclusion in national standards and the local generation of maker curricula by schools.

Keywords

Maker movement • Constructivism • Constructionism • Hands-on learning • Experiential education

P. Blikstein (✉)
Graduate School of Education and (by courtesy) Computer Science Department, Stanford University, Stanford, CA, USA
e-mail: paulob@stanford.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_33

Contents

Introduction: A Revolution in the Making for a Century

The maker movement in education has been a revolution in waiting for 100 years. The conceptual and material pillars upon which it rests – interest-driven curricula, project-based pedagogies, constructivism, constructionism, critical pedagogy, and rich, expressive, low-cost technological tools – have been engendered and engineered in schools, universities, and research labs for decades. Progressive educators and constructivist researchers have been prescribing interest-driven, student-centered, and experiential approaches for more than a century (Dewey 1902; Freudenthal 1973; Fröbel and Hailmann 1901; Montessori 1965; Von Glaserfeld 1995). Scholars have also dedicated considerable attention to the symbiotic relationships between the human mind and external artifacts when performing complex tasks (distributed cognition, see Hutchins 1995), as well as alternative orchestrations for learning environments such as apprenticeship-based models (legitimate peripheral participation, see Lave and Wenger 1991). Critical pedagogy then highlighted the importance of learners' empowerment, culturally authentic learning experiences, convivial tools, and the connection with local communities and their funds of knowledge (Freire 1974; Illich 1970; Moll et al. 1992). Critical theorists such as Freire fervently advocated that students should perceive themselves as change makers, capable of producing transformations in a world that should never be taken as static or immutable. Seymour Papert brought to the forefront the importance of rich tools and media. After working with Jean Piaget in Geneva for several years, Papert added to constructivist theory the idea that students' interactions and experiences would happen more robustly if learners were engaged in building public, shareable artifacts, such as robots, inventions, sand castles, or computer programs. Papert elevated the cognitive status of building and making and reevaluated the hierarchical relationship between abstract and concrete. His students and collaborators became increasingly focused on designing and making available rich computational materials and toolkits for children to build those sharable objects. Such protean technological tools would then enable students to design, engineer, and construct complex artifacts, also enabling a variety of new forms of work and expression (epistemological pluralism, Turkle and Papert 1991). Therefore, the main building blocks of what we call today the "maker movement" in education have been around for a long time, but never they have come together so forcefully. It was not until the advent of the *Maker Faires* and the *FabLabs* that the movement gained its current designation and started to enjoy high levels of popularity.

However, the fact that the movement now enjoys wide acceptance does not a guarantee that it will survive in school environments. A fundamental concern is to make sure that this movement does not join laptops, tablets, and video-based learning on the long list of overhyped educational fads of the past decades. A second issue is that, within the history of technology education itself, it has been common for hands-on activities to be considered second-class tasks in schools, inferior to scholastic work, and associated only to technical and vocational education (Bennett 1937). This chapter seeks to offer a definition of what the movement is, provide a brief account of its history, and make recommendations about how to build a sustainable future.

For an Alternative History of the Maker Movement in Education

It is tempting, but often less useful, to examine world history as a product of great kings, generals or leaders. Frequently, however, such individuals were simply in the right place at the right time, and larger infrastructural, economic, and technological transformations made their political or strategic projects possible. This lesson is as important for understanding the origins of the maker movement as it is for an understanding of world history. The history of the movement has been disproportionately attributed to visionary characters and specific individuals and focused on events that took place in the last 5 or 10 years (see, for example, Peppler et al. 2016). In place of such narratives, this history should be told as the conjunction of societal and economic preconditions and the contributions of the visionary individuals and organizations that helped shape it. Understanding the maker movement in this light can help us on two fronts. First, it shows us that the movement is the culmination of a long tradition of educators seeking to put children and youth at the center of the educational process; second, it helps us understand which infrastructural elements must be kept alive for the movement to thrive while keeping students at the center in complex institutions, such as schools, and particularly in technology education. In the following sections, the societal trends that helped create a favorable scenario for the movement to appear and become popular are discussed.

First Trend: Social Acceptance of the Ideas of Progressive and Constructivist Education

Since the beginning of the twentieth century the field of educational research and practice has been divided into two camps, *grosso modo*: traditionalists/instructivists and progressives/constructivists (this is an oversimplification: for a more elaborate discussion, see, for example, Kirschner et al. 2006; Papert 2000). The debate has swung from one side to the other several times throughout the past several decades, but especially over the last 15 years an unprecedented acceptance has emerged for many of the ideas of progressive education. It is a challenge to set a precise date for the inception of this trend, but several events contributed. First, there have been widespread demands from the business world for workers who are more creative and flexible, better able to function in the new global economy, and more capable of understanding the twenty-first century's manufacturing and business management workflows. These business groups have actively incentivized an increased focus on the STEM disciplines – especially computer science – and also newer, more up-to-date, educational approaches for teaching them. A second type of initiative came from governments, science academies, and international organizations in the form of new national curricula and international tests. In the USA, for example, the Next Generation Science Standards (*Next Generation Science Standards: For States, By States* 2013) placed a very strong emphasis on problem solving, scientific practices, and interdisciplinary work, and gave engineering and design a momentous place in K-12 education. Other countries, such as Australia, Finland, and Canada, also restructured their national standards to put engineering and design much more prominently. International organizations such as the OECD, which used to focus only on math, reading, and science (OECD 2006), also began to devise new international tests to measure skills such as collaboration, in line with the need for workers to move away from the isolated production modalities of the past. Many of those newly demanded abilities have been grouped under the heading "twenty-first century skills," a catchphrase that has been widely publicized and adopted by ministries of education, corporations, and educational organizations worldwide. However, it seems that as the term "twenty-first century skills" became popular, its connection to progressive education and constructivist theories was lost, and ironically, this very failure of recollection might have contributed to the popularity of the concept. Since most of the advocates of twenty-first century skills in education were unaware of their connection to progressive education and constructive/critical pedagogy theorists, it could well be that their adoption in national educational frameworks became less controversial, since it escaped the academic and political debate between traditionalists and progressive educators. The result of this trend is that previously controversial topics and practices, such as critical thinking, problem solving, creativity, design, and complex communication, were moved into the national agenda of many countries, not anymore as "nice to haves," but as necessities for modern societies to thrive.

Fig. 1 President Obama at the first White House Maker Faire in 2014 (Image source: United States White House)

Second Trend: Countries Looking for the Innovation Holy Grail

Virtually every nation on the planet wants to shift away its current economic activity to a knowledge- and innovation-based economy. Often, the first realization to confront such intentions is that innovative workforces must be educated differently and that such education should start early on. These governments are also quick to realize that "business as usual" in education simply will not suffice to achieve these goals. Even though governments are still caught between the desire to bring about radical educational change and its actual implementation, many are actively pursuing such agenda, creating environments much more favorable to progressive educational ideas and practices, and funding innovative research programs. In the USA, for example, the White House has been organizing science and maker fairs on its grounds since 2014 (see Fig. 1). Several states and cities, such as New York, are considering or implementing large scale programs for teaching computer programming as part of the official school curriculum. As recently as 2016, a large national initiative in England led by the BBC gave to thousands of seventh graders low-cost computer boards (the BBC micro:bit, Fig. 2) together with curricula and several programming environments.

Third Trend: Growth of the Mindshare of Coding and Making

As a result of this more favorable outlook for progressive education, many ideas, content, activities, and classroom practices that used to be restricted and limited

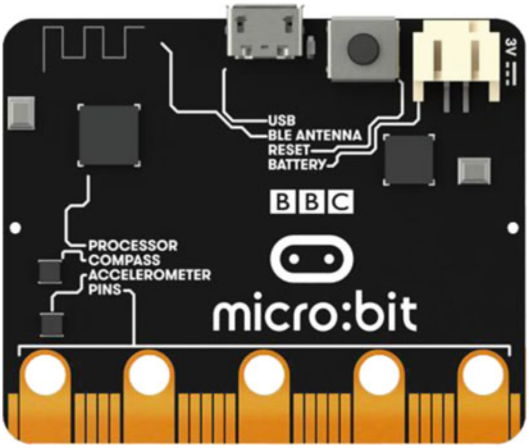


Fig. 2 BBC micro:bit, a small scale computer being distributed to schoolchildren in the UK

to just a few schools went mainstream. In the early 2000s, Neil Gershenfeld started teaching a course at the MIT Media Lab called “How to make almost anything” – a “crash course” in the nascent field of digital fabrication for MIT graduate students. Packed in the basement of the iconic 20 Ames St. building in Cambridge, MA, students of widely divergent interests, majors, and backgrounds rubbed shoulders building technologies and inventions that defy the imaginations of traditional engineers and technology educators. The course was the first ever to deliver such content to students from diverse disciplinary backgrounds – artists, programmers, educators, engineers, and interaction designers. At the same time, the regulations of the National Science Foundation in the United States mandated that scientists should increase the outreach component in their federal grants, so Gershenfeld devised the idea of packaging much of his lab equipment – including a laser cutter and small milling machine – into a “portable,” standardized lab that could be transported to various Boston locations (Gershenfeld 2007). The first lab was deployed at an inner-city Boston community center that catered to underserved youth. Gershenfeld teamed up with Bakhtiar Mikhak, another MIT professor, to create precise specifications for the lab, and, after many redesigns, they ultimately deployed their project in Costa Rica, India, and Norway. In a 2002 paper (Mikhak et al. 2002) they termed these environments “FAB LABs,” a humorous wordplay on “Fabrication” and “Fabulous.” For a few years, FabLabs grew slowly, probably as a result of high costs, novelty, and a lack of mainstream publicity, and were concentrated mostly in the United States and Europe. Starting in the late 2000s, their growth accelerated and presently more than 1000 are estimated to exist worldwide. FabLabs are one of the crucial cultural and infrastructural roots of the maker movement, and their rapid growth in recent years can be also attributed to the arrival of two big players in the field: *Make Magazine* and the *Maker Faire*.

In January 2005, the O'Reilly publishing house produced the first issue of *Make Magazine*, founded by Dale Dougherty (2013). The magazine brought back the San Francisco Bay Area DIY ethos with a twist: it targeted a broader audience and made use of the new tools starting to appear in the marketplace, including new low-cost microcontroller boards such as Wiring and Arduino, electronics kits, 3D printers, and other digital fabrication machines. In April 2006, the first Maker Faire took place in the San Francisco Bay Area, attracting tens of thousands of people. The magazine and "Faire" were both seeds of a movement and beneficiaries of four existing developments: FabLabs, a new breed of low-cost microcontroller boards, a general sentiment against "black boxed," opaque consumer electronics, and the popularization of open source software and hardware. Through these media, the maker's movement reached hundreds of thousands of people and grew globally – there are currently tens of "Maker Faires" worldwide every year.

In 2013, a group of Silicon Valley entrepreneurs and CEOs created *Code.org* (http://code.org), a nonprofit organization aimed at popularizing computer programming for children. The organization released an introductory video featuring the most important CEOs of the technology world. The video, which includes Mark Zuckerberg and Bill Gates, has received over 13 million views to date. Propelled by an efficient marketing machine, *Code.org* (http://code.org) created popular (although controversial, see Resnick and Siegel 2013) campaigns such as the Hour of Code, which made the idea of coding popular in ways not seen since the heyday of the Logo programming language in the 80s (Papert 1980). At the same time, many large corporations jumped on the making and coding bandwagon and started programs of their own further increasing the momentum of making and coding in K-12 education.

Fourth Trend: Dramatic Reduction in Cost of Digital Fabrication Technologies

Another important occurring over the past 20 years has been the dramatic cost reduction in several technologies closely related to fabrication and making, a trend that Gershenfeld (2007) compared to the shift from mainframes to personal computers. At the beginning of the 2000s, 3D printers could only be found in large corporations and would cost hundreds of thousands of dollars. Halfway through the decade they had fallen to several tens of thousands of dollars, and in 2017 some models are available for $300 or less (see Fig. 3).

In the 1990s, the use of microcontrollers required an enormous technical knowledge, and a plethora of electronic components were required to power them, enable their sensors, and trigger external devices such as motors. New products lines from Atmel and Microchip, together with much cheaper (or free) development platforms, led to inexpensive and easy-to-use microprocessors. Microcontroller boards such as the Basic Stamp (for hobbyists) and the MIT Crickets (for education) made microcontroller use even simpler by providing on the board itself much of the circuitry necessary for sensing and device control. In 2005, the Wiring and Arduino

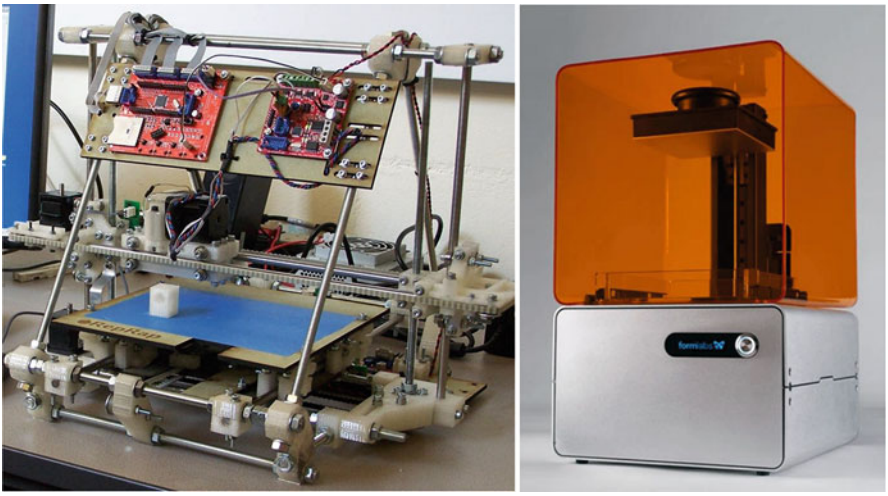


Fig. 3 The evolution of low cost 3D printers: from the first RepRap Mendel in 2005 (Photo: Adrian Bowyer) to Form 1 in 2011, which can reach resolutions of 25 μ using stereolithographic technology

platforms started a new chapter in this revolution by offering an inexpensive hardware platform, free development tools, and stable software and hardware design (for a full review, see Blikstein 2015). At that point, the Internet was already ubiquitous, so self-sustaining web communities propelled the use and adoption of Arduino to levels never before seen (see Fig. 4 for several of these platforms).

Fifth Trend: Better Tools and Research from Academic Labs

The last important trend necessary for understanding the growth of the maker movement in education is the improvement and creation of new software and hardware tools specifically focused on children and the increased research output of academic labs. The best example is the Scratch programming language (Resnick et al. 2009), developed by the MIT Media Lab beginning in 2002. Scratch took the world by storm, making computer programming much easier through the substitution of manual entry of typed code for a block-based graphical coding interface. Other tools, such as Alice and NetLogo, extended programming to new areas, including 3-D worlds and storytelling (in the case of Alice, Cooper et al. 2000) and scientific modeling (NetLogo, Wilensky 2006). All such tools benefited from a research field that was then taking form: interaction design for children. This nascent field adapted the lessons of human-computer interaction and applied them creatively to the design of computational and tangible tools for children. The first Interaction Design for Children Conference (IDC), in 2002, solidified this emerging movement of designers and researchers, and the community remains extremely active and behind many of the most significant efforts in bringing the maker movement to

Fig. 4 The evolution of technology kits for children: the Erector Set (1940s), the Lego Mindstorms kit (1998), the GoGo Board (2001), the Arduino (2005), the Lilypad (2006), and LittleBits (2011)

education. Some of the seminal papers on digital fabrication and physical computing for children were published at IDC. Mike Eisenberg, in a visionary and trailblazing paper, first proposed the use of new "output devices" such as 3D printers in education (Eisenberg 2002), and Leah Buechley pioneered the use of e-textiles and new, flexible materials (Buechley 2006; Buechley and Eisenberg 2008).

However, researchers did not simply design new interfaces and toolkits; they were also studying them and publishing research focused specifically on the effect and impact of these new technologies on learning. This research tradition had a strong start at the MIT Media Lab, but Northwestern University also contributed significantly with its creation of the first Learning Sciences program in 1991. This new research field spread quickly within the United States and Europe, as well as in other countries such as Singapore and Australia, offering new perspectives for research at the intersection of technology and learning. Breaking away from the strict traditions of educational psychology, large econometric studies, and critical theory, the learning scientists began developing, refining, and applying novel methods, often adapted from other disciplines, including design-based research (Edelson 2002; The Design-Based Research Collective 2003), computational modeling (Abrahamson et al. 2007; Blikstein 2013b; Worsley and Blikstein 2013), new types of ethnographies, and thick descriptions of learner-produced artifacts (Nemirovsky 2011; Sherin 2001). At the same time, they generated a much more plastic and diverse body of research that significantly influenced the creation of the Next Generation Science Standards in the United States and research that inspired innovative educational experiences worldwide. Additionally, learning sciences researchers were very well equipped to study the complex, unconventional, and at times eccentric educational interventions typical in maker environments, including small workshops and after-school environments. Not by coincidence, the field of the Learning Sciences brings together the main researchers studying the maker movement in education (Halverson and Sheridan 2014; Martin 2015; Peppler and Bender 2013), many of whom have recently published an entire volume on research on the maker movement in education (Peppler et al. 2016).

FabLabs, Makerspaces, and Other Fabrication Spaces: A Primer

The confluence of these five trends brought us to a special moment in the history of educational technologies and technology education. There is an unprecedented social acceptance for the changes that the maker movement can bring to education, as well as a strong research infrastructure to measure its outcomes. The costs of software and hardware tools are quickly dropping, and several new, student-friendly tools are being created in research and design labs. Not by coincidence, many types of spaces and formulations are being attempted in schools and informal learning spaces. Therefore, it is useful to understand the exact nature of each of these new spaces for making and fabrication and how they differ (see examples in Fig. 5).

Hackerspaces

Hackerspaces began to appear in the 1980s and 1990s in several cities in the USA and Europe as places where technology enthusiasts could come together, invent devices, repurpose them, or explore the nascent technologies, such as low-cost microcontrollers. Such spaces were also inspired by the open source software community. Hardware engineers also began imagining a world in which hardware design would be free and open source, in a reaction against the overly protected model of most consumer electronics manufacturers. Hackerspaces were envisioned as places of resistance, the breeding grounds of a counterculture opposed to

Fig. 5 Three different spaces for making and fabrication, in East Palo Alto, USA (top); Bangkok (middle), Thailand; and Melbourne, Australia (bottom)

overconsumption, stringent intellectual property, programmed obsolescence, and proprietary devices. Even though hackerspaces were inspirational for the maker movement, their typical audience were high-end programmers, hackers, and engineers, and some authors have noted that the male-centric, technical culture that developed in many of these spaces is problematic and exclusionary for novices (Buechley 2013) and that the culture of autodidactism in which their adherents live and breathe might not be the best for young learners and schools (Blikstein and Worsley 2016).

FabLabs

FabLabs followed hackerspaces in the desire to open up and demystify everyday objects and technologies. They were the first spaces designed for digital fabrication and rapid prototyping at low cost (Gershenfeld 2007; Mikhak et al. 2002). Engendered at the Massachusetts Institute of Technology Media Lab, they had a strict list of machines and rules required for all labs seeking a FabLab designation. The idea behind standard equipment was to allow collaboration and cross-pollination of ideas among participating labs and the creation of a worldwide network of very similar small scale fabrication facilities. FabLabs must also follow the Fab Charter and they must employ at least one staff member trained at the Fab Academy, the training program sanctioned by the global FabLab community. The mindset of the FabLab network, with these more prescribed forms of organization, certification, and training, assures that all labs allow the fabrication of products at a minimum level of complexity, using similar technologies and practices. FabLabs around the world enjoy relative freedom and independence, but the denomination itself is centrally controlled by the Fab Foundation, so the labs – even in schools – have to possess a minimum set of equipment.

Makerspaces

Makerspaces represent a radically different mindset that arose from the culture and community of the *Maker Faires* and the *Make Magazine*. Makerspaces are physical spaces for making that range enormously in format. They represent a flexible set of technologies and concepts put forth by Dale Dougherty and his Make Corporation and MakerEd nonprofit organization (Dougherty 2013). Makerspaces started as a new kind of digital fabrication and invention space intended to be much less structured than the MIT FabLabs. Whereas FabLabs are required to contain a specific set of machines, a connection to a global network, and affiliation to a virtual academy for lab management training, makerspaces are more of a label than a well-defined, intentional project. There is no set formula or specification to build a makerspace; as a result, they are able to play a variety of roles, may range greatly in size, capability, and cost, and permit a number of management possibilities. Makerspaces may contain a few basic craft and woodworking tools or they may offer cutting-edge 3D printers and laser cutters. However, this lack of any precise definition for the concept has led to confusion for school leaders and teachers. Some schools provide a small room with a table and some glue guns and consider that a makerspace, while others offer professional-grade 3D design equipment. The fact that the Make Corporation, the movement, the "faires," and the nonprofit activities of MakerEd all share the "make" denomination, has also brought some confusion to schools and criticism by scholars as to the need to better separate the institutions and brands (Bean and Rosner 2014). Compared with FabLabs, despite their flexibility, makerspaces have a much harder time comanufacturing products, connecting with each other, and sharing best practices.

Commercial Ventures and TechShop

Apart from the three main types of digital fabrication spaces, private companies have sought to create commercially viable fabrication spaces. The TechShop is the best known commercial version of FabLabs and makerspaces. Started in 2006 in Menlo Park, California, the company now operates in three countries at 11 locations. Most TechShop installations have similar equipment, usage policies, costs for facility rental, and architecture: users pay for access to the machines and receive support from the staff. The TechShop is perhaps the best example of an economically sustainable digital fabrication space, and it is used mostly by inventors and entrepreneurs, with little impact on formal education.

Challenges and Opportunities for the Maker Movement in Schools

This multiplicity of spaces and maker "philosophies" certainly creates difficulties for schools attempting to understand the differences between them. It is challenging to choose between the models and know, in each case, how to build the spaces, train teachers, manage labs, and incorporate the particular maker practices pertaining to each model. The final section of this chapter offers some research-based insights and recommendations for building robust maker infrastructure in schools and districts and for the creation of national initiatives aimed at democratizing the maker movement for students.

Lab Design that Is Well Adapted to the Needs of Schools

Tool and environment design turned out to be quite fundamental in the creation of inclusive, functional spaces for making (Blikstein 2013a; Buechley et al. 2008; Perner-Wilson et al. 2011). The architecture and workflow requirements of labs destined for students are quite different than those of labs designed for high-end engineers working professionally. Students normally come to a digital fabrication space in large groups for short periods of time and require intense facilitation, whereas inventors are typically few, work long hours, and are autodidacts.

Consequently, the number of machines and the architecture for these distinct kinds of space cannot be the same. Many schools stumbled on this issue in their attempts to install traditional, “adult” FabLabs, hackerspaces, and makerspaces within their walls. Schools often purchased equipment that was designed for individual use, not for large groups, which made direct manipulation by students all but logistically impossible. For example, whereas in a professional space it would be more useful to have one high-end 3D printer, in educational spaces it would be better to use the same amount of funds to buy several low-end machines that can be used simultaneously by students.

Educational designers also struggled with gender bias and self-selection. Architecturally, special concern must be given to making these spaces well organized, inviting, colorful, and engaging. Consequently, it is necessary to avoid creating the appearance of “a hacker’s garage,” which would appeal mostly to male students and children with previous engineering experience (Blikstein 2013a). Standardization was a hallmark of the MIT FabLab model, but that requirement conflicted with the differing needs and funding levels of individual schools. Many schools had small amounts of funding available to get started, so they could not afford the entire set of equipment mandated by the FabLab network. At times, some of that equipment, such as machines to create printed circuit boards or large routers, were not very relevant to projects typically undertaken by young learners. At the same time, the Make Corporation’s vague recommendations for makerspaces did not offer schools a definition of what constitutes a proper space for making, generating a plethora of ad hoc characterizations that did not offer much guidance for the design of robust programs. In summary, there is still considerable latitude for designers to create and adapt models that would efficiently work in schools, with their differing instructional, workflow, and funding requirements.

Systemic Incentives for Innovative Schools and Teachers

A second component that could democratize the maker movement in schools is the creation of incentive systems that reward the teachers who promote innovation in schools. For the most part, the creation of spaces for digital fabrication in schools is driven by visionary, energetic teachers who take initiative to do things differently. Rarely, it is the case that the development of such spaces is driven by top-down models. This has much to do with the very nature of the activities and learning requirements of children. It would make no sense, for example, to have a rigorously scripted maker curriculum for an entire nation, because making in education is committed to some level of free choice and project-based learning. Before adopting such top-down curricula, countries considering the institution of standardized spaces for digital fabrication should weigh very carefully the outcome of such approaches for their teachers’ creativity and innovation. Detailed implementation plans certainly do require structure and planning, but they also require real incentives at the local level for innovative teachers and schools to continue their innovation and experimentation with new curricula, pedagogies, and tools. Such incentives might include fellowship programs for innovative teachers, national prizes for innovative educational experiences, national science and engineering fairs, and other high-profile national events.

Inclusion in National Standards: They Should Reward Innovation!

A third very important component in ensuring the movement's sustainability is its inclusion within national standards. In the USA, the Next Generation Science Standards (NGSS) was quite felicitous in its inclusion of engineering practices beginning in the early grades. The inclusion of such considerations into national documents has a twofold advantage. It rewards teachers and schools already producing and teaching innovative curricula, even if they are not specifically seeking to comply with national standards. For example, in the USA, thousands of teachers have been teaching robotics and engineering in public schools, but outside of the school day or the school curriculum. Budget cuts and the natural wear and tear of sustaining an innovative educational experience have led many creative and innovative teachers to reduce or curtail such projects. However, as the NGSS is being enacted in several states in the USA, these teachers are finally gaining recognition and institutional support because, now, their innovative activities are acknowledged for their compliance with national standards.

The second advantage of including maker activities in national curricula is that they offer immediate incentives for entire school systems to restructure themselves to offer such activities and to devise concrete and objective schedules for implementation. The Australian government, for example, created a brand-new Information Technology curriculum and will deploy it over the next several years, thus Australian schools have been preparing for the types of content that will be required. Therefore, to ensure the promise of making in education, national standards should reward innovation in schools rather than compliance with past approaches and standards. Such standards should also offer guidance for the creation of new types of content, labs, and activities to be implemented nationally.

Because of these revised national standards, schools will need to redistribute time throughout the school day, and it will soon be apparent that there is no way to offer maker activities within the confines of the traditional school day and structure. The hiring of new types of teachers with new skill sets will be necessary, and existing teachers will require retraining. Spaces will need to be retooled and assessments redesigned. Such changes may appear overwhelming, but with the correct planning, incentives, and resources, they are quite feasible.

Local Generation of Curriculum and Redesigned Lesson Plans

The year 2011 saw the creation of one of the first digital fabrication spaces in the world at a school in the San Francisco Bay Area. The methodology utilized to develop a local curriculum for this project demonstrates the existence, in a real educational environment, of a sustainable implementation model based upon the creation of a critical mass of curricular units by local teachers. In this school, one of the main elements of the implementation was the establishment of a "curriculum factory." Teachers would bring their current lesson plans to the maker lab teacher/ manager and they would redesign them to make use of the best features of the lab. The school released both parties from their normal duties for a few hours a week to write these maker lesson plans. For the disciplinary teacher, the collaboration with the maker lab teacher meant that he or she did not need to learn in depth the technical details of the machines, which made for a much less intimidating experience. Since the lab teacher was available for assistance on these technical issues, the teachers could concentrate on course content and pedagogy, while the lab teacher's focus was on lab usage ideas. Typically, the process would continue for several weeks until a satisfactory quality was achieved for the lesson plan redesign. The curriculum units generated through this process would range from a week to a month and would include various elements such as the creation of materials, design of a final exhibition, assessment rubrics, evaluation, and technical tutorials. The redesigned lesson plans would then be implemented, evaluated in conjunction with the school leadership, and refined. The following year, the lesson plans were again implemented and further refined. Within 4 years, the school had built a database of maker units and lesson plans tightly integrated within its curricula, so the maker activities are now implemented during the regular school day on a regular basis. This school is now one of the most well-known models for a successful implementation of a maker space in middle-school.

Conclusion and Future Directions

Every few decades or centuries, a new set of skills and intellectual activities become crucial for work, conviviality, and citizenship – often democratizing tasks and skills previously only accessible to experts. But in the history of technology education, rarely there has been special attention to going beyond strict vocational and technical skills (Bennett 1937). In fact, there are two ways for the maker movement to be radically innovative. First, going beyond stereotypical views of technical education and breaking the dichotomy between hands-on and intellectual work. Second, when operating in schools, the maker movement could pay special attention to the insights of developmental psychology, interaction design, constructionism, and progressive education. Digital fabrication and "making" could be a new and major chapter in a process of bringing powerful ideas, literacies, and expressive tools to children, instead of merely providing technical training for the job market. Theorists such as Papert advocate technology in schools not as a way to optimize traditional education, or teach technological skills for better alignment with the demands from the professional world, but rather as an emancipatory tool that puts the most powerful construction materials in the hands of children. The machines and tools made available through the maker revolution have been proven to enable student design, engineering, and construction of unimaginable objects and inventions, and cater to many forms of working, expressing, and building (Martinez and Stager 2013). The chameleonesque adaptivity embedded in the technologies of the makers' movement permits the acknowledgement and embracing of different epistemologies, engendering convivial environments in which students can concretize their ideas and projects with intense personal engagement. We have enough research into the efficacy of the learning experiences that students undergo when they are engaged in making. But the main issue with educational technologies is always going beyond the demonstration phase. The next challenge for the maker movement will be the challenge of democratization: how do we bring such experiences to the children with the greatest disadvantages to make the movement an equalizing force, rather than another type of technology that widens the gap between private and public schools, affluent and low-income communities? This time, it seems that we have all the elements needed to formulate an answer and to realize, at last, the promise and the potential of educational technologies and progressive education.

Acknowledgments This chapter was made possible through the generous support of the Google Making and Science program, and Stanford's Lemann Center for Educational Entrepreneurship and Innovation in Brazil.

References

Abrahamson, D., Blikstein, P., & Wilensky, U. (2007). Classroom model, model classroom: Computer-supported methodology for investigating collaborative-learning pedagogy. Paper presented at the Proceedings of the 8th International Conference on Computer Supported Collaborative Learning, Rutgers University, New Brunswick.

Bean, J., & Rosner, D. (2014). Making: Movement or brand? *Interactions, 21*(1), 26–27.

Bennett, C. A. (1937). *History of manual and industrial education, 1870 to 1917*. Peoria: The Manual Arts Press.

Blikstein, P. (2013a). Digital fabrication and "making" in education: The democratization of invention. In J. Walter-Herrmann & C. Büching (Eds.), *FabLabs: Of machines, makers and inventors* (pp. 203–221). Bielefeld: Transcript Publishers.

Blikstein, P. (2013b). Multimodal learning analytics. Paper presented at the Proceedings of the Third International Conference on Learning Analytics and Knowledge, Leuven.

Blikstein, P. (2015). Computationally enhanced toolkits for children: Historical review and a framework for future design. *Foundations and Trends in Human-Computer Interaction, 9*(1), 1–68.

Blikstein, P., & Worsley, M. (2016). Children are not hackers: Building a culture of powerful ideas, deep learning, and equity in the Maker Movement. In K. Peppler, E. R. Halverson, & Y. Kafai (Eds.), *Makeology: Makerspaces as learning environments* (Vol. 1, pp. 64–79). New York: Routledge.

Buechley, L. (2006). A construction kit for electronic textiles. Paper presented at the IEEE International Symposium on Wearable Computers (ISWC), Montreux.

Buechley, L. (2013). Plenary talk at FabLearn 2013. Paper presented at the FabLearn 2013, Stanford. http://edstream.stanford.edu/Video/Play/883b61dd951d4d3f90abeec65eead2911d

Buechley, L., & Eisenberg, M. (2008). The LilyPad Arduino: Toward wearable engineering for everyone. *IEEE Pervasive Computing, 7*(2), 12–15.

Buechley, L., Eisenberg, M., Catchen, J., & Crockett, A. (2008). The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science

education. CHI 2008 Proceedings. April 5–8, Florence, Italy, margaritabenitez.com/readings/lilypad.pdf.
Cooper, S., Dann, W., & Pausch, R. (2000). Alice: A 3-D tool for introductory programming concepts. *Journal of Computing Sciences in Colleges, 15*(5), 107–116.
Dewey, J. (1902). *The child and curriculum*. Chicago: University of Chicago Press.
Dougherty, D. (2013). The maker mindset. In M. Honey & D. E. Kanter (Eds.), *Design, make, play: Growing the next generation of STEM innovators* (pp. 7–16). New York: Routledge.
Edelson, D. C. (2002). Design research: What we learn when we engage in design. *The Journal of the Learning Sciences, 11*(1), 105–121.
Eisenberg, M. (2002). Output devices, computation, and the future of mathematical crafts. *International Journal of Computers for Mathematical Learning, 7*(1), 1–43.
Freire, P. (1974). *Pedagogy of the oppressed*. New York: Seabury Press.
Freudenthal, H. (1973). *Mathematics as an educational task*. Dordrecht: Reidel.
Fröbel, F., & Hailmann, W. N. (1901). *The education of man*. New York: D. Appleton.
Gershenfeld, N. (2007). *Fab: The coming revolution on your desktop – from personal computers to personal fabrication*. New York, NY: Basic Books (AZ).
Halverson, E. R., & Sheridan, K. (2014). The maker movement in education. *Harvard Educational Review, 84*(4), 495–504.
Hutchins, E. (1995). How a cockpit remembers its speed. *Cognitive Science, 19*(3), 265–288.
Illich, I. (1970). *Deschooling society*. New York: Harper & Row.
Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.
Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research (J-PEER), 5*(1), 4.
Martinez, S. L., & Stager, G. (2013). *Invent to learn: Making, tinkering, and engineering in the classroom*. Torrance: Constructing Modern Knowledge Press.
Mikhak, B., Lyon, C., Gorton, T., Gershenfeld, N., McEnnis, C., & Taylor, J. (2002). *Fab Lab: An alternative model of ICT for development."development by design"(dyd02)*. Bangalore: ThinkCycle.
Moll, L. C., Amanti, C., Neff, D., & González, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into Practice, 31*(2), 132–141.
Montessori, M. (1965). *Spontaneous activity in education*. New York: Schocken Books.
Nemirovsky, R. (2011). Episodic feelings and transfer of learning. *The Journal of the Learning Sciences, 20*(2), 308–337.
NGSS Lead States. (2013). *Next generation science standards: For States, by States*. Washington, DC: The National Academies Press.
OECD. (2006). Assessing scientific, reading and mathematical literacy: A framework for PISA 2006. Retrieved from http://www.oecd.org/document/33/0,3343,en_32252351_32236191_37462369_1_1_1_1,00.html#HTO
Papert, S. (1980). *Mindstorms : Children, computers, and powerful ideas*. New York: Basic Books.
Papert, S. (2000). What's the big idea: Towards a pedagogy of idea power. *IBM Systems Journal, 39*(3&4), 720–729.
Peppler, K., & Bender, S. (2013). Maker movement spreads innovation one project at a time. *Phi Delta Kappan, 95*(3), 22–27.
Peppler, K., Halverson, E. R., & Kafai, Y. (2016). *Makeology: Makers as learners* (Vol. 2). New York: Routledge.
Perner-Wilson, H., Buechley, L., & Satomi, M. (2010). Handcrafting textile interfaces from a kit-of-no-parts. Paper presented at the Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction. New York: ACM, 61–68.

Resnick, M., & Siegel, D. (2013). A different approach to coding. *Bright*. Retrieved from https://medium.com/bright/a-different-approach-to-coding-d679b06d83a#.d45mbi757

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., et al. (2009). Scratch: Programming for all. *Communications of the ACM, 52*(11), 60–67.

Sherin, B. L. (2001). A comparison of programming languages and algebraic notation as expressive languages for physics. *International Journal of Computers for Mathematical Learning, 6*(1), 1–61.

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 1*(32), 5–8.

Turkle, S., & Papert, S. (1991). Epistemological pluralism and revaluation of the concrete. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 161–192). Norwood: Ablex Publishing Co.

Von Glaserfeld, E. (1995). A constructivist approach to teaching. In L. P. Steffe & J. Gail (Eds.), *Constructivism in education* (pp. 3–15). Hillsdale: Lawrence Erlbaum.

Wilensky, U. (1999, updated 2006). NetLogo [computer software] (version 3.1). Evanston: Center for Connected Learning and Computer-Based Modeling. Retrieved from http://ccl.northwestern.edu/netlogo

Worsley, M., & Blikstein, P. (2013). Towards the development of multimodal action based assessment. Paper presented at the Proceedings of the Third International Conference on Learning Analytics and Knowledge, Leuven, Belgium, 94–101.

Part IV

Teaching and Learning

Teaching and Learning in Technology: Section Introduction

31

Wendy Fox-Turnbull

Abstract

For most of the previous two centuries teaching has occurred with one teacher and 20–40 students in one classroom using a teacher-centered approach to teaching. Learning in this "classic" type class room focused on the predetermined learning of discipline-based facts, knowledge, and skills with some subsequent application in frequently contrived unfamiliar or outdated contexts. With the introduction of the twenty-first century, we are seeing a significant shift in teaching philosophy and approaches to learning. Teaching pedagogies and spaces need to become more flexible to facilitate a wider range of students' interests and needs and include the development of skills and knowledge and dispositions vital for twenty-first century living such as: collaboration, cooperation, critical thinking, and problem solving skills, while at the same time ensuring "curriculum content" knowledge is not lost, but available to students when needed.

Keywords

Materials • Authenticity • Problem based learning • Language of technology • Authenticity • Interaction • Emotions

For most of the previous two centuries teaching has occurred with one teacher and 20–40 students in one classroom using a teacher-centered approach to teaching. Learning in this "classic" type classroom focused on the predetermined learning of discipline-based facts, knowledge, and skills with some subsequent application in frequently contrived unfamiliar or outdated contexts (Bolstad and Gilbert 2008). With the introduction of the twenty-first century, we are seeing a significant shift in teaching philosophy and approaches to learning (Claxton and Carr 2010). Teaching

W. Fox-Turnbull (✉)
School of Sciences and Physical Education, University of Canterbury, Christchurch, New Zealand
e-mail: wendy.fox-turnbull@canterbury.ac.nz

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_71

pedagogies and spaces need to become more flexible to facilitate a wide range of students' interests and needs and include the development of skills and knowledge and dispositions vital for twenty-first century living such as: collaboration, cooperation, critical thinking, and problem solving skills, while at the same time ensuring "curriculum content" knowledge is not lost, but available to students when needed (Wagner 2008).

In former times assessment typically occurred through regurgitation of facts in tests, examinations, or assignments. Due to recent advances in understanding how students learn and the arrival of the information and digital ages, educational practice and achievement in the twenty-first century no longer focuses on discipline content knowledge but rather the development of appreciative dispositions such as those mentioned above, that enable students to react to situations they face for which they may not be specifically prepared.

Technology is particularly well suited to what is currently termed modern learning pedagogies and when fully implemented uses a range of problem centered, constructivist, and socioculturally based pedagogical approaches (Snape and Fox-Turnbull 2011b). When participating in technology students should be engaged in context-based problem solving to understand and develop products and systems. Students should have opportunities to develop multiple outcomes, as opposed to very similar or the same outcomes, within and across a range of authentic contexts. Teachers should facilitate learning, identify and teach generic and specific knowledge and skills only when the need arises. The terms "authentic" or "authenticity" have been synonymous with technology. Technology education for students needs to be authentic (Fox-Turnbull 2003; Snape and Fox-Turnbull 2011a).

Authentic technology education has two aspects (i) authentic to technological practice – the practice of technologists and (ii) authentic to the cultural, social, and historical world of the students (Hennessy 1993). Authentic learning in technology education means that students need to be involved in practices which reflect understanding of the culture of real technological practice, because skills and knowledge are far less relevant and meaningful if taught in isolation. Students need to, and have a right to, understand the relevance and place of their learning; therefore in technology they need to develop understanding, knowledge, and skills of authentic technological practice. Technology teachers model the practice of technologists (Fox-Turnbull 2003). By serving as a role model, technology teachers can show students how to locate, gather, and use information to solve technological problems, thus helping their students realize that not all problems have straightforward and simple solutions.

Our challenge therefore is to make Technology holistic rather than fragmented, thus developing students' understanding of the relationships of specific tasks to the whole design and development process. To develop this understanding students need to be aware of the whole process and how the components are linked together. This is best done in contexts authentic to practice so students are aware of what the technologist is involved in during their design process.

This section is a large section comprising of 12 chapters related to a range of aspects of teaching and learning in technology aspects from the language of technology to the nature of teaching about materials. Also covered are aspects of design, modeling, emotions, and attitudes in technology. Below is a brief summary of the contents of each chapter.

In her chapter, Svensson discusses technological solutions as systems from a learning perspective and the relevant content and concepts needed to assist students in their understanding of systems. The role of system thinking in relation to technology as a knowledge field in today's society and systems theory and thinking are also discussed.

In ▶ Chap. 33, "Influences of Materials on Design and Problem Solving Learning About Materials" Potter investigates the relationship between design and problem solving and materials. How materials impact knowledge requirements and skills needed is discussed and illustrated within the area of resistant materials and mechanical engineering. Traditionally, resistant materials is an important area in technology education and provides opportunities to explore the multifaceted complexity of and interaction between design, problem solving, and materials.

Authentic learning and its relationship to technology education is discussed by Hill in ▶ Chap. 34, "Authentic Learning and Technology Education." A much used term, authentic learning is defined and theorized. A number of significant factors of authentic learning are described. Hill then looks at the relationship between authentic learning and technology education and discusses the implications for and application in technology classrooms.

Problem-based learning (PBL) is explored in ▶ Chap. 35, "Problem-Based Learning in Technology Education." Problem-based learning (PBL) is an approach to learner-centered education in which learners explore, collaborate, research, and respond to authentic, real-world problems and situations. Best suggests that it is an appropriate pedagogy for Technology Education, as technology is all about solving problems (design problems, making problems, maintenance, and repair problems). This chapter will describe PBL and its possible role in Technology Education.

In ▶ Chap. 36, "Emotion and Technology Education" Spendlove surprises and challenges us to consider the place of emotion in learning in technology education. Initially two aspects of emotion are highlighted, that of emotional literacy and the situated landscape of emotion. The chapter then evolves to discuss the role of emotion in creativity and technology education.

Stroble in ▶ Chap. 37, "Technology Education as a Practice-Based Discipline" presents a model that conceptualizes technology education as a practice-based discipline. First, existing prevalent model of technology and engineering that focuses on the attainment of conceptual knowledge are briefly discussed. Then the new model is introduced, suggesting engineering and technology as a complex and contextualized practice. The model reframes the fundamental questions of technology and engineering and technology/engineering practice, and the possible implications for technology/engineering education and practice.

In ► Chap. 38, "Teaching the Language of Technology: Toward a Research Agenda" van Dijk Hajer suggests that language plays an important role in learning technology, as in any other subject. This chapter gives an overview of insights into the language demands that technology education places on students. In the second section of this chapter, teaching approaches that help students to understand and to produce the language of technology are discussed.

► Chapter 39, "Classroom Interaction in Technology Education" discusses classroom interaction in technology education, particularly interstudent conversation. Fox-Turnbull argues that authentic technological practice is largely collaborative. A vital part of working collaboratively is the ability to talk about and explore possibilities through conversation. This chapter explores the place and nature of conversation in learning technology and suggests the facilitation of interstudent intercognitive conversation as a powerful tool for advancing learning and collaborative practice in technology education.

The central issue in ► Chap. 40, "Linking Knowledge and Activities: How Can Classroom Activities in Technology Reflect Professional Technological Knowledge and Practices?" is the relationship between professional technologist practice and that of students in technology. Esjeholm and Bungum investigate the nature of technological practice and knowledge and then used an historical development within the aeronautical industry to illustrate characteristics of the above. In the latter section of the chapter they discuss the relationship between professional technological practice and that of students in technology education.

Ankiewicz in ► Chap. 41, "Perceptions and Attitudes of Pupils Toward Technology," investigates the construct of attitudes towards technology, such as definitions of attitude, and fundamental reasons for measuring students' attitudes. This chapter presents a survey of investigations made into what pupils think about technology, both in terms of what they think it is and the feelings they have about it. The latter part of the chapter provides general research findings from just over three decades of PATT studies on students' attitudes towards technology, as well as examples of recent multidimensional versus unidimensional studies.

Kangas and Seitamaa-Hakkarainen examine how collaborative designing could be promoted in Technology Education classrooms in ► Chap. 42, "Collaborative Design Work in Technology Education." Pedagogical models which include design process through collaborative inquiry are presented as a way to structure and support students' design learning processes. One approach, *Learning by Collaborative Design*, which focuses on object-oriented learning, is described in detail because of its unique applicability to technology education.

► Chapter 43, "Modeling in Technology Education: A Route to Technological Literacy" concludes this section on teaching and learning in technology with a close look at modeling. France argues that modeling is a central part of the technological enterprise and its scope and purpose are important to examine when developing technological literacy. An understanding of the role of models provides an epistemological foundation to the concept of functionality. This chapter explores aspects of modeling in technology through a case-study situated in New Zealand.

References

Bolstad, R., & Gilbert, J. (2008). Disciplining and drafting or 21st century learning? Rethinking the New Zealand senior secondary curriculum for the future.

Claxton, G., & Carr, M. (2010). A framework for teaching learning: The dynamics of disposition. *Early Years: An International Journal, 24*(1), 87–97.

Fox-Turnbull, W. (2003). *The place of authentic technological practice and assessment in technology education* (MTchLn Thesis for Master of Teaching and Learning), Christchurch College of Education, Christchurch.

Hennessy, S. (1993). Situated cognition and cognition apprenticeship: Implications for classroom learning. *Studies in Science Education, 22*, 1–41.

Snape, P., & Fox-Turnbull, W. (2011a). Perspectives of authenticity: Implementation in technology education. *International Journal of Technology and Design Education* (early access online).

Snape, P., & Fox-Turnbull, W. (2011b). Twenty-first century learning and technology education nexus. *Problems of Education in the 21st Century*, *34*, 149–161.

Wagner, T. (2008). *The global achievement gap: Why even our best schools don't teach the new survival skills our children need- and what we can do about it*. New York: Basic Books.

Learning About Systems 32

Maria Svensson

Abstract

Technological systems are established in relation to theories and philosophical traditions within technological practice. The question is whether and how this tradition can help to shape technological systems as a field of knowledge for compulsory schooling. From a literacy perspective, knowledge about technological systems is essential in today's society. In order to create good conditions for students to learn about technological systems, the theoretical and philosophical traditions must be supplemented with an educational tradition, an understanding of how, what, and why to work with technological systems in schools, on different levels. Research concerning technological systems in education focuses to a great extent on students and teachers' understanding of system-relevant concepts such as input and output, components, and subsystems. By reviewing relevant theories of technological systems, educational research of technological systems and technology, qualities emerged as a basis for constituting technological systems as a field of knowledge for students, thus enabling the identification of strategies for further development within this field.

Keywords

Technological systems • System thinking • System nature • Complicated • Complex

M. Svensson (✉)
Department of Curricular, Pedagogical and Professional Studies, University of Gothenburg, Gothenburg, Sweden
e-mail: Maria.svensson@ped.gu.se

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_34

Contents

Introduction

What does it mean to learn about systems? We are today able to travel, within a day, between cities in different countries in high-speed trains or airplanes, it is even possible to travel to the moon. All this, and many other things, are a part of our everyday lives. An important factor in this is the systems that man has invented, designed, and developed. Systems are today interwoven into our society to the extent that they almost become invisible. It is therefore more important than ever to develop systemic awareness, to enhance the quality of lives on Earth, and to think and understand about the impact humans have when they act in the world; it is technological literacy. Systemic awareness is not a new phenomenon. The Greek philosopher Aristotle (384–322 BC) presented a vision of systemic order of nature in his *biological systematics*. In later times the first comprehensive exposition of systemic thinking was presented by Jan Smuts (1850–1950) in his book *Holism and Evolut*ion in 1926. However the origin of modern system thinking is associated mainly with Ludwig von Bertalanffy (1901–1972). System thinking was established in the pre-World War II optimism, in an era of increasing resources, as an alternative answer to needs which were then considered pressing. Now, 70 years later, both needs and answers are timelier than ever.

In this chapter, system theories and system thinking represent a basis from which common paths as well as unexplored paths between theoretical and philosophical traditions of technological practice and teaching traditions of technological systems are investigated.

System Theory and System Thinking

System theory and system thinking have been developed, applied, and evolved in many disciplines and in relation to both ontological and epistemological dimensions. To understand what learning about technological systems implies, a view of the theoretical and philosophical traditions concerning system theories and system thinking are presented. The presentation made here is by no means exhaustive but gives a glimpse into a larger field with the intention of supporting the educational discussion that follows.

System Theories

System theories are used to describe our world (Ison 2010). System theories are about understanding a whole, which cannot be done only by having knowledge of the parts and their properties but also the relationships between them. Together, the parts and the relationships between them constitute a whole where the parts can be replaced to maintain or change the system (Ingelstam 2012). System theory has its basis in biology, mathematics, and engineering (Assaraf and Orion 2005; von Bertalanffy 1968). They are inherently multidisciplinary, with knowledge from many different fields brought together. There have been attempts to find a general system theory that highlights the interdisciplinary nature of systems. Von Bertalanffy (1968), a biologist, introduced General System Theory that deals with systems and defines their characteristics as a whole using concepts and ideas borrowed from different scientific areas. Cybernetics, another theory (Wiener 1961), highlights the interdisciplinary nature of systems. In cybernetics, information and exchange of information are seen as the bases of all systems, and mathematical models can be used to describe them. There have also been other more pragmatic ways to describe the connections and the borrowing between different scientific fields in relation to systems (see, e.g., Churchman 1967; Hughes 1989). Although there have been attempts to formulate general system theories, it is important to remember that it is difficult to find a common and comprehensive description of system theory that applies to various fields of science.

The fact that systems are inherently interdisciplinary is important to keep in mind when it comes to learning about technological systems. System theory does not respect the usual disciplinary boundaries but extends across different areas, for example, energy studies integrate technical, scientific, and social research and environmental issues integrate knowledge from a variety of disciplines such as biology, meteorology, urban planning, and economics. It can be understood as a skeleton that builds together different traditions of knowledge.

A map is one way of visualizing system theory. Although this only presents a rough classification of systems, it assists understanding relations and differences between system areas. Ingelstam (2012) uses Luhmann's (1995) map to visualize system theory on two levels. The first level is a general system level where we find general system theory (von Bertalanffy 1968) with mathematical and abstract models. Under this general system level, there are six different system families that are constituted in relation to the nature of their components: machines, organisms, social system, psychological systems, socio-technical system and science-technology society, and psychological systems. Among the families are similarities and ideas have been transferred from one family to another. However, in this chapter two of the system families, machines and socio-technical systems are of particular interest because the physical nature of the components in these families relates to technology and are thus interesting in learning about technological systems:

- Machines – input-process-output, components, connections, feedback, e.g., coffee machine
- Socio-technical systems – physical components, social components, and connections, e.g., transportation systems

Technological systems are the focus of this chapter; however, it is important to keep in mind that technological systems are part of a larger family, the system theory family.

Technological Systems

When talking about technological systems, it implies something that can be represented materially as physical components. It is not about an intellectual property system that describes a method, a practice, or a classification such as Linnaeus' (1735) sexual system. One way to think about the technological system is to ensure system theory as a framework for understanding the natural and constructed world by seeing it as a whole with the parts and relationships to the environment (von Bertalanffy 1968; Öqvist 2008). In today's society, technology has become increasingly systemic. When we talk about technology today, it is hardly ever about single objects that an individual has made to fulfill a need or desire, as it was when humans made their own tools and clothes; it is about technological systems that aims to deliver both to society and to individuals, as the production system and electrical system.

Technology as systemic implies different characteristics and dynamics compared to single objects and artifacts. People visualize differences between seeing technology as an artifact or a system. Focusing on the artifacts, and the process of production of these, could be described as an instrumental view of technology. This view is based on the idea that technology is a tool of human choice. According to Dusek (2006), technology is perceived as neutral, neither good nor evil, when viewed from an artifact point of view. Humans are outside the artifacts and can choose to use, abuse, or not use them at all. In this way, humans can be said to control the technology. If, instead seeing the human role in technology differently, as an integrated part of technology, a more systemic view of technology emerges (Dusek 2006; Kline 1985/2003). In this view, human involvement is seen as part of the system; technology is not isolated to individual artifacts. Rather it includes the linking of artifacts, processes, policies, and people. The integrated role of humans is particularly evident in socio-technical systems, where the technical and the social are interwoven in a way that make it difficult to see them as separated – they are a seamless web (Hughes 1989). Two perspectives of understanding systems as socio-technical are as large technical systems (LTS) (Hughes 1989) and social construction of technological systems (SCOT) (Bijke et al. 1989). In socio-technical systems, the interest is to describe how the components of three different characters interact with each other: (1) the technical core – technological artifacts; (2) technological and scientific knowledge, technical regulatory system safety, and standardization; 3) actors – users, entrepreneurs, organizations, companies, etc. Another way to understand the core elements of system theory and technological systems is in terms of system significants as described by Klasander (2010). The system significants are developed based on the criteria that they constitute or represent key concepts and lines of thought that characterize the way we think of and describe the world as a system. System significants could be perceived as a potential guide when connecting theories of system with knowledge about education of technological systems.

System Thinking

System thinking is used to understand things that happened. As noted by Meadows (2008), system thinking is a "way of thinking that gives us the freedom to identify root causes of problems and see new opportunities" (p.8). At the heart of system thinking in problem-solving situations is the ability to enlarge the systems' borders and expose hidden dimensions within. System thinking according to Senge (1990) is a conceptual framework of knowledge, principles, and tools that enable observing the "whole," understanding the interrelationships between system elements and identified patterns of change. The time is another important aspect of system thinking. When analyzing the behavior of the system's cause and effect might not be closely related in time and space; therefore, retrospective and predictions should be continuously included in the analysis.

The use of system thinking becomes important when it is no longer possible to think of technology in terms of single machines but of systems (von Bertalanffy 1968). When developing technological solutions, the aim is to meet human needs and desires. This is especially important because it is rarely the issue of individual solutions for an individual, but rather solutions that should be seen as solutions for a society. When different specialists are required for developing, designing, building, and maintaining the technological solutions, a system approach becomes necessary:

> A certain objective is given; to find ways and means for its realization requires the system specialist (or team of specialists) to consider alternative solutions and to choose those promising optimization at maximum efficiency and minimal cost in a tremendously complex network of interactions (ibid, p. 2)

System thinking implies "new" ways of thinking. When solving a problem, the thinking process is central and thinking should be an integral part of the problem-solving process from the start. A main idea with system thinking is to first think about the overall objective and then begin to describe the system in terms of this overall objective (Churchman 1967). This means first asking the question of what it is for, the purpose of the objective, and not start to make a list of what items make up its structure. A common way of describing things in the world is to start with describing them in terms of structure and not purpose. In technology education, problem-solving is a central part of the content and thus include system thinking. Churchman (1967) highlights that there isn't one single way of system thinking, but there are several system approaches that can be used to understand problems in the world; looking for the trouble spot in the system, making models of the system, identify human values in the system or to live in and experience the system.

One important issue is that many problems in today's society are poorly structured such as environmental problems and poverty. To understand those problems, system thinking with openness to different ways of thinking is of particular importance and should be an inherent part of technological literacy.

The Systems: Complicated, Complex, and Wicked

Technological solutions and issues affect humans, for example, through extending their abilities, by positive as well as negative consequences for health; they also affect the global natural environment in an increasingly complex way, for example, using resources, pollute and exploit the environment. The nature of technological solutions as systems needs to be sorted out and described in relation to their complicatedness, complexity, and wickedness (Törnberg 2017). These three descriptions are overlapping, but there are no sharp lines between them. It can however be helpful, particularly in the educational context when selecting systems to study, to think about whether they are understood as complicated, complex, or wicked.

Complicated Systems

The character of complicated systems is that they have a large number of components that are organized in compartments on different hierarchical levels. A coffee machine is an example of a complicated system. The structure of a coffee machine enables certain acceptable interactions and simplified assumptions, and it is hardly necessary to have any knowledge about the embedding system to operate locally on its components (ibid).

Complex Systems

Complex technological systems include many components, both physical and human, on different levels in the system and interactions in and between the levels. One difference between complicated and complex systems is the integration of humans as components in a complex system. The traffic system can be described as complex with physical parts: cars, busses and traffic lights, and humans; car drivers, pedestrians, and bikers that act together in the system. There is not a single definition of complexity, but Andersson et al. (2014) describes it in the following way:

> complexity is associated with bottom-up self organization – like the behavior of a school or fish or crowd – while complicatedness is associated with top-down organization, such as engineering. (ibid, p. 146)

There is a high degree of resilience in a complex system which means that unexpected events are more likely to occur in such a system. Analysis of these systems occurs by looking at what happens in different organizational (developing and maintaining the traffic system) or operational (using and maintaining the traffic system) levels (Ingelstam 2012).

Wicked Systems

Wicked systems are systems that are better described as arenas where adapting systems interact and compete over limited resources (Andersson et. al. 2014). They are most likely large socio-technological systems which contain large uncertainties in relation to a lot of aspects such as outcome, effects, and interactions between entities. Environmental problems are often described as wicked. Wickedness is described by Rittel and Weber (1973) as problems that lack definitive formulations. It is unclear when and if they are solved, they are caused by many other problems and require unique solutions.

By looking at the technological system as complicated, complex and/or wicked highlights a differentiation of the system nature that can be helpful when selecting technological systems to teach about. To be faced with a variety of systems opens for a more developed awareness of what a technological system is and how to understand technology as systemic.

System Methods

Models are used when developing and learning about systems. A model is a representation of system, a group of functional interrelated components forming a complex whole. When using a model, it has to have a clear purpose, and that purpose should be to solve a particular problem. A model should address a specific problem and simplify rather than attempting to mirror in detail an entire system. Even though, not all of us are going to be model builders, we are all becoming model consumers, since we will be faced with the results of models, such as models of energy distribution or metro maps, and have to make decisions based on those models (Sterman 1991). Computer models are widely used and have become commonplace in forecasting and public policy analysis. One advantage with computer models are that they are comprehensive and able to interrelate many factors simultaneously, but a disadvantage is that they are unable to deal with relationships and factors that are difficult to quantify or lie outside the expertise of the model builder. Another disadvantage is that they are black boxes; they are so poorly documented and complicated that no one can examine their assumptions (Sterman 1991).

There are different methods used to describe, develop, and control technological systems. Some of those may be relevant in an educational context and have an impact on learning about technological systems. Some relevant commonly used methods are presented here: System Dynamic Model (SDM), Life Cycle Analysis (LCA), and Material Flow Analysis (MFA).

System Dynamic Model

SDM are used to describe complex problems with different feedback loops, flow of energy, material and money, production, distribution, sales, and recycling. It was introduced in the 1960s by Forrester (1961) as a modeling and simulation methodology in dynamic management problems. The focus on system dynamics was to study the interactions between natural resources, technology, and economy. It is a method used for obtaining insight into problems of dynamic complexity and policy resistance. Since 1960s, SDM has been applied to various problems that are related to sustainability. Supply chain models are developed to describe the system dynamics. A supply chain is a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer including a lot of feedback loops. When using supply chains as a method in system dynamics, the emphasis is often on reducing nonrenewable resource usage (Georgiadis and Besiou 2008). Using SDM in education helps to visualize and structure complex systems and enables visibility of critical parts of the system.

Life Cycle Assessment

LCA is a method used to identify the environmental impacts of a product or process at each stage of its life cycle (Baumann and Tillman 2004). It is presented as a decision-making instrument for companies, but it has also proven to be an important application to understand and learn about potential improvements and risks in production processes. An additional application area for LCA is the communication of the life cycles of products, especially important for companies when marketing products. LCA is often used in the early stage of a product and process design, to assess and improve the production system. By using a life cycle model physical processes and flows of energy and matter can be identified (see Fig. 1).

The procedure for studying LCA is described by four elements: goal and scope definition – what to study and how to do it; inventory analysis – flow identification, input, and output; impact assessment – interpreting the physical flows of natural resources and pollutant emissions in relation to environmental impact; and interpretation – analyzing the results and draw conclusions (Baumann and Tillman 2004). From an educational point of view, LCA could be a model to use when understanding of different flows and processes in systems are in focus, and the ability to visualize this in concrete form is limited.

Material Flow Analysis

MFA is a method that focuses on resources in a system. It is used for quantifying the stocks, flows, input, and losses of resources; normally, it is directed to a specific resource such as a particular metal or plastic, but it sometimes is used for mixed materials such as construction minerals (Graedel and Lifset 2016). MFA builds on the first law of thermodynamics: energy could not be "consumed" physically. To understand what happens during different processes with the flow of materials in the system, it is important to follow each substance and identify potential losses and what can be done to reduce them. Aluminum, cobalt, and cadmium are examples of substances that have been studied to make risk analyses and visualize the importance

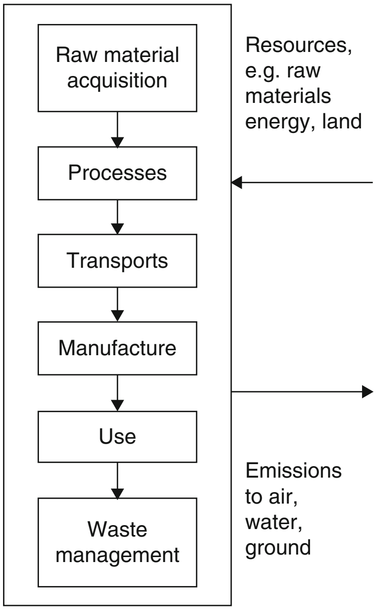


Fig. 1 The life cycle model (reproduced from Baumann and Tillman 2004)

of recycling and technological transformation. Geographical aspects are of high importance in MFA because the substance is extracted somewhere, maybe in a country other than where it is then processed, and affects the environment both locally and globally. MFA could be used in education about technological systems to identify and follow a specific material, how it is affected and changed during the transfer in the system, and what impact it has on the environment.

A System Approach in Technology Education

The understanding of systems is essential in developing technology knowledge (Jones 2003; McCormick 2004). Since the 1990, system approach has been visible in technology education research, and during the 2000s, research has increased and broadened (e.g., Compton and France 2007; Frank 2005; Jones 2003; Klasander 2010; Svensson 2011).

System Concepts

There has been and still is a demand to identify what can be considered as fundamental concepts, laws, and principles of technology education. There are some studies (e.g., Custer et al. 2010; Rossouw et al. 2011) which has resulted in lists of basic concepts such as design, systems, modeling, and innovation. However, those lists are of a general character, related to concepts that can be understood as important parts of the technology education. The concepts are not specified for different content-specific areas which means that they give no advice about different concepts in the area of, for example, systems. What are the important concepts to include in technology education when learning about technological systems? After completing a brief literature review of research concerning technological systems education, there are concepts that recur and that seem to have some significance for the learning of systems (e.g., Ginns et al. 2005; Koski and de Vries 2013; Svensson and Ingerman 2010). Concepts highlighted in the research include input and output, flow, components, relationship between components, processes, feedback, and subsystems.

There are indications of the importance of understanding of input, output, and the flow in systems (Compton and Compton 2013; Koski and de Vries 2013; Svensson and Ingerman 2010). To understand systems, we must understand that there is a flow of energy, matter, and information (Svensson 2011). The flow of information in systems is most difficult to identify; it may be that information is part of another system and therefore is overlooked (Hallström and Klasander 2016). A flow of information is needed to control processes in components, to enable feedback and sometimes to establish connections between components. Every system could be described as having a primary input that is directly connected to the purpose with the system; for example, in a coffee machine, the input of matter is the primary input and in the mobile phone system information is the primary input. Both the coffee machine and the mobile phone system have energy as a secondary input, but for younger students (age 8–10 years old), the concept of the primary input is more obvious than the secondary input. They also find it harder to identify the output. It is easier to understand and describe that water is needed in the coffee machine than the energy required to warm the water) (Koski and de Vries 2013).

Most studies conducted about technological systems conclude that students and teachers are able to identify and describe components in the system. The structure of systems is usually described as linear, starting with a primary input and ending with a primary output and there between a number of components. Students also seem to have an understanding about the interaction between components (e.g., Ginns et al. 2005; Hallström and Klasander 2016; Svensson 2011). However, there seems to be a lack of understanding about the component function, the processes, what components do with the flow, such as transporting, transforming, storing, or controlling. In many systems, the processes are embedded in the components in a way that it is hard to investigate how they work in detail, and they become “black boxes” (Hallström and Klasander 2016; Koski and de Vries 2013).

A way to address the gaps that exist in the understanding of technological systems can thus be to implement theories and methods from the technological practice field such as SDM, LCA and MFA.

Developing System Thinking in Technology

System thinking in technology proposes a way to teach technology without first teaching details. The focus is instead on handling the complete system, conceptually and functionally, without knowledge of all the details (Frank 2005). How this teaching is supposed to happen is not clear, and there is a need for research to find out more about what teaching for learning about systems requires. Looking at some studies that have been conducted, there is some interesting indications about teaching to be taken into account and that should be investigated further. In a study by Andreucci et al. (2012), a positive transfer effect of the systems approach in teaching from one area (industrial systems) to another (physical system problems) have been found. This indicates that, if teachers in different disciplines together consciously develop and use system thinking, it is more likely that they contribute to developing students' knowledge of systems, generally and specifically, in the same way that theories of systems have developed over time. However, to get a long-term effect continuity of education in system thinking is needed.

Barak and Williams (2007) stress that the learning of concepts in technological systems must progress in small steps, making the transition to formal reasoning a slow process that takes place through learning experiences that are context specific. Rather than seeing the possession of formal thinking abilities as a prerequisite for learning general system concepts, educators have to see the study of the physical and functional nature of systems as a framework for helping pupils to develop their formal thinking abilities. New concepts and general ideas about a system's behavior can be learned through *examples and analogies* related to pupils' prior knowledge. The teaching of dynamic processes in systems should be applied to as many different environments and forms of experiences as possible, both in school and out of it. This implies a *contextual learning*. To learn interdisciplinary concepts in systems, pupils' need a *variety of learning experiences*. Learning about systems implies learning about different system natures: complicated, complex, and wicked systems (Andersson et.al. 2014). When reviewing research, there is a focus on control systems or artifacts with integrated electronic that can be understood as complicated systems. These systems are part of the system theory family described as *Machines* by Luhmann (1995), systems where input-process-output, components, connections, and feedback are at the core. There is thus some research conducted that relate to other kinds of systems. Systems that also integrate humans and subsystems, for example mobile phone systems and transportation systems, systems with a high degree of resilience and multi-level hierarchizing. In the system theory family, those systems are described as *socio-technical system* (Luhmann 1995). This indicates the importance to emphasize a variety of systems in education.

Klasander's (2010) study of system thinking among teachers shows that teachers can be impeded either by the focus on scientific, reductionist aspects of systems or a focus on single artifacts. In a study of technology teachers planning in lower secondary school of teaching about systems, it emerged that the teachers needed more knowledge about the similarities and differences between various technological systems. They also required a better understanding of the system's components and different layers to plan the teaching in a more thoughtful way (Svensson and Klasander 2012). Technology student teachers' conceptions of technological systems indicate that they could see and describe various parts of systems but were unable to connect them to a wider context. Most of the students were interpreted as that they had an atomistic view on systems (Hallström and Klasander 2016).

Control Systems

Understanding of machines and control systems have been part of the technology education for some years which is not surprising since they are accessible and transparent in a different way than the more complex *socio-technical systems* such as transport systems and energy systems. During the late 1980 and 1990, research mainly focused on control systems (e.g., Martin 1990; Mioduser et al. 1996). It may be important to remember that during this period, computers made its entry in everyday life and control systems became more clearly integrated into everyday products such as washers and alarm clocks. Martin (1990) emphasizes that when working with electronics in a design process, it is important to start by answering the question what the system needs to do? not how it will do it? The focus should be on the function instead of the structure; this means that the input, process, and output are identified first, and then they are unpacked, and subunits are described. This is in line with how Churchman (1967) characterizes system thinking from the overall object. The research about control system indicate that students tend to grasp the structure of the system, identifying components, but, they find it more difficult to understand how components affect the system, the control features of the system, and the flow of information in the system (Compton and Compton 2013; Mioduser et al. 1996). It is worth noting that research about control systems are especially based on system's internal structure and components and not primarily on what is around the system. In the digitalized world that we currently live in, it is important to continue research about control systems to better understand how and what learning about system implies.

Socio-Technical Systems

Some studies have been conducted on socio-technical systems from a different point of view other than the internal structure of systems and the processes. As mentioned earlier, systems are more complex in nature as humans are integrated into the system and the external structure, subsystems, and environment are viewed as key aspects of the overall system. The socio-technical systems place different demands on the teaching and learning than if machines and control systems are studied since they are more complex, usually scattered across a larger geographic area and thus more difficult to study as a whole. Studies have been conducted on students' experiences of mobile phone systems, energy systems, and transport systems (Svensson 2011). To introduce the socio-technical systems, artifacts such as mobile phones, washing machines, and light bulbs have been used to talk about what is required in the environment in order to use them. In the same way as with the control systems, students discern the components and the structure of the systems quite well, but they have problems describing how components interact in the systems and how humans and subsystems are connected to the system at hand. The function of the system appears to be backgrounded in favor of the structure. Socio-technical systems are part of our everyday life, and understanding of both structure and function of those systems is crucial to be able to make informed decisions in a society.

Conclusion and Future Directions

What is the idea with understanding technology as systems? This is an important question to ask when learning about systems. There is always risk for impoverishment when using a concept without considering why, how, and when to use it. When using a system approach in technology education, the aim is to understand something as whole in relation to its entities (von Bertalanffy 1968; Meadows 2008). One problem with systems is that, as Ison (2010) emphasizes, they are subjective, and definitions of systems are "brought forth" by someone for a purpose. However, when teaching about systems, there are things that have emerged from available research about technological systems that may inform teachers and researchers about what can be considered as important aspects to take into count when planning, implementing, and evaluating teaching. The majority of the research on technological systems in education focuses on concepts. It is clear that understanding of key concepts plays an important role when trying to understand what learning about systems implies. Key concepts used in education about technological systems need to be reflected against system theories; an example is Klasanders' (2010) use of system significants. System concepts that do not appear as clearly in the research review conducted here is hierarchies, isolated systems, closed or open systems, dynamics, development, and change. It is thus important that technology teachers discuss and problematize the concepts used in the teaching of technical systems to offer good possibilities for learning about systems.

In the research about teaching technological systems, it seems to be more common to use a complicated system such as a coffee machine and elevator (e.g., Ginns et al. 2005; Koski and de Vries 2013) than a complex or wicked system when teaching about systems. However, investigations of a variety of system natures are needed to prepare students to understand that there are different kinds of technological systems in the society. Research has also shown that teachers need more knowledge about the similarities and differences between various technological systems (Svensson and Klasander 2012). Although there are no sharp boundaries between complicated, complex, and wicked systems, it may be, from an analytical point of view, an idea to see the differences between systems using these aspects (see, e.g., Andersson et.al. 2014).

Research about technological systems have been conducted on different levels in the school system, but there is no research that problematizes the progression of technological system knowledge. When organizing and supporting learning processes of technological systems, a better understanding of system concepts and contexts as well as system thinking are driving forces. There are attempts in the research that highlight strategies that teachers use to progress students understanding (Compton and Compton 2013). Those strategies suggested making input, output, and transformations explicit in a range of different simple technological systems before trying to grasp concepts in more complex socio-technological systems. Barak and Williams (2007) also stress that the learning about technological systems must progress in small steps, making the transition to formal reasoning a slow process that takes place through learning experiences that are context specific. Is it better to start with simple tangible systems and then move on to more complex and transparent systems or could just as easily the reverse be used to provide a progression? Further research on how to plan and implement progression about systems is necessary.

In the research about technological systems, no visible strategies are found concerning how to use different system methods to describe, develop, and control systems. To use system methods, established in a theoretical and philosophical technological practice traditions, could be an important contribution to the development of technological system education. When using different system methods, it is crucial to understand the insight each enables. Models and modeling is one suggested method that could be used to a greater extent in education of systems if the idea of what the model helps the students to see is clear (see, e.g., Barak and Williams 2007; Sterman 1991). Barak and Williams (2007) suggest that a variety of learning experiences is important when learning about systems. One of their suggestions is to use problem-based learning that includes design and construction of physical working systems. This is questionable in most school situations, especially the students are to learn about the socio-technical systems. Is it realistic or even possible to design and construct physical system of a mobile phone system, for example?

System theory and system thinking have been developed, applied, and evolved in many disciplines. To do more cross-educational research about systems is another interesting field of research that has a potential to provide new insights about technological system education. Learning about systems is a growing research area that has developed and probably will continue doing so in the future especially as technological systems are part of our society and knowledge about them is fundamental for using, developing, and maintaining them. The role of technology education in developing technological literacy of next-generation citizens requires learning about systems and an understanding of technology as systemic. To enable good learning opportunities, merging of different traditions is necessary; the theoretical and philosophical tradition must be integrated with an educational tradition.

References

Andersson, C., Törnberg, A., & Törnberg, P. (2014). Societal systems–Complex or worse?. *Futures, 63*, 145–157.

Andreucci, C., Chatoney, M., & Ginestie, J. (2012). The systemic approach to technological education: Effects of transferred learning in resolving a physics problem. *International Journal of Technology and Design Education, 22*(3), 281–296.

Assaraf, O. B.-Z., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching, 42*(5), 518–560.

Barak, M., & Williams, P. (2007). Learning elemental structures and dynamic processes in technological systems: A cognitive framework. *International Journal of Technology and Design Education, 17*(3), 323–340.
Baumann, H., & Tillman, A-M. (2004). *The Hitch Hiker's Guide to LCA. An orientation in life cycle assessment methodology and application*. Studentlitteratur, Lund.
Ben-zvi-Assarf, O., & Orion, N. (2005). A study of junior high students' perceptions of the water cycle. *Journal of Geoscience Education, 53*(4), 366–373.
Bijke, W., Hughes, T., & Pinch, T. (1989). *The social construction of technological systems. New directions in sociology and history of technology*. Cambridge, MA: First MIT Press.
Churchman, C. W. (1967). *The system approach*. New York: Dell Publishing.
Compton, V., & Compton, A. (2013). Teaching the nature of technology: Determining and supporting student learning of the philosophy of technology. *International Journal of Technology and Design Education, 23*(2), 229–256.
Compton, V., & France, B. (2007). Towards a new technological literacy: Curriculum development with a difference. *Curriculum Matters, 3*, 158–176.
Custer, R. L., Daugherty, J. L., & Meyer, J. P. (2010). Formulating a concept base for secondary level engineering: A review and synthesis. *Journal of Technology Education, 22*(1), 4–21.
Dusek, V. (2006). *Philosophy of technology: An introduction* (Vol. 90). Malden/Oxford/Carlston: Blackwell.
Forrester, J. W. (1961). *World dynamics*. New York: M.I.T Press.
Frank, M. (2005). A system approach for developing technological literacy. *Journal of Technology Education, 17*(1), 19–34.
Georgiadis, P., & Besiou, M. (2008). Sustainability in electrical and electronic equipment closed-loop supply chains: A system dynamics approach. *Journal of Cleaner Production, 16*, 1665–1678.
Ginns, I., Norton, S., & McRobbie, C. (2005). Adding value to the teaching and learning of design and technology. *International Journal of Technology and Design Education, 15*, 47–60.
Graedel, T. E., & Lifset, R. J. (2016). Industrial ecology's first decade. In R. Clift & A. Druckman (Eds.), *Taking stock of industrial ecology*. New York: Springer.
Hallström, J. & Klasander, C. (2016). Visible parts, invisible whole: Swedish technology student teachers' conceptions about technological systems. *International Journal of Technology and Design Education*, 1–19.
Hughes, T. (1989). The evolution of large technological systems. In W. Bijker, T. Hughes, & T. Pinch (Eds.), *The social construction of technological systems*. Cambridge, MA: M.I.T Press.
Ingelstam, L. (2012). *System– att tänka över samhälle och teknik. (Energimyndigheten)*. Kristianstad: Kristianstads Boktryckeri AB.
Ison, R. (2010). *Systems practice. How to act in climate-change world*. London: Springer & The Open University.
Jones, A. (2003). The development of a national curriculum in technology for New Zealand. *International Journal of Technology and Design Education, 13*(1), 83–99.
Klasander, C. (2010). *Talet om tekniska system – förväntningar, traditioner och skolverkligheter*. Vol (32), Studies in Science and Technology Education, Linköpings universitet. Linköping: LiU-Tryck.
Kline, S. J. (1985/2003). What is technology. In R. Scharff & V. Dusek (Eds.), *Philosophy of technology. The technological condition* (pp. 210–212). Oxford: Blackwell Publishing.
Koski, M.-I., & de Vries, M. J. (2013). An exploratory study on how primary pupils approach systems. *International Journal of Technology and Design Education, 23*(4), 835–848.
Luhmann, N. (1995). *Social systems*. Stanford: Stanford University Press.
Martin, D. J. (1990). Stages in systems thinking, modelling and realisation in school electronics. *International Journal of Technology and Design Education, 1*(1), 14–20.
McCormick, R. (2004). Issues of learning and knowledge in technology education. *International Journal of Technology and Design Education, 14*(1), 21–44.

Meadows, D. (2008). *Thinking in systems*. Vermont: Chelsea Green Publishing White River Junction.

Mioduser, D., Venezky, R. L., & Gong, B. (1996). Students' perceptions and designs of simple control systems. *Computers in Human Behavior, 12*(3), 363–388.

Öquist, O. (2008). *Systemteori i praktiken: konsten att lösa problem och nå resultat*. Stockholm: Gothia.

Rittel, H., & Weber, M. (1973). Dilemmas in a general theory of planning. *Policy Sciences, 4*, 155–116.

Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–424.

Senge, P. (1990). *The fifth discipline: The art and practice of the learning organization*. New York: Double day.

Sterman, J. (1991). A skeptic's guide to computer models. In G. O. Barney et al. (Eds.), *Managing a nation: The microcomputer software catalog* (pp. 209–229). Boulder: Westview Press.

Svensson, M. (2011). *Att urskilja tekniska system. Didaktiska dimensioner i grundskolan.* [*Discerning technological system. Pedagogical possibilities in compulsory school. Authors translation*]. Ph.D. Thesis, Linköpings universitet, Norrköping.

Svensson, M., & Ingerman, Å. (2010). Discerning technological systems related to everyday objects: Mapping the variation in pupils' experience. *International Journal of Technology and Design Education, 20*(3), 255–275.

Svensson, M. & Klasander, C. (2012). *Teacher's professional growth in planning and teaching technological systems*. Technology Education Research Conference, Surfers Paradise.

Törnberg, P. (2017). *Worse than Complex* (Doctoral dissertation, Chalmers University of Technology).

von Bertalanffy, L. (1968). *General system theory: Foundations, development, applications*. New York: George Braziller.

Wiener, N. (1961). *Cybernetics or control and communication in the animal and the machine*. New York: M.I.T Press/Wiley.

Influences of Materials on Design and Problem Solving Learning About Materials

33

Patricia Potter and Bev France

Abstract

When exploring how students learn to design and problem solve, it is relevant to recognize the importance of the materials used and how they impact the design and problem-solving processes. The chapter illustrates this in the area of resistant materials in technology education and explores the multifaceted complexity of and interaction between design and problem solving and materials. Consequently, an exploration of the role of experiences with materials enables an analysis of how this learning can occur when situated within the context of resistant materials and the domain of mechanical engineering.

Keywords

Design • Problem solving • Context • Resistant materials • Experiences • Mechanical engineering

Contents

P. Potter (✉)
Pompallier Catholic College, Whangarei, New Zealand
e-mail: patricia.potter@pompallier.school.nz

B. France
School of Curriculum and Pedagogy, Faculty of Education and Social Work, The University of Auckland, Auckland, New Zealand
e-mail: b.france@auckland.ac.nz

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_35

Introduction

This chapter draws on the domain of mechanical engineering for much of its identification of relevant technological knowledge and understanding. Drawing on the domain of mechanical engineering enables an exploration of the unique features of technological design and problem solving in resistant materials and how it is distinguished from other contexts. The chapter focuses on elements that can help students to learn to design and problem solve in a specific technological area with a particular focus on the importance of learning about materials**.** Wiener (1993) identifies that "besides the conditioning of new inventions by the ideas on which they depend, there is a further conditioning in terms of the materials and processes available" (p. 37). In other words, the field and materials determine and yield different design considerations and processes.

This chapter argues that materials are a determining factor that influence the type of learning and conceptual understanding and knowledge required to design and problem solve (Cordon et al. 2007). Consequently, a generic process or rubric depicting design and/or problem solving is neither valid nor representative of how expert technologists design or problem solve and therefore unhelpful to student learning. Resistant materials technology education replaced technical or manual education that had traditionally involved activities and experiences carried out in a metal or wood workshop (Potter 2013). Nevertheless, practical experiences and activities remain a common feature in technology education in resistant materials which include metals, woods, and rigid plastics (McNair and Clarke 2007).

When working with resistant materials, the role of experiences with these materials is central, and therefore the positioning and relevance of such experiences and activities need clarification. Because mechanical engineering is a domain associated with resistant materials technology education, particularly in secondary schools, this chapter looks to experts within the domain of mechanical engineering to find out what constitutes design and problem solving and what experiences and activities with materials they consider contribute to learning design and problem solving. Likewise, it looks to practicing secondary teachers who teach in the area of resistant materials to clarify their understanding of design and problem solving in this context.

While design, problem solving and engineering sit comfortably within technology education, engineering is gaining increasing prominence as a domain through Science, Technology, Engineering and Mathematics (STEM) education initiatives. Therefore, an exploration of learning to design and problem solve in a context of resistant materials and the specific domain of mechanical engineering not only informs learning in technology education but, likewise, contributes to understanding about learning that is relevant to the technology and engineering components of STEM education.

Design and Problem Solving

The research literature presents disparate views of the interrelationship and differences between design and problem solving in technology education (McCormick and Davidson 1996; McCormick et al. 1994; Middleton 2005; Stein et al. 2003;

Taylor 2000). However, in the context of resistant materials, it is essential to clarify and specify this interrelationship for both teachers and their students. This context requires a much deeper and more specific understanding of the interrelationship of design and problem solving than what has been presented in previous technology education literature (McCormick and Davidson 1996; McCormick et al. 1994; Middleton 2005; Stein et al. 2003; Taylor 2000).

Within the area of resistant materials, design and problem solving have a very specific and distinct relationship that can be explored through the domain of mechanical engineering. The generic design and problem-solving rubrics so often presented in technology education are inadequate in this domain.

Impact of Materials on the Interrelationship of Design and Problem Solving

A qualitative research project by Potter (2015) involved five expert technologists who worked in the domain of mechanical engineering as well as four resistant materials secondary technology teachers. Situated in resistant materials, this research recognized the necessity to find the interrelationship between design and problem solving when learning both in the work place and in technology education. A key overarching element from this research characterizes an interrelationship of design and problem solving that identifies the role of *subsidiary* problem solving as an integral component that contributes to the complex nature of design with resistant materials.

This interrelationship of design and problem solving includes but extends beyond the notion of design solving an overarching problem posed. Instead, in this specific context, it identifies a myriad of subsidiary problems, nested and sequential. For example, the conception of the interrelationship of design and subsidiary problem solving includes predicting, addressing, and solving the many subsidiary problems within a design so that the design *detail* can be mapped out appropriately to enable the production of a final realized functioning product or system in situ. In the words of an expert technologist: “you drill down through the overall problem into all the detail” for the design concept to “practically work.” In other words, when designing and problem solving in resistant materials, subsidiary problem solving recognizes that the design detail must take into account many practicalities that relate directly and indirectly to materials. These include an awareness of tolerances, the selection and processing of materials, and issues relating to mechanisms that determine different choices of materials, described by an expert technologist as a designer needs to think, “how can we build it?, and then looking at smart ways of doing it . . . you’ve got to have that practical side.” Subsidiary problem solving also includes predicting and addressing the practical problems that may arise in the manufacture of a design and installation in situ. As noted by one expert technologist when describing a large railway bridge structure his company was manufacturing: “Because it’s so heavy . . . how are we going to transport it? How do we get it into position without too much disruption?” In this research, one resistant materials technology teacher identified when considering design projects with his students: “We look at . . . whether or not we’ve got the facilities to actually manufacture that solution to that problem, whether it's going to cost too much, take too much time, take too much expertise."

Potter (2015) recognized the necessity to explore the interrelationship between design and problem solving in this context so it could be made more explicit for teachers and students in technology education. As one teacher noted, there are "concepts of design, but in terms of resistant materials it has to work and it has to be processed and has to be functioning." The findings indicate that design is very much a problem-solving process and that subsidiary problem solving is an integral part of design. While design always strives to be innovative and creative, it must address the subsidiary problems that arise within the design including the practicalities of manufacturing materials that produce the design. One expert technologist identified design in engineering is about "detail, detail, detail," and therefore design could not be "separated at all" from problem solving. It is summarized further by a teacher in this research: "I see design and problem solving as one and the same thing really... when you're designing something you're problem solving. . . . Probably design is the ultimate problem solving" (Potter 2015).

In conclusion, resistant materials determine the role of problem solving in design and therefore are an integral component of design. This is an important element for both educators and students to recognize in planning programs and experiences. Significant components of problem solving are embedded in practicalities and the fact that artifacts are made of singular or multi-materials that behave in different ways. Such problem solving requires many different types of knowledge and skills that are developed through real experiences centered on materials.

Link Between Knowledge and Technological Design and Problem Solving

Faulkner (1994) and Lewis (2005) observe design cannot occur in a vacuum, disconnected from some form of a knowledge base. Knowledge in technology education has been identified as a key component underpinning learning to design and problem solve, just as it is a key component in designing itself (Lewis 2005; McCormick 2004). Norman (1998) comments that designers in the "real world" require knowledge bases to be able to perform as designers and identifies clearly the importance of context in what type of knowledge is required to design:

> Designers in the real world are trained in distinct approaches to designing in relation to the different technologies of their fields and different knowledge bases about materials, processes, values and practical skills. (p. 71)

Technological knowledge is defined by its context and, in this discussion, that context is design and problem solving in resistant materials. It is important to characterize relevant technological knowledge about resistant materials that relates directly to design and problem solving if technology educators are to create meaningful learning opportunities that support students learning this knowledge.

A first step in identifying relevant knowledge is identification of some of the distinguishing characteristics of technological knowledge as a distinct body of knowledge. Establishing technological knowledge as a body of knowledge separated from scientific knowledge recognizes that technology is not simply applied science (de Vries 2006; Herschbach 1995; Vincenti 1991). While scientific knowledge predominantly is generalized knowledge and deals primarily with abstractions that tend to strip away the context, its technological knowledge equivalent is much more context specific (de Vries 2012; McCormick 2004). In fact, in much school learning, knowledge often is stripped of its context (Hill and Smith 2005). As technological knowledge is applied to technological activities that have purpose and meaning in specific contexts, a generic technological knowledge is difficult either to categorize or codify (Herschbach 1995). Although technological knowledge may, when appropriate, utilize knowledge from learning domains such as science and mathematics (McCormick 2004), such knowledge of materials can be identified in terms of propositional knowledge of material (knowing that) ("Pedgley, this volume).

Propositional knowledge about materials is also identified as descriptive knowledge of materials that describes things as they are – including the physical properties and strengths of individual materials (Anderson and Felici 2012). In the context of resistant materials, expert designers regard knowledge about the physical properties and the strength of materials as crucial because this knowledge enables them to predict how a material will perform when used in a design (McCormick 2004). For example, an understanding of the specific properties of different steels will influence decisions made when designing. A shaft will likely use a particular type of steel that is tough and strong and able to be heat-treated after machining. In different applications, the heat treatment of the shaft will also vary depending on the loading (e.g., torsional or shear).

Recognition and evaluation of *constraints* have long been acknowledged as necessary knowledge considerations when designing and problem solving. Consideration of constraints when solving a problem is significant because it reduces the size of the problem and its solution; it helps novice designers confine ideas within more manageable chunks of information (Merrill et al. 2008). Design always occurs in a specific context, and a key part of that context is the type of materials the designer intends to use (McCormick 2004). An understanding of the constraints imposed by the materials used in design and problem solving requires an understanding of the properties of those materials, how and why they are used, and both their potential and their limitations (Potter 2013). Thus, when a technologist is dealing with design constraints, the laws that predict the behavior of materials also can be a key factor to consider (McCormick 2004). Knowledge of constraints may incorporate the cost including that of the materials to produce an artifact, the expertise available, the time involved to process materials, and the availability of manufacturing processes. Consideration of all these constraints requires extensive procedural and conceptual knowledge (Petrina 2007) and also includes knowing-how and knowing-what about materials as mentioned by Pedgley in this volume.

Strategic knowledge is a significant category that integrates all types of knowledge and is described by Gott (1989) as knowledge that enables a designer and problem solver to know "how to decide what to do and when" (p. 100). It would seem that is what an expert designer and problem solver is able to do is to draw on many different types of knowledge (knowing-how and knowing-what) and know when to apply them to new situations (Shulman 1986). To design and problem solve requires knowledge of materials including their specific properties, processes, mechanisms, and manufacturing, many of which are linked to activity and experience. If technology teachers are to enable novice student designers and problem solvers to design and problem solve, they need to provide suitable learning experiences that will allow them to develop this knowledge and understanding. While recognizing that strategic knowledge is what professional designers and experts use, McRobbie et al. (2001) note that reflection on what knowledge professional designers use can provide a suitable base to analyze the types and "nature" of knowledge student designers might need also when designing and solving technological problems.

Role of Experiences with Resistant Materials in Learning to Design and Problem Solve

Learning to design and problem solve with materials is a complex matter. As noted in previous sections, design and problem solving are key functions both in an expert technologist's world and in technology education. The role of learning experiences has long been a distinguishing feature of technology education. However, such experiences need to be clarified, justified, and recognized in terms of their contribution to learning design and problem solving given that this aspect needs to remain a key focus in technology education. In fact, there is some recent speculation that experiences with materials and working hands-on in terms of *actual* making in technology education may disappear if its relevance cannot be justified (Martin and Owen-Jackson 2013). When considering experiences with materials that build knowledge and understanding to enable design and problem solving, it is essential to turn to experts in this field to inform educators. In other words, students' experiences with materials need to be purposeful and informed by experts (Daly et al. 2012).

Therefore, it seems relevant to consider in what ways experiences with materials might contribute to learning design and problem solving in the area of resistant materials. Potter's (2013) research investigated the role of experiences with resistant materials and its effect on learning design and problem solving from the perspective of expert technologists in the domain of mechanical engineering. The expert designers and problem solvers in this research described many different types of experiences with resistant materials that they considered essential to their learning as designers and problem solvers in the area of resistant materials. Their experiences included working directly with materials and being in industries where they saw firsthand the material processes that formed and made their designs into products and outcomes. It involved seeing their designed products successfully functioning and operating in many different environments and having firsthand experiences of significant failed design outcomes that included the failure of materials. In the words of an expert technologist: "Absolutely, you have to have the whole loop to understand whether or not your ideas are good, building it, testing it, being involved in it, breaking it, fixing it, making it better is all part of the process" (Potter 2013, p. 76).

One technologist discussed how, every day, he observed and reflected on others' designs and uses of resistant materials including how problems had been solved: "Everything I see I look at as an engineer. Any piece of machinery or structure I always pay close attention. I'm the guy that stops and looks at the hinges on the aircraft when I'm getting on board and looks at the conveyor on the baggage line" (Potter 2013, p. 80). These technologists identified how they gathered valuable information that helped them to design effectively with resistant materials by communication that included talking and listening to others such as machinists who worked directly with these materials, thereby utilizing the knowledge and experiences of relevant communities of practice (Lave and Wenger 1991).

In Potter's (2013) research, technologists recognized the informed choice of material as critical to creating effective designs. "Material selection is critically important to engineering. You've got to understand what you're dealing with what the machine or structure is doing, the environment it's doing it in. You've got to understand the physical and mechanical properties of materials. . .select the wrong materials and the design won't work. . .every day and everything I do that comes into play" (p. 78). They identified knowledge of material as an essential factor and aspect of design and problem solving and that through different experiences over prolonged periods of time, they learnt about the properties of different materials. For example, the knowledge of how steel is made and how it behaves when its heated and welded was identified as absolutely essential contextual knowledge by these experts to design and problem solve in this domain: "You couldn't design anything without the knowledge of how steel is made and how steel behaves when it's heated up and how to weld it. . .to make it practical you have to know about what you're using . . . the materials you intend to use" (Potter 2013, p. 80).

Faulkner (1994) identified practical experiences, knowledge of the properties of materials, and knowledge about the performance of a final product as knowledge that is used by expert technologists. As Pedgley previously stated, such knowledge is described as empirical knowledge of materials (knowing-how), and its acquisition includes physical sensory encounters with real materials.

The experts' findings recognize experiences that involve working with materials used in *real* design situations over "working lifetimes" developed their knowledge about which materials to use for particular design applications (Brown et al. 1989). They recognized that these ongoing experiences developed their understanding of what works well and were built on their successful and, in some cases, unsuccessful past experiences. Therefore, their contextual knowledge compounded through many experiences with materials over a long time period. Knowledge built through a lifetime of experiences can link to tacit knowledge, which Ropohl (1997) acknowledges evolves over a long period of time through both successful and failed experiences, and requires much practice. These experiences developed their tacit knowledge and built their prescriptive knowledge about the size and dimensions to use in design situations. The application of safety rules and regulations and technical specifications of materials (dimensions/tolerances) are examples of prescriptive knowledge in that they are created bodies of knowledge that serve specific and important functions in design with resistant materials (Mokyr 2002). As one technologist commented: “Everything you do and everything you learn, it’s available for you to use as experience so you get better at it because your experience base is broader. . . .You’ve seen good and bad things and you have a better idea of what works and what doesn’t work. I get better at this [design] as time goes by” (Potter 2013, p. 78).

These experts stated that to design a realized functioning product requires practical knowledge of how to process materials and the accessibility of processes: “It’s got to be built, [If] there’s no practical understanding of that then you’re going to find you’re in trouble” (Potter 2013, p. 76). Faulkner (1994) recognized that expert designers require knowledge relating to the final product; that is, knowledge that enables the production and manufacture of designed artifacts. Vincenti (1991) also identifies this essential technological knowledge as *practical considerations*; it includes knowledge of material production and how best to make a component or artifact. In the area of resistant materials and the domain of mechanical engineering, the role of contextual experience is of vital importance for learning to design and problem solve. The importance of experiences with materials in learning to design and problem solve is signaled clearly by the expert technologists in this research (Potter 2013). Indeed, expert technologists’ learning experiences in the domain of mechanical engineering have been analyzed utilizing four learning theories and thus informing a pedagogy for student learning through experiences in resistant materials (Potter and France 2016).

The implications for technology education are that students should be provided with opportunities to have practical experiences with materials in real contexts. However, the construct of experiences needs to be broadened so students develop an understanding of the complexities of design and problem solving within a range of materials and the complex knowledge required in each area. In Materials Chapter, Pedgley suggests that for students in technology education, making activities provides a “mechanism” for learning about materials that support learning to design. This is illustrated in Potter’s (2013) research as she identifies a broadened construct of experiences that includes working with and observing how resistant materials perform in various situations and environments. For example, opportunities to work directly with a wide range of different materials to build knowledge of materials and to see how they change through various processes such as heat treatments. Finally, students should have experiences of being able to work directly in a hands-on way with materials in practical environments to develop an understanding of subsidiary problem solving as well as experiencing firsthand concrete experiences of both successful and failed functioning design outcomes using materials.

Conclusion

Design and problem solving in resistant materials are complex and multifaceted. This is further complicated because individual materials behave in differing ways. Developing programs of work for students in technology education in this context requires thinking beyond the generic rubrics so often presented in technology education. It requires an understanding that problem solving is an integral component of design identified as subsidiary problem solving (Potter 2015). Consequently, learning to design requires experiences that link to building different types of knowledge and understanding about materials addressing the problem-solving nature of design. The chapter reported on a study in which expert technologists identified that a range of experiences with materials were critical to their learning to design. Such experiences when translated to learning in technology education require educators to recognize that a broadened construct of experiences with materials is essential in order to facilitate and address the learning of complex knowledge and understanding that is necessary to design, acknowledging the integral role of subsidiary problem solving within the context of resistant materials.

References

Anderson, S., & Felici, M. (2012). *Emerging technological risk: Underpinning the risk of technology innovation*. London: Springer-Verlag. doi:10.1007/978-1-4471-2143-5.

Brown, J., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42. doi:10.3102/0013189X018001032.

Cordon, D., Williams, B., Beyerlein, S., & Elger, D. (2007). *Distinguishing among processes of problem solving, design, and research to improve project performance* (Report No. AC 2007–2287). Moscow, ID: American Society for Engineering Education. Retrieved 30 July 2014 from Pacific Crest Resources & Development website: http://www.pcrest2.com/institute_resources/RI/AC_2007-2287_Final.pdf

Daly, S., Adams, R., & Bodner, G. (2012). What does it mean to design? A qualitative investigation of design professionals' experiences. *Journal of Engineering Education, 101*(2), 187–219. doi:10.1002/j.2168-9830.2012.tb00048.x.

de Vries, M. (2006). Technological knowledge and artifacts: An analytical view. In J. Dakers (Ed.), *Defining technological literacy: Towards an epistemological framework* (pp. 17–29). New York: Palgrave MacMillan.

de Vries, M. (2012). Philosophy of technology. In P. J. Williams (Ed.), *Technology education for teachers* (pp. 15–34). Rotterdam: Sense Publishers. doi:10.1007/978-94-6209-161-0_2.

Faulkner, W. (1994). Conceptualising knowledge used in innovation: A second look at the science-technology distinction and industrial innovation. *Science, Technology & Human Values, 19*(4), 425–458. doi:10.1177/016224399401900402.

Gott, S. (1989). Apprenticeship instruction for real-world tasks: The coordination of procedures, mental models and strategies. In E. Rothkopf (Ed.), *Review of research in education, 15, 1988–1989* (pp. 97–169). Washington, DC: AERA.

Herschbach, D. (1995). Technology as knowledge: Implications for instruction. *Journal of Technology Education, 7*(1), 31–42.

Hill, A., & Smith, H. (2005). Research in purpose and value for the study of technology in secondary schools: A theory of authentic learning. *International Journal of Technology and Design Education, 15*(1), 19–32. doi:10.1007/s10798-004-6195-2.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511815355.

Lewis, T. (2005). Creativity: A framework for the design/problem solving discourse in technology education. *Journal of Technology Education, 17*(1), 35–52.

Martin, M., & Owen-Jackson, G. (2013). Is design and technology about making or knowing? In G. Owen-Jackson (Ed.), *Debates in design and technology* (pp. 64–73). London: Routledge.

McCormick, R. (2004). Issues of learning and knowledge in technology education. *International Journal of Technology and Design Education, 14*(1), 21–44. doi:10.1023/B:ITDE.0000007359.81781.7c.

McCormick, R., & Davidson, M. (1996). Problem solving and the tyranny of product outcome. *The Journal of Design and Technology Education, 1*(3), 230–241.

McCormick, R., Murphy, P., & Hennessy, S. (1994). Problem solving processes in technology education: A pilot study. *International Journal of Technology and Design Education, 4*(1), 5–34. doi:10.1007/BF01197581.

McNair, V., & Clarke, R. (2007). Effective technology and design teaching: Getting it right in the classroom. *International Journal of Technology and Design Education, 17*(3), 271–290. doi:10.1007/s10798-006-9003-3.

McRobbie, C., Stein, S., & Ginns, I. (2001). Exploring designerly thinking of students as novice designers. *Research in Science Education, 31*(1), 91–116.

Merrill, C., Custer, R., Daugherty, J., Westrick, M., & Zeng, Y. (2008). Delivering core engineering concepts to secondary level students. *Journal of Technology Education, 20*(1), 48–64.

Middleton, H. (2005). Creative thinking, values and design and technology education. *International Journal of Technology and Design Education, 15*(1), 61–71. doi:10.1007/s10798-004-6199-y.

Mokyr, J. (2002). *The gifts of Athena: Historical origins of the knowledge economy.* Princeton, NJ: Princeton University Press.

Norman, E. (1998). The nature of technology for design. *International Journal of Technology and Design Education, 1*(1), 61–71.

Petrina, S. (2007). *Advanced teaching methods for the technology classroom*. Hershey, PA: Information Science Publishing.

Potter, P. (2013). Technologists talk: Making the links between design, problem solving and experiences with resistant materials. *International Journal of Technology and Design Education, 23*(1), 69–85. doi:10.1007/s10798-011-9159-3.

Potter, P. (2015, October 4–7). *Exploring the interrelationship of problem solving and design in resistant materials technology.* Paper presented at TENZ conference, 20/20 vision, Hamilton.

Potter, P., & France, B. (2016). Informing a pedagogy for design and problem-solving in resistant materials by theorising technologists' learning experiences. *International Journal of Technology and Design Education, 26*(3). doi:10.1007/s10798-016-9376-x.

Ropohl, G. (1997). Knowledge types in technology. *International Journal of Technology and Design Education, 7*(1), 65–72. doi:10.1023/A:1008865104461.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14. doi:10.3102/0013189X015002004.

Stein, S., Docherty, M., & Hannam, R. (2003). Making the processes of designing explicit within an information technology environment. *International Journal of Technology and Design Education, 13*(2), 145–170. doi:10.1023/A:1022312323398.

Taylor, P. (2000). How to develop problem-solving in design and technology. In J. Eggleston (Ed.), *Teaching and learning design and technology* (pp. 34–44). London: Continuum.

Vincenti, W. (1991). *What engineers know and how they know it: Analytical studies from aeronautical history.* Baltimore, MD: John Hopkins University Press.

Wiener, N. (1993). *Invention: The care and feeding of ideas*. Cambridge: MIT Press.

34 Authentic Learning and Technology Education

Ann Marie Hill

Abstract

This chapter introduces and provides a definition of the term "authentic learning." It also presents the *theory of authentic learning*, a theory that has evolved from substantial research conducted in technology education classrooms. Literature on authentic learning from various viewpoints is discussed within each factor of the theory, as is discussion for applicability in technology classrooms. The chapter concludes with implications of authentic learning for technology education.

Keywords

Theory of authentic learning • Authentic learning • Technology education • Elementary school • Secondary school

Contents

A.M. Hill (✉)
Faculty of Education, Queen's University, Kingston, ON, Canada
e-mail: annmarie.hill@queensu.ca

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_36

Introduction

Authentic learning is a term espoused from many different viewpoints (Kreber et al. 2007; Snape and Fox-Turnbull 2013). These differences are grounded in diverse life experiences – personal, professional, and research experiences. They change and grow over time as knowledge and experience increase and connections are made across fields of study. The proliferation of interpretations around the term "authentic learning" leads to difficulty in sorting out the term authentic learning. Is it a theory, a conceptual framework, a teaching/learning strategy? Different views on how to engage authentic learning and how to interpret, or organize, the literature on authentic learning for sense-making are found in the literature. Many recent and popular views are gleaned from writings in various fields, for example, in online learning where Herrington and colleagues (Herrington and Oliver 2000; Herrington and Herrington 2005; Herrington et al. 2014a, b) examine an instructional design framework for authentic online learning environments, in assessment where Newmann and colleagues identify five standards of authentic instruction and established three criteria to guide authentic achievement (Newmann and Archbald 1992; Newmann and Wehlage 1993; Newmann et al. 2007), in educational philosophy where Splitter (2009) examines authenticity as a concept and its relevance in education, and in technology education in New Zealand (Snape and Fox-Turnbull 2013; Turnbull 2002). Snape and Fox-Turnbull (2013) suggest on three "dimensions of authenticity" which are "authentic pedagogy and instruction, authentic teachers and learners, and authentic activities" (p. 54).

For the purposes of this chapter, and in the context of technology education, authentic learning is defined as both learning that connects what is learned in school to the real world or the world outside of school and learning that connects to student identity and advances their life goals. Therefore, there are *external* and *internal* aspects to authentic learning. External to the learner is where student learning is engaged in a concrete context allowing for connections and applications of student learning in school to real-life or professional practice. Internal to the learner is where a learner's intellectual thinking or work interest – or student's lifeworld – draws upon their identities as a way of making sense of and applying knowledge. This definition has significant meaning for teaching and learning in technology education. As Anstey (2016) posits, "discussions of authenticity must consider authenticity not only in terms of the target professional domain, but also in terms of the student's life-world" (p. 31).

In the remainder of this chapter, authentic learning will be discussed within the context of this definition and through the theoretical viewpoint of the *theory of authentic learning* and its recent version of 12 factors (Hill et al. 2013a, b) which builds on the earlier work of Hill and Smith (1998, 2003, 2005). Literature on authentic learning viewed as conceptual or as teaching/learning strategies is presented within the discussion of each factor comprising the theory, as are secondary school technology education applications. The decision to frame this chapter's discussion in the *theory of authentic learning* is purposeful for three reasons: (1) the theory is derived from three substantial research grants from the federal funding agency, the Social Science and Humanity Research Council of Canada (SSHRC) over a 22 year period – so it is grounded in research, (2) the theory evolved from research in the technology education context, and (3) much of the literature viewing authentic learning as conceptual or as teaching/learning strategies finds a place in this theory. Further, this theory is presently being used beyond research in and the enactment of technology education, as other fields and educational levels adopt alternative ways to think about learning. For example, Anstey (2016) used the theory of authentic learning as her theoretical framework to examine students' experiences in a university undergraduate anatomy class that used inquiry learning to determine if their inquiry experiences were authentic.

The Theory of Authentic Learning

John Dewey's books titled *Democracy and Education* (1916) and *Experience and Education* (1938) where he wrote about learning by doing and relating learning in school to the real world and Whitehead's (1929) writing of inert knowledge and learning existing within the context of the classroom are foundational to the idea of authentic learning. Authentic learning has gained attention since the 1990s and is examined here from the viewpoint of the theory of authentic learning.

The *theory of authentic learning* emerged through funded research that examined practice in technology education classrooms (Hill and Smith 1998, 2003, 2005; Hill et al. 2013a, b). Four main factors (*situatedness*, *mediation*, *embodiment*, *distribution)* and two supporting factors *(multiple literacies and motivation)* were identified in a first study (Hill and Smith 1998). Research from a second grant identified four additional factors *(identity*, *career planning*, *human relationships*, and *teacher attributes)* (Hill and Smith 2003, 2005). Research from a third grant identified two new factors *(support network* and *program)* (Hill et al. 2013a, b).

Factors Comprising the Theory of Authentic Learning

Twelve factors comprise the theory of authentic learning. Each is described below with connections to literature and classroom practice in technology education.

Mediation

Mediated learning originates from the notion that humans use cultural tools, or mediational means, when engaged in action of various forms (Wertsch 1998). The writings of Peirce (1992, 1998), Dewey (1938), and Vygotsky (1978) are key works that support mediation. Driver (1983) understood tools and signs that mediate Vygotskian theory, or mediation, as essential aspects of mental functioning in the individual derived from social life and a key to understanding human action, both on the social and individual planes. In contrast to traditional learning that treats students as passive recipients of knowledge (e.g., Dreyfus 1995), mediation emphasizes the need for learners to engage in authentic cultural tasks, such as community-based project in technology education (e.g., Hill 1999) where human action uses relevant cultural tools for cultural tasks. Hence, mediation refers to sociocultural human thought and action that engage cultural tasks and the use of cultural and physical tools (e.g., language, signs, systems, computers, physical tools and equipment, computers, materials, and supplies).

Cultural tools, equipment, and machines are invented for different applications by people in cultural or professional settings. Yet, in technological education, prior to the late 1980s, learning about these items was taught in abstract ways, that is, out of context. The number of any given tool, piece of equipment, or machine in a classroom frequently designated course enrolment. Teachers taught the name, parts, and operation for each item in a teacher-directed way. Typically lecture and then demonstration pedagogies were used, until required knowledge on all items was complete, sometimes taking up weeks at the beginning of a course. It did not matter that a tool, piece of equipment, or machine would be used a month later or that learning did not include their contextual use. Unfortunately, even today, this abstract learning in technological education can be found. In authentic learning environments of technology education, tools, equipment, and machines are learned when use is actually needed to advance student work. So learning is in context and there is a cultural understanding of use.

Embodiment

Embodiment, as a factor in authentic learning, is the use of body (senses and sense-making abilities) and mind in learning; both are equally central to learning. Embodiment embraces cognitive, emotional, physical, and social dimensions (Epstein 1994; Hutchins 1995; Johnson 1987; Varela et al. 1991). "In embodied learning, cognition, perception, cultural tools, and action all work together in the learning process" (Hill and Smith 2005, p. 23). Unlike learning from a cognitive perspective, that separates body and mind, embodiment is seen as sense making using the body as a medium, where "tool-use behaviour is not simply the result of innate structures that in time lead to sudden insight, but is rather a process of continuous embodied activity" (Rabusch and Ziemke 2005, p. 1806).

Technology education has historically engaged in cognitive, emotional, and physical dimensions of embodiment. Learning by doing was frequently status quo. Learning was cognitive in terms of knowledge and procedures, emotional with the pleasure of doing something well or completing a fine finished product and physical by engaging in physical activities to do something. However, past pedagogies have accomplished embodied activity using step-by-step, teacher-directed approaches, with an entire class following the teacher's pace to complete, individually, the same teacher-selected project. In authentic learning, students select the context for learning that is meaningful to them, for example, a project. As such, there are numerous different projects ongoing in a class. In addition, students typically work in groups, and projects can be linked to needs in the community outside the class; hence, social dimensions of embodiment are embraced. Students also engage their bodies in learning by doing and make sense of their learning by trying things out; for example, Hill and Smith (1998) describe a student spending time in a wheelchair when designing a garden table for a retirement home where many individuals who enjoyed gardening were confined to wheelchairs.

Distribution

In authentic learning environments, learning is not confined to the individual mind but extends outward to include the ongoing actions provided by cultural tools and other persons (Clark 1998), connects to sociocultural activities beyond school (Newman et al. 2007; Newman and Wehlage 1993), and requires collaborative learning (Brown and Thompson 2000). This contrasts with traditional formal schooling that treats learning as individual and private with students completing their own individual assignments, readings, exercises, and tests. The idea of learning as distributed recognizes explicitly that many tasks cannot be completed by one person working alone, such as docking a ship (Hutchins 1995) and that, in the classroom, knowledge is distributed among all class members (Rogoff 1990; Vygotsky 1978). This perspective aligns with the idea that in most work places, individuals must work cooperatively in pursuit of common goals, where individuals share knowledge and learning from each other in a Vygotskian way, and different abilities are needed to complete projects, assignments, or tasks successfully (Hill and Smith 1998). In real-world settings, no one person has a monopoly on knowledge. Further, distributed learning is characterized by the fact that both individual and collective memories often reside in artifacts and actions that lie outside the brain (Kirlik 1998).

Past practice in technology education required individual students to produce a teacher-selected project. Each student worked individually to produce the same project that was marked as an individual assignment, frequently against the example of the teacher and the work of other students, and individual competition was inherent. Distribution of knowledge was between the teacher and student alone. This is turned upside down in technology education that fosters an authentic learning environment. Here, students work collaboratively in groups sharing skills, knowledge, processes, cultural tools, materials, and a final outcome. Frequently – as learning is connected to professional practice beyond school – individuals in locations outside the classroom or who visit the classroom are part of the student learning process. So persons other than the teacher join students in the student learning process.

Situatedness

Situatedness is learning in context, or learning that is situated in a context where it would be used in the world outside of a classroom, or authentic situations. It is learning as ordinary practices of culture and real communities of practice. This factor corresponds to literature on situated cognition (Anderson et al. 1996; Brown et al. 1989; Collins et al. 1987; Hennessey 1993; Lave 1988; Lave and Wenger 1991). Anstey (2016, p. 38) posits that "If the above assumptions are accepted to be true, then learning occurs when tasks are contextually situated within real life contexts found beyond the confines of the classroom, if not directly (i.e., learners participating in a community of practice), then cognitively (i.e., the task develops cognitive skills that facilitate transfer by nature of their resemblance to the cognitive demands of the targeted context)." One issue that arises in situatedness is what are "real-world" or "real-life" problems. Renzulli et al. (2004) offer four criteria to assist in this identification. Chen (in progress) considers the ideas of "real" and "realistic" contexts in authentic learning as posed by Bergeron and Rudenga (1996). Further, Chen examines the idea of realistic contexts for authentic learning. Based on the work of Rule (2006), she sees these as rooted in the real world, with instructors adapting real cases that contain issues that are faced in the real world.

Teacher-directed, or planned, projects that are designed to efficiently cover course content and where each student makes the same artifact are not examples of situatedness. Neither are projects that are concerned with the ideation of a project alone. Wiener (1993, p. 37) makes this association when he says, "in contrast with the more general process of discovery, invention is not complete until it reaches the crafts person. Besides the conditioning of new inventions by the ideas on which they depend, there is a further conditioning in terms of the materials and processes available." Authentic learning in technology education would have students' problem posing (Lewis et al. 1998) to address human and environmental needs in their lifeworld. Open-ended problem-solving would then be used to determine a solution with all stakeholders involved in the decision-making process – all members of the student group, the teacher, and community stakeholders. As such, the learning is situated in real life and the students' lifeworld.

Motivation

Positive learning motivates students. Motivation is grounded in survival, culture, and self-determination. Culturally, survival is enhanced by becoming competent in the signs valued by the surrounding culture (Smith 1992). Scholastically, survival is achieved by students becoming competent in matters of concern to them (White 1959). Motivationally, this is accomplished by the acknowledgement of students' interests in the classroom and a learning environment that fosters tasks or activities that allow students to investigate their interests and accomplish their learning goals. Hill and Smith (2005, p. 24) state that "Generally, these matters are essentially sociocultural in nature and should be placed in the context of meaningful classroom tasks while recognizing the need to support students' self-esteem and autonomy in learning (Beane and Lipka 1984; Harter 1986)." Hence, theories of self-determination are key to student motivation (Deci and Ryan 1985; Deci et al. 1999). Hill (2007) and Pintrich (2002) provide further reading on motivation. Hill (2007) examines motivational theories of achievement goals, interest and intrinsic motivation, self-efficacy, expectancy-value theory, self-determination theory, attribution theory and control beliefs, and competency motivation with discussion of relevance to technology education.

When projects in technology education are determined by the teacher to efficiently cover course content, without any input from students, motivation can be connected to achievement goals in terms of marks. But when student engages in problem posing (Lewis et al. 1998), identifying problems of interest to them and the world around them, and then problem-solving in the real-life context (Hill 1998) for solutions, most theories of motivation are activated in this kind of a learning situation.

Multiple Literacies

Research acknowledges that humans have different ways of knowing, making sense of the world, and learning and that individuals differ in their capabilities, interests, and ability systems. Gardner's research (2003) is well known for representing these ability systems, which he calls multiple intelligences (MI). MI has evolved from the original intelligences of logical-mathematical, linguistic, musical, spatial, bodily-kinesthetic, interpersonal, and intrapersonal later adding addition of naturalist and existential, emotional, spiritual, sexual, and digital intelligences. Hill and Smith (2005) state: "Authentic learning recognizes a range of abilities and talents and deliberately seeks to foster them across a variety of contexts" (p. 25). For purposes of the theory of authentic learning, these different abilities, or intelligences, are termed "multiple literacies." This factor acknowledges differences and encourages recognition and attention to all intelligences in the classroom through teacher planning, teaching, and assessment and through student learning.

Technology education has always addressed the needs of spatial and bodily-kinesthetic learners. In the past, this was accomplished through individual, teacher-directed projects. However, when students work in groups to pose and solve problems of interest to them that are in real-life contexts, technology education addresses additional intelligences. Community-based projects (Hill 1999) address interpersonal, intrapersonal, and emotional intelligences as students meet needs to better the human condition. Projects that improve environment conditions address naturalist and potentially spiritual intelligences. As students plan the design, fabrication, and document of their project, logical-mathematical, linguistic, and digital intelligences can be addressed. When the internal aspects of authentic learning are addressed to advance students in their lifeworlds, existential aspects of intelligence are tapped.

Identity

Identity represents the idea of who one is and a sense of self, which evolves over time through personal growth and development. Anstey (2016), in further detailing this factor, associates this factor with the construct of lifeworld and states: "This factor may be most closely associated with an understanding of the lifeworld, which posits that, just as learning is situated with the context of its acquisition, humans are situated within their lifeworld" (p. 43). In their research into design disciplines, Solomonides and Reid (2009) have formulated a model of *sense of being* that emphasizes student thinking about their confidence, happiness, imagination, and self-knowledge; the student is at the core of affective, internal relationships with learning. When a student's sense of being is a part of learning, identity is activated, and students are engaged in their learning, which is meeting personal growth toward their academic and career goals.

Technology education has represented – in the past – ritual, non-contextualized learning that does not connect with students' sense of identity, such as teacher-directed projects which are frequently "hit or miss" with regard to student identity. Identity aligns with the internal part of the definition of authentic learning used in this chapter. In a technology education learning environment of authentic learning, individual student learning in the context of their authentic interests can advance desired life paths and career progression.

Career Planning

Career planning refers to students thinking about what they want to do in the future and making plans to realize their goals. This includes contexts such as future courses, programs, careers, apprenticeships, other postsecondary education, or vision of personal life. Decisions are influenced by educational experiences – including positive and negative experiences, connections to what is learned in school to future goals, and the relevance of content to their future goals.

Technology education is well placed to assist students in their career planning if student learning corresponds to or activates identity. Human relationships, teacher attributes, and program all work together to support student identity through a positive (engaging and motivating) learning experience. However, in a teacher-directed class, the road toward a professional career is much more indirect. When learning extends beyond the school and is situated in the world outside of school and the student's lifeworld, career planning is far more direct.

Human Relationships

"Human relationships are expressions, either positive or negative, about being with others, especially peers" (Hill and Smith 2005, p. 27). These expressions manifest themselves as interactions based on feelings. In the classroom, relationships are typically teacher to student, student to teacher, and student to student. The research of Ruznik et al. (2016) found that when teacher are emotionally supportive, students reported engagement in their learning, and hence, more were more motivated to learn. “Emotionally salient experiences” (p. 102) were identified in such a learning environment, such as opportunities for student autonomy in class leading to “positive and supportive relationships with their peers” (p. 102). Taking human relationships one step further, in authentic learning environments, human relationships extend to professionals and other community members outside of the classroom with whom students collaborate in an authentic context for their learning. Human relationships are complex and can influence other factors, for example, career planning, engagement, and motivation.

Traditional human relationships in the technology education classroom have been predominately teacher-student relationships, with the teacher as expert. Some student-teacher relationships take place when students seek clarification. In authentic learning environments, where technology education practice is based on group work in real-world contexts associated with student interests, or student lifeworld, student-to-student relationships and relationships with individuals beyond the classroom are actively sought.

Teacher Attributes

Teacher attributes are the personal and professional characteristics that a teacher or supervisor publically display and which make up their *being*. Important to the classroom are characteristics that show interest in human beings and that influence and mediate student learning. Hill and Smith (1998) identified teacher attributes in an authentic learning environment, such as the teacher respected students as individuals; knew the students’ home lives; demonstrated to students that they did not know everything, that they were always learning, and that students’ project ideas might be better than theirs; high flexibility in terms of what was achieved or not in any one class; worked with students to determine some of the course content; and were a moderate risk takers without the need for formal closure on some matters. Teacher attributes, sometimes seen as characteristics, are prevalent in literature where authentic learning is seen as a teaching/learning strategy. Kreber et al. (2007), Slavkin (2004), and Snape and Fox-Turnball (2013) portray teacher characteristics in their discussion on authentic learning, such as dialoguing with students about their learning, purpose, significant issues, and connections to real world while demonstrating care for the students’ education.

Clearly there is a move from “sage on the stage” to “guide on the side” in authentic learning environments, and this has significance for technology education teachers. In technology education, Hill (1999) outlines the impact on teachers when they connect school learning to real-life and lifeworld experiences through community-based projects and attributes of teachers who engages in this approach to technology education:

- Faith in students' abilities to learn. Relax in being a facilitator.
- Teach a short lesson of about 10 min at the beginning of every 70 min class and then trust and manage.
- Rearrange expectations of the teacher and students, for example:
  - Don't spend too much time with one group, one project.
  - Give students encouragement and clues and then move to another group.
  - Encourage students to ask the teacher for help when needed.
  - Inform students that if they are waiting for teacher help, or for the community partner visit, etc., they should be doing some other activity while waiting.
  - If students need materials, they are responsible to make a list and give it to the teacher.
  - Inform students they are also responsible for their learning.
- Accept that they do not know everything and that they are not the purveyors of all knowledge for all projects. Students are responsible for their learning also. Then the teacher can focus on managing students' learning and projects.
- Be enthusiastic and energetic.
- Be an ongoing learner.
- Use human and resource materials in the world outside of school (Hill 1999, p. 24).

Program

The work of curriculum theorists, for example, the work of Eisner and Vallance (1974) and McNeil (2006) on conceptions of curriculum or Shiro's (2008) curricular orientations illustrate that each conception, or orientation, has a different philosophical foundation which guides the planned or intended curriculum, the enacted curriculum, and the learned or assessed curriculum. Each orientation and its elements offer different learning environments and different learning experiences for students. Programs planned using authentic learning fit in a curriculum that focuses on the learner and their goals [theoretically speaking, curriculum for self-actualization (Eisner and Vallance 1974), humanistic curriculum (McNeil 2006), and learner-centered curriculum (Shiro 2008)]. When a curriculum moves outside of the school to address social or environmental issues, the curricular conception/orientation shifts to that of social reconstruction/relevance (Eisner and Vallance 1974, social reconstructionist (McNeil 2006), and social reconstruction (Shiro 2008). Hill (1997), when discussing philosophical shifts in technology education, argues for this latter.

Parallel to this larger picture of curriculum in authentic learning are authentic instruction and authentic learning pedagogy. Much of the literature on authentic learning examines some aspect of these categories, for example, the work of Herrington and colleagues (Herrington and Oliver 2000; Herrington and Herrington 2005; Herrington et al. 2014a, b; Newmann and colleagues (Newmann and Archbald 1992; Newmann and Wehlage 1993; Newmann et al. 2007), and technology education in New Zealand (Snape and Fox-Turnbull 2013; Turnbull 2002).

In technology education, program change for authentic learning, with corresponding curriculum and pedagogical planning, is significantly different than in past practice. There is a clear move from a transmission of knowledge model to a model of discovery and inquiry that meet real-world and lifeworld student interests. Students and teacher plan together, and teacher preplanning is more general.

Support Networks

In authentic learning environments, students take risks in the learning process, learn in challenging ways, and move between school and real-world environments. This is not typical for learning in school, and a multitude of support networks are needed for students in this new learning context. Student support networks vary depending on each student's needs and the activity they are completing. Support networks can include the students' teachers, other teachers, peer groups, other students, parents, social agencies, community member, and partnerships (e.g., business, industry, government, professionals).

Support networks are essential in authentic learning in technology education. Most importantly, individuals external to the class can provide a connection to a real-work projects that align with student lifeworlds and provide access to required tools, materials, and professional expertise. This establishes in-school learning connected to real-life and student lifeworlds.

Conclusion and Future Directions

Clearly, authentic learning in technology education calls for a shift in philosophical assumptions (Hill 1997) from traditional, teacher-lead learning as seen within an education framed in realism and idealism to more student-centered learning grounded in pragmatism and, for the brave, reconstructionism. Authentic learning can be grounded in both of these latter educational philosophies, the deciding feature being purpose. A student-centered approach to respond to the student lifeworld could parallel a pragmatic foundation. A view to use technology to improve human or environmental conditions responds to real life and could be seen from a reconstructionist philosophical approach. Of course, these are not mutually exclusive. In either case, the different philosophical underpinnings have a direct influence on course design (the planned curriculum), teaching and learning (the enactment of the curriculum), and evaluation of student knowledge (the learned curriculum).

Suggestions in this chapter advocate a project approach in technology education, beginning with student problem posing in real-world and lifeworld contexts. Teacher and students, in project groups, then engage in a curricular discussion to ensure that a selected project from problem posing aligns with the course curriculum, the course timeframe, and student abilities. Problem-solving follows with engagement of group members in with in-school and potentially out-of-school experiences and expertise; the teacher becomes a guide through the process, facilitating and managing student learning. In this authentic learning environment, a course cannot be preplanned in every detail, as in a teacher-directed course, but can be in terms of required content, process, timelines, and assessment. Both teacher and students negotiate curricular (or content) flow, according to each groups' needs to advance their project. This engages students in responsible ways and requires great teacher flexibility. Short teacher lessons on content that aligns with group needs are key, and repetition of the lesson to different groups of students to advance group learning in relation to project advancement is critical. That said, frequently timing across groups affords teaching content simultaneously across groups. Teachers manage a number of different projects in and one course. A course outline becomes a guide to a course, outlining content, process, and assessment. Each group project provides the basis for content organization and lesson planning for content delivery. In addition, project ideas are worked out in sketches and models, but final prototypes are made in real life in materials. This is particularly important in senior grades. The life of a teacher changes; it may seem like chaos at the beginning but settles into a learning environment where one of the teacher's roles is to support students as students plan and engage in their learning. An understanding of the theoretical aspects of authentic learning provides teachers with knowledgeable to confidently understand, plan, and enact the curriculum for authentic student learning, which is much more profound that simple teaching/learning recipes to give to teachers for use in their classrooms.

References

Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated learning and education. *Educational Researcher, 25*(4), 5–11.

Anstey, L. M. (2016). *Student experiences in undergraduate anatomy: An exploration of inquiry learning as an authentic experience* (Doctoral dissertation). Retrieved from QSpace at Queen's University; 2016. http://hdl.handle.net/1974/14125

Beane, J. A., & Lipka, R. P. (1984). *Self-concept, self-esteem, and the curriculum*. Boston: Allyn & Bacon.

Bergeron, B. S., & Rudenga, E. A. (1996). Seeking authenticity: What is "real" about thematic literacy instruction? *The Reading Teacher*, 544–551. Retrieved from http://www.jstor.org/stable/20201662

Brown, D., & Thomson, T. (2000). *Cooperative learning in New Zealand schools*. Palmerton North: Dunmore Press.

Brown, J., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42.

Eisner, E., & Vallance, E. (1974). Five conceptions of the curriculum: Their roots and implications for curriculum planning. In E. Eisner & E. Vallance (Eds.), *Conflicting conceptions of curriculum* (pp. 1–18). Berkeley: McCutchan Publishing.

Chen, V. (in progress). *Are students' learning experiences authentic in active learning classrooms?* (Doctoral dissertation). Queen's University, Kingston.

Clark, A. (1998). Embodied, situated, and distributed cognition. In W. Bechtel & G. Graham (Eds.), *A companion to cognitive science* (pp. 506–517). Malden: Blackwell.

Collins, A., Brown, J. S., & Newman, S. E. (1987). *Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics*. Champaign: University of Illinois at Urbana-Champaign.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York: Plenum.

Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin, 125*(6), 627–668.

Dewey, J. (1916). *Education and democracy*. New York: Macmillan Press Limited. Retrieved from http://xroads.virginia.edu/~hyper2/dewey/ch11.html

Dewey, J. (1938). *Education and experience*. New York: Touchstone. Retrieved from http://ruby.fgcu.edu/courses/ndemers/colloquium/experienceducationdewey.pdf

Dreyfus, H. L. (1995). Cognitivism abandoned. In P. Baumgartner & S. Payr (Eds.), *Speaking minds: Interviews with twenty eminent cognitive scientists* (pp. 70–83). Princeton: Princeton University Press.

Driver, R. (1983). *The pupil as scientist*. Milton Keynes: Open University Press.

Epstein, S. (1994). Integration of the cognitive and the psychodynamic unconscious. *American Psychologist, 49*, 709–724.

Gardner, H. (2003, April). *Multiple intelligences after 20 years*. Paper presented at the meeting of the American Educational Research Association, Chicago.

Harter, S. (1986). Cognitive-developmental processes in the integration of concepts about emotions and the self. *Social Cognition, 4*, 119–151.

Hennessy, S. (1993). Situated cognition and cognition apprenticeship: Implications for classroom learning. *Studies in Science Education, 22*, 1–41.

Herrington, A., & Herrington, J. (2005). What is authentic learning? In A. Herrington & J. Herrington (Eds.), *Authentic learning environments in higher education* (pp. 1–13). Hershey: Information Science Pub.

Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational Technology Research and Development, 48*(3), 23–48. doi:10.1007/BF02319856.

Herrington, J., Parker, J., & Boase-Jelinek, D. (2014a) Connected authentic learning: Reflection and intentional learning. *Australian Journal of Education, 58*(1), 23–35. Retrieved from http://dx.doi.org/10.1177/0004944113517830

Herrington, J., Reeves, T. C., & Oliver, R. (2014b). Authentic learning environments. In J. M. Spector et al. (Eds.), *Handbook of research on educational communications and technology* (pp. 401–412). New York: Springer. doi:10.1007/978-1-4614-3185-5_32.

Hill, A. M. (1997). Reconstructionism in technology education. *International Journal of Technology and Design Education, 17*, 121–139.

Hill, A. M. (1998). Problem solving in real-life contexts: Alternatives for design in technology education. *International Journal of Technology and Design Education, 8*(3), 203–220.

Hill, A. M. (1999). Community-based projects in technology education: An approach to relevant learning. In W. E. Theuerkauf & M. J. Dyrenfurth (Eds.), *International perspectives on technology education: Outcomes and futures* (pp. 258–298). Braunschweig: Ames.

Hill, A. M. (2004). Secondary school, university, and business/industry cooperation yields benefits to technological education students. *Journal of Technology Studies, 30*(3), 19–16.

Hill, A. M. (2007). Motivational aspects. In M. de Vries, R. Cluster, J. Dakers, & G. Martin (Eds.), *Exemplary practices in technology education* (pp. 203–211). Rotterdam: SensePublishers.

Hill, A. M., & Smith, H. A. (1998). Practice meets theory in technology education: A case of authentic learning in the high school setting. *Journal of Technology Education, 9*(2), 29–45.

Hill, A. M. Smith H. A. (2003, June). *Many paths to meaning: Research support for the study of technology in secondary school curriculum*. Paper presented at the meeting of Pupils Attitudes towards Technology Annual Conference, Glasgow.

Hill, A. M., & Smith, H. A. (2005). Research in purpose and value for the study of technology in secondary schools: A theory of authentic learning. *International Journal of Technology and Design Education, 15*, 19–32.

Hill, A. M., Anstey, L. M., Gallinger, K., & Penn, A. (2013a, June). *Authentic learning situations for secondary students with developmental disabilities*. Paper session presented at the meeting of Society for Disabilities Studies Conference, 26th Annual Meeting Orlando.

Hill, A. M., Anstey, L. M., Gallinger, K., & Penn, A. (2013b). Curriculum possibilities: Enabling students with "developmental disabilities". *Proceedings of the European Conference on Curriculum Studies. Future Directions: Uncertainty and Possibility* (pp. 724–729). Braga: University of Minho. Available from: http://webs.ie.uminho.pt/euroacs/

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Johnson, M. (1987). *The body in the bind: The bodily basis of meaning, imagination, and reason*. Chicago: University of Chicago Press.

Kirlik, A. (1998). Everyday life environments. In W. Bechtel & G. Graham (Eds.), *A companion to cognitive science* (pp. 702–712). Malden: Blackwell.

Kreber, C., Klampfleitner, M., McCune, V., Bayne, S., & Knottenbelt, M. (2007). What do you mean by "authentic"? A comparative review of the literature on conceptions of authenticity in teaching. *Adult Education Quarterly, American Association for Adult and Continuing Education, 58*(1), 22–43.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge, UK: Cambridge University Press.

Lave, J., & Wegner, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Lewis, T., Petrina, S., & Hill, A. M. (1998). Problem posing – Adding a creative increment to technological problem solving. *Journal of Industrial Teacher Education, 36*(1), 6–36.

McNeil, J. D. (2006). *Contemporary curriculum in thought and action* (6th ed.). Hoboken: Wiley Jossey-Bass Education.

Newmann, F. M., & Archbald, D. (1992). The nature of authentic academic achievement. In H. Berlak, F. M. Newmann, E. Adams, D. A. Archbald, T. Burgess, J. Raven, & T. A. Romberg (Eds.), *Toward a new science of educational testing and assessment* (pp. 71–84). Albany: SUNY Press.

Newmann, F. M., & Wehlage, G. G. (1993). Five standards of authentic instruction. *Educational Leadership, 50*(7), 8–12.

Newmann, F. M., Bruce, M. B., & Carmichael, D. L. (2007). *Authentic instruction and assessment: common standards for rigor and relevance in teaching academic subjects*. Report for the Iowa Department of Education. Retrieved from http://centerforaiw.com/sites/centerforaiw.com/files/Authentic-Instruction-Assessment-BlueBook.pdf

Peirce, C. S. (1992). In N. Houser & C. Kloesel (Eds.), *The essential Peirce: Selected philosophical writings* (Vol. 1). Bloomington: Indiana University Press. 1992.

Peirce, C. S. (1998). In Peirce Edition Project (Ed.), *The essential Peirce: Selected philosophical writings* (Vol. 2). Bloomington: Indiana University Press.

Pintrich, P. R., & Schunk, D. H. (2002). *Motivation in education: Theory, research, and applications* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall International. This is the 2nd edition of the book.

Rambush, J., & Ziemke, T. (2005, July). *The role of embodiment in situated learning.* Paper presented at the XXVII Annual Conference of the Cognitive Sciences, Stresa.

Renzulli, J., Gentry, M., & Reis, S. (2004). A time and place for authentic learning. *Educational Leadership, 62*(1), 73–77.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. New York: Oxford University Press.

Rule, A. C. (2006). Editorial: The components of authentic learning. *Journal of Authentic Learning, 3*(1), 1–10. Retrieved from https://dspace.sunyconnect.suny.edu/handle/1951/35263

Ruzek, E. A., Hafen, C. A., Allen, J. P., Gregory, A., Mikami, A. Y., & Pianta, R. C. (2016). How teacher emotional support motivates students: The mediating roles of perceived peer relatedness, autonomy support, and competence. *Learning and Instruction, 42*, 95–103.

Shiro, M. S. (2008). Introduction to the curriculum ideologies. In M. S. Shiro (Ed.), *Curriculum theory: Conflicting visions and enduring concerns* (pp. 1–12). Thousand Oaks: Sage.

Slavkin, M. L. (2004). *Authentic learning*. Maryland: Scarecrow Education.

Smith, H. A. (1992). Semiotics and modern schooling. In M. Balat & J. Deledalle-Rhodes (Eds.), *Signs of humanity* (Vol. 1, pp. 121–126). Berlin: Mouton de Gruyter.

Snape, P., & Fox-Turnbull, W. (2013). Perspectives of authenticity: Implementation in technology education. *International Journal of Technology and Design Education, 23*, 51–68. doi:10.1007/s10798-011-9168-2.

Solomonides, I., & Reid, A. (2009). Understanding the relationships between student identity and engagement with studies. In H. Wozniak & S. Bartoluzzi (Eds.), The student experience. *Proceedings of the 32nd HERDSA annual conference*, Charles Darwin University, Northern Territory.

Splitter, L. (2009). Authenticity and constructivism in education. *Studies in Philosophy and Education, 28*(2), 135–151.

Turnbull, W. (2002).The place of authenticity in technological in the New Zealand curriculum. *International Journal of Technology and Design Education, 12*(1), 23–40. Retrieved from http://dx.doi.org/10.1023/A:1013056129283

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wertsch, J. V. (1991). *Voices of the mind: A sociocultural approach to mediated action*. Cambridge, MA: Harvard University Press.

Wertsch, J. V. (1998). Mediated action. In W. Bechtel & G. Graham (Eds.), *A companion to cognitive science* (pp. 518–525). Malden: Blackwell.

White, R. W. (1959). Motivation reconsidered: The concept of competence. *Psychological Review, 66*, 297–333.

Whitehead, A. N. (1929). *The aims of education*. New York: MacMillan. Retrieved from http://dx.doi.org/10.4324/9780203003985

Wiener, N. (1993). *Invention: The care and feeding of ideas*. Cambridge, MA: The MIT Press.

Problem-Based Learning in Technology Education

35

Marnie Best

Abstract

Technology education challenges learners to think in ways few learning areas afford: to think critically and creatively and to question ways of thinking, doing, and knowing. In doing so, learners develop dispositions which support their ability to problem solve and devise solutions to perceived problems. Problem-based learning (PBL) is a curricular and instructional approach to a learner-centered education in which learners are afforded opportunities to explore, collaborate, research, and respond to authentic, real-world problems and situations. Such experiences provide immense scope for interdisciplinary learning in which learners draw on knowledge, skills, and experiences across the curriculum in their search for new learning. Given the emphasis of collaboration and problem solving within technology education, such an approach is arguably the most appropriate pedagogy for such a unique learning area. Engaging in authentic tasks to devise and develop design-based solutions, PBL facilitates a powerful opportunity to foster students' intrinsic motivation to learn, within the classroom and beyond. This chapter provides a brief history of PBL and the general characteristics often associated with such an approach, before overviewing the processes of PBL, associated tensions, and discussing its possible role in technology education.

Keywords

Problem-based learning • Technology education • Pedagogy • Problem solving • Authentic learning

---

M. Best (✉)
School of Education, University of South Australia, Adelaide, SA, Australia
e-mail: Marnie.Best@unisa.edu.au

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_37

Contents

Introduction

Problem-based learning (PBL) has been positioned as "perhaps the most innovative instructional method conceived in the history of education" (Hung et al. 2008, p. 486). While this is arguably a contentious claim within the educational community, it does foreground PBL as an innovative approach to the processes of teaching and learning. However, as this chapter will highlight, PBL supports learners to be more than just effective problem solvers; it provides opportunities for them to develop an extensive, responsive, and flexible knowledge base, work and learn collaboratively, foster intrinsic motivation to learn, and develop the skills to be self-directed inquirers (Barrows 1985, 1986). These capacities are important within education and, in particular, technology education, where the ability to problem solve, question, and think critically and creatively are at the forefront of learning (Best and MacGregor 2015; Kimbell 2005).

Central to technology education is the process of designing, a process that Barlex (2011, p. 10) defines, "the act of generating, developing and communicating ideas for products, services, systems and environments in response to user needs and wants and/or market opportunities." Inherent within this definition is the understanding that designers must adopt, adapt, and apply new knowledge which addresses a particular design task, audience, or situation (Barlex 2011; Best et al. 2017). That is, efficient and effective design responds to a perceived need or problem. Positioning learning around needs or problems promotes rich and authentic learning experiences, a key characteristic of both PBL and technology education. In essence, this chapter progresses definitions of PBL to capture the *applied* nature of learning and knowledge as seen in technology education.

In technology education, where learning experiences center on creating designed solutions, framing learning around a central problem guides pedagogy. As learners are immersed in a rapidly changing world, it is imperative they are afforded opportunities and experiences to develop the skills requisite to engage and, indeed, contribute to the societies they inhabit. If technology education is "conceptualised as an education for an increasingly global and culturally diverse community where ideas, innovation and enterprise are central to the design and development of sustainable, socially responsible, preferred futures" (Best et al. 2017, p. 1), then it is imperative that educational curriculum, pedagogy, and practices mirror this. On the premise that learning occurs amidst social and dialogical exchanges

(Best et al. 2015), the future of technology education must therefore concentrate on developing students' capacities to collaboratively research, design, and disseminate outcomes which specifically pursue preferred futures, for example, outcomes which carefully consider sustainability, social responsibility, and resourcefulness. If a problem can be foreseen, then educators have the potential to scaffold students to be discerning choosers, users, and makers of products, processes, and systems. That is, learning experiences must push the boundaries of classroom walls and engage with real-world, authentic problems, as PBL practices espouse. As Hung et al. (2008, p. 488) have contended, "In addition to supporting more meaning by anchoring learning in authentic problems, problems provide a purpose for learning."

Therefore, underpinning PBL is the understanding that when we "solve the many problems we face every day, learning occurs" (Barrows and Tamblyn 1980, p. 1). Inherent in Barrows and Tamblyn's (1980) view is the notion that learning is a lifelong process, one which occurs outside of and beyond classroom settings. This is particularly pertinent in education, and indeed technology education, where learning is derived from problem solving, thinking critically and creatively and questioning the world in which we live (Middleton 2005). As Hung et al. (2008, p. 488) have stated, "If all life is problem solving, then all life is replete with learning opportunities."

This chapter begins with a discussion of the origins of PBL, highlighting how and why it has gained interest within the educational community. Following this, the chapter then overviews the characteristics and processes of PBL, highlighting the tensions and implications for education, before leading to a discussion regarding the possible role of PBL in technology education. The chapter concludes with suggestions for future directions of PBL, both within technology education and further afield.

Origins of Problem-Based Learning

Problem-based learning follows the traditions of Dewey (1938) in emphasizing the importance of real-world, practical learning experiences. Emerging from the field of health sciences at McMaster University Medical School in Hamilton, Canada, over 40 years ago (Neufeld and Barrows 1974), PBL underpinned a central philosophy in which curriculum was learner-centered, multidisciplinary, and "lifelong learning in professional practice" (Boud and Feletti 1997, p. 2).

Existing approaches, primarily within medical education, were criticized for placing too much emphasis on the memorization of fragmented knowledge, where experiences failed to equip learners with problem solving and lifelong learning skills (Barrows 1996). Through challenging traditional classroom approaches, researchers and practitioners reasoned that it was more effective and engaging for students to learn through problem solving than by conventional teaching methods (Barrett 2005). In response, traditional approaches to medical education were interwoven with experiences in which students worked in small groups to problem solve under the facilitation of an educator (Barrett 2005). The introduction of "problems" in student learning was not the source of innovation per se, but rather, it was the presentation of the problem to students as the *starting point* of the learning process, before students were exposed to other curriculum inputs, that heralded a new way of teaching (Barrows 1996). As Savery (2006) has contended, traditional lecture approaches to teaching discipline-specific curriculum fail to provide learners with a real-world context for the content conveyed, and thus, PBL serves to challenge conventional approaches to teaching and learning. The increasing presence of PBL suggests educators are embracing learning experiences that address real-world and authentic problems. The section that follows provides an overview of the characteristics often associated with PBL.

Characteristics of Problem-Based Learning

Following the adoption of practice within the medical education field, PBL has gained popularity in K-12 schooling and across disciplines in higher education (Barrows 2000; Dochy et al. 2003; Hmelo-Silver 2004; Hung et al. 2008). One key reason for an increasing momentum as an educational and instructional approach to teaching and learning is that PBL situates learning within real-world problems. According to Hung et al. (2008, p. 488), PBL can be defined as "an instructional methodology; that is, it is an instructional solution to learning problems." This definition is furthered by Hmelo-Silver et al. (2007, p. 99) who describes PBL as an approach to "situate learning in problem-solving or investigations of complex phenomena." Kwan (2000) furthers these definitions, highlighting PBL as a process of *active learning* where there is particular relevance to *specific learning objectives*. Crucially, as Graube and Theuerkauf (2005, p. 39) have claimed in their support of PBL approaches, "Education must not remain limited to imparting knowledge and functional abilities."

PBL emphasizes the collaborative construction of knowledge which is developed though active learning (Donnelly 2010). Drawing on higher-order thinking skills, and, in particular, problem solving, PBL is a student-centered approach to learning that is designed to support students to be self-directed, independent, and interdependent (Barrett 2005). PBL is premised as an instructional method in which student learning is facilitated through a problem-solving process that targets a particular problem or scenario in which there is no one correct answer (Hmelo-Silver 2004; Jonassen and Hung 2008). Through its cognitive apprenticeship approach (Kolodner et al. 2003), students learn from more experienced others through cognitive and metacognitive skills and processes (Dennen 2004). In doing so, PBL scaffolds learners to undertake research, integrate theory, and practice and apply skills, understanding, and knowledge to devise authentic solutions to a defined problem (Savery 2006). As Hung et al. (2008, p. 488) have stated, "knowledge that is anchored in specific contexts is more meaningful, more integrated, better retained, and more transferable." This is particularly notable in highlighting the nexus which exists between contextualized knowledge and rich, valuable learning experiences. In doing so, PBL can be positioned as the *application of knowledge* through meaningful learning in authentic contexts.

Significantly for technology education, PBL follows an open mode of inquiry that requires learners to be "real-life problem solvers, involved in real-world open-ended problem solving" (Etherington 2011, p. 56). Fundamental to technology education, PBL "is not about problem solving per se, but rather it uses appropriate problems to increase knowledge and understanding" (Wood 2002, p. 8). Therefore, PBL has been touted as "one of the best exemplars of a constructivist learning environment" (Savery and Duffy 2005, p. 1) as it supports learners to construct new knowledge which is a product of research, collaboration, and meaningful discussion. In positioning PBL as a constructivist approach to teaching and learning, Hung et al. (2008, p. 488) have identified associated assumptions inherent within PBL, namely:

- Knowledge is individually constructed and socially co-constructed from interactions with the environment; knowledge cannot be transmitted.
- There are necessarily multiple perspectives related to every phenomenon.
- Meaning and thinking are distributed among the culture and community in which we exist and the tools that we use.
- Knowledge is anchored in and indexed by relevant contexts.

PBL approaches within technology education and more broadly are distinct from traditional approaches to teaching and learning, where the characteristic practices of both the educator and the learner are premised: the educator's role is to facilitate learning, while the learner is self-directed and self-regulated with their learning. Such an approach challenges the practice of many educators as PBL necessitates educators to be facilitators of learning rather than knowledge providers. As students become more familiar and knowledgeable with PBL processes and self-directed with their learning, educator interventions tend to diminish over time (Hmelo-Silver and Barrows 2008).

The notion of students as passive recipients of knowledge is therefore contested. In PBL, students are the initiators of their own learning, inquirers, and problem solvers (Hung et al. 2008). Such a shift in process necessitates students to adopt new ways of learning and interacting: skills and dispositions that require teaching. Likewise, PBL practices require a marked change in educators' practices. That is, the role of an educator shifts to one of a facilitator. In doing so, they facilitate the development of students to become independent and self-directed learners who possess the thinking and reasoning skills that underpin problem solving, metacognition, and critical thinking (Allen et al. 2011; Hung et al. 2008). As Barrows (1992) has explained, the educator facilitates learning at a metacognitive level (other than for "housekeeping tasks") and avoids voicing opinions or providing information to students. Essentially, a PBL educator *facilitates* learning and does not use their knowledge of the content to ask guiding questions which lead students to the "correct" answer (Savery and Duffy 2001).

In essence, PBL is an instructional approach to education which is primarily focused upon problem solving. It is a methodology which is characterized through the key features. PBL is:

- Problem-focused, where learning is based around authentic, ill-structured problems.
- Learner-centered, where students assume responsibility for their own learning.
- Based on problems that should be unfamiliar and conducive to inquiry.
- Interdisciplinary and should support the integration of skills and understandings across learning areas.
- Collaborative learning.
- Self-directed learning which is used to inform problem solving through critical analysis and reflection.
- Reflective, where a debriefing of learning events with a discussion of key learning occurs.
- Assessed through self and peer assessment of learning.
- Focused around tasks that are authentic and connected to real-world situations and skills.
- A pedagogical approach to the curriculum.
- A shift in educators' practices: educators are facilitators of learning rather than disseminators of knowledge. (Hung et al. 2008; Savery 1999, 2006).

Given that problem solving is central to technology education, the characteristics Hung et al. (2008) and Savery (1999, 2006) identify emphasize PBL as a methodology which fosters creativity and the ability to devise solutions to perceived problems. Open or semi-structured design briefs, for example, facilitate such approaches to PBL, where learners investigate, critique, and (re)design new and existing products, processes, and systems. Such exploration and invention supports learners to cross traditional discipline-specific boundaries and collaboratively foster collective knowledge and understanding. Particularly for technology education, where PBL problems are not premised on "one correct answer," the student-centered nature of learning results in outcomes which are significantly more diverse than traditional approaches to learning may invite.

PBL assumes a reciprocal relationship between learners' knowledge and the problem. That is, a student's knowledge and understanding is informed through the problem, and the problem requires students to explore, explain, and expand their understandings. In this sense, PBL requires students to be reflective practitioners, where they respond to situations and problems through drawing on existing and newly acquired knowledge. This is particularly pertinent in technology education, where students devise, design, and produce outcomes to meet perceived needs or responses to design briefs. In doing so, students draw on prior knowledge, in addition to researching and investigating existing designs in order to create responses appropriate to the brief – or problem. The processes of devising, designing, and producing are not linear but require learners to reflectively evaluate their progress against design constraints and the brief they are endeavoring to address.

The term “problem-based learning” is therefore particularly apt when it is conceptualized as an instructional approach to education which is primarily focused upon problem solving. Such problem solving, it is argued, is the foundation for technology education. Although PBL does not focus on the necessity to solve problems per se, the underlying principle is for students to develop the ability to explain or understand the underlying mechanisms of the problem (Loyens et al. 2011). Thus, students need to essentially understand problems in terms of the underlying theoretical explanations (Loyens et al. 2011). PBL problems should therefore be designed to scaffold students’ brainstorming, formulation of learning issues (questions which guide self-directed learning), and self-direct learning (Loyens et al. 2011).

According to Loyens et al. (2011, p. 9), well-structured problems are defined as “problems that lead to one solution by applying one or a limited set of rules,” whereas ill-structured problems “can lead to multiple solutions and can be solved in multiple ways.” Thus, the implementation of ill-structured problems in PBL experiences better reflects real-world and authentic experiences (Etherington 2011). While the focus of PBL is problem solving, Jonassen and Hung (2008) argue that problem difficulty must be a key consideration underpinning tasks. In particular, a problem with an appropriate level of difficulty generally sits within a learner’s cognitive readiness and is therefore solvable. However, an inappropriate level of difficulty will often fall beyond a learner’s readiness and therefore result in failure (Jonassen and Hung 2008). PBL problems should provide cognitive challenge by not providing learners with all of the information but enough to facilitate a context for learning. In doing so, PBL aims to motivate a self-directed search for information and explanation (Allen et al. 2011; Donner and Bickley 1993).

Although reference to the term “problem” implies difficulty, Barrett (2005) argues that problems are much more than this. She conceptualizes problems as challenges, dilemmas, triggers, puzzling phenomenon, or difficult concepts. Moreover, and particularly relevant to technology education, devising more inclusive, ethical, or economical alternatives can be considered a problem, as can designing and creating a designed solution which addresses a specific need or purpose (Barrett 2005; Best et al. 2017). That is, as de Vries (2005) argues, when learners work technologically, their designs and projects must consider ethical and other values: factors that are fundamental in shaping authentic problems for PBL experiences.

Researchers such as Loyens et al. (2011) and Dolmans et al. (1997) have identified five key features of effective problems appropriate to PBL experiences. In particular, problems must capture and advance prior knowledge; promote discussion; foster self-directed learning; facilitate knowledge integration, retention, and transfer; and be relevant to students’ lives beyond the school years. Positioning technology education within authentic learning contexts facilitates the transfer of knowledge, skills, and understanding from within classrooms to broader real-world contexts. Such dispositions are crucial for preparing students with skills necessary for life beyond the school years.

Problems can vary in length, scope, and complexity. For example, problems may be designed for resolution within several classes or tutorials, while others are designed to extend over a greater period. To illustrate, such a design may involve a progressive disclosure mode, where leaners are presented with the problem at the outset, with further information provided at a later stage (Barrett 2005). This approach reflects real-world scenarios where results of a report, a phone call, or email may impact the problem being addressed (Barrett 2005). This is particularly pertinent to technology education where designs are often developed and redesigned in consultation with an end user (Best et al. 2017). Based on feedback and critique, designs are often modified to better address the intended outcome. Likewise, the outcome of one problem may serve to inform, or follow up, another problem, thereby providing further information or insight which is necessary for consideration (Barrett 2005).

Processes of Problem-Based Learning

Like inquiry-based learning approaches in technology education, PBL is driven by the process of inquiry. That is, PBL presents a problem to learners *prior* to the delivery of curriculum inputs, with the problem (and learner) driving the learning experience. Such pedagogical approaches signal a shift from a teaching paradigm to a learning paradigm (Barr and Tagg 1995).

Fundamental to PBL is the focus on an unfamiliar or open-ended problem, situation, or task, such as an issue which supports exploration and discovery to derive possible solutions. During this process, learners decide how they will approach the problem-solving process. In doing so, learning generally occurs in small groups and enables learners to draw on prior knowledge of the topic area and identify gaps in existing knowledge as they work through the problem-solving process. Problem-based learning is comprised of a series of processes in which learner-centered tasks are scaffolded by educators (or tutors). PBL learning is sequenced through a series of key processes:

Posing the question

Learning begins with a complex, ill-structured problem that relates to one or more observable phenomena, events or situations (Schmidt 1983).

Collaborative learning

Learners work in groups of five to eight to reason through the problem and define their own learning objectives (Wood 2002). Given the often complex nature of problems, groups of students work collaboratively to share their collective knowledge (Kolodner et al. 2003).

This process occurs prior to any curriculum input, with students initially drawing on prior knowledge alone. In doing so, they define the problem, identify learning goals through stocktaking current knowledge, devise hypotheses, and consider further learning in order to better understand the problem, what learning activities are required, and who will undertake them. According to Wood (2002), each participant assumes one of four key roles:

Tutor (or educator): The tutor acts as the facilitator of learning, encouraging each group member to participate. Tutors oversee much of the learning process including assisting the chair to manage group dynamics and time and supporting the scribe with record keeping. The tutor facilitates the group to work toward achieving their learning objectives through checking understanding and performance.

Chair*:* One student often acts as the chair and guides their fellow learners through the PBL process. It is their role to encourage each member to participate, oversee dynamics, and manage time.

Scribe: The role of the scribe is to contribute ideas, record the group's key ideas, order thoughts, and record the group's use of resources.

Group member: Each group member is responsible for following the sequence of PBL processes. Their role is to participate in discussion and to listen to the contributions of their fellow group members. They are encouraged to ask questions, research the learning objectives, and share information with those in their group. (Wood 2002)

Collaborative learning therefore not only scaffolds the acquisition of new knowledge but also supports teamwork, communication skills, problem solving, and sharing of information (Wood 2002). Assigning roles to each team member, either randomly or strategically, supports learners to assume responsibility and accountability in acquiring individual and collective knowledge.

Self-directed learning

Building on their prior knowledge and identified gaps, students engage with learning tasks, collecting and studying resources, and selecting relevant literature to inform their report to the group or to present at their next group meeting.

Shared learning

Individual learners share their learning with the group, revisit the problem, and (re) consider and re (design) hypotheses based on their developing understanding.

Consolidating and reporting

Students consolidate and summarize their learning, reporting their knowledge and presenting responses to the problem presented (Allen et al. 2011; Hung et al. 2008).

In supporting the processes of PBL within technology education and beyond, the role of the educator is to stimulate discussion, facilitate the learning process (through asking questions to guide learning), evaluate progress, monitor student contributions, and engage in a debrief at the conclusion of the learning experience (Savery 2006; Schmidt et al. 2007; Wood 2002). In doing so, educators prompt learners to explain their hypotheses and ideas (Kolodner et al. 2003). Recording responses as in-process reflections enables learners to explain their thinking while formulating concept maps and diagrams (Kolodner et al. 2003). Such an approach scaffolds learners to make connections between problem-solving goals and the processes they employed throughout the learning process. Developing such capacities is instrumental in scaffolding students to become active citizens who question, challenge, and devise solutions to perceived needs or problems. The section which follows provides further discussion of the role of PBL in technology education and its associated implications and tensions.

Future Directions and Implications for Problem-Based Learning Within Technology Education

As this chapter has argued, adopting PBL within technology education supports the development of specific skills such as critical and analytical thinking, real-world problem solving, cooperative learning, and effective communication (Duch et al. 2001; Savery 2006). As Hung et al. (2008) and Scott (2014) have reported, one of the most consistent findings of PBL research is that learners who have experienced authentic problem solving are more engaged in lifelong learning. That is, authentic learning enables students to interactively connect with real-world and meaningful experiences (Smith 2002; Snape and Fox-Turnbull 2013).

However, despite the inherent merits of PBL approaches, it has likewise attracted criticism and debate. For example, the effectiveness of PBL has been disputed (Pagander and Read 2014) in relation to its theoretical conception and student learning outcomes. In particular, there is relatively little discussion regarding the implementation of PBL within and across research studies (Hung 2011). Although PBL has been widely implemented, Hung (2011) has argued that through doing so, various PBL models have arisen, each with varying degrees of problem-solving and self-directed learning. Such inconsistent approaches to implementation consequently results in different types of student learning outcomes (Hung 2011). Therefore, future research focusing on PBL must clearly articulate how PBL has been specifically implemented within classrooms when reporting effectiveness. Thus, technology educators must be particularly mindful of how, when, and why they implement PBL to support the development of students' capacity to problem solve and self-direct learning.

While PBL emphasizes the facilitation of higher-order thinking and problem-solving skills, it has been criticized by educators and students who claim this is at the expense of lower-order knowledge acquisition (Angeli 2002; Lieux 2001). Given an increasing performativity culture, evidenced through a growing emphasis on curriculum, lead national testing programs in Australia and beyond, where there is a distinct emphasis on literacy and numeracy, such a tension appears to be a valid one. Technology educators, in particular, are immersed in a learning area which affords ample opportunity to foster higher-order thinking skills while developing lower-order knowledge acquisition. That is, while such a unique learning area provides scope to apply knowledge to design-based problem solving (while simultaneously drawing on students' literacy and numeracy skills), it appears to be in competition amidst a crowded curriculum and competing governmental agendas.

Such tension is specifically emphasized in particular areas and disciplines, where there is a high level of discipline-specific knowledge. While this may be linked to learning areas such as mathematics and science education, initiatives such as STEM (science, technology, engineering, and mathematics) are blurring traditional subject boundaries in seeking cross-disciplinarity. Although the self-directed nature of PBL has been criticized for enabling students to guide and direct learning, often overlooking essential topics (Mills and Treagust 2003), this emphasizes the role of the technology educator in guiding effective PBL processes. PBL fundamentally centers on learning that is instigated by presenting a problem, to suggest that there is no specific teaching of content is a fallacy. At its core, PBL is premised on the presentation of the problem *prior* to the explicit teaching of curriculum. Although a key facet of technology education relates to problem finding, not just problem solving, it is argued that this serves to provide richer, deeper, and more authentic PBL experiences. Therefore, the crucial role that educators play in facilitating student learning as part of PBL experiences cannot be underestimated; it is fundamental to the success of such learning experiences.

Similarly, research regarding the retention of content knowledge following PBL experiences has been mixed. Allen et al. (2011), for example, have noted – albeit acknowledging inconsistent findings – that students in traditional medical programs outperform students who learn through PBL experiences. However, they furthermore suggest the disaggregation of data may fail to capture the underlying richness of PBL; that is, examining student achievement on content recall exams fails to portray understanding and learning more holistically. This is a particularly valid caveat given the emphasis on creativity and innovation in technology education: characteristics and dispositions which are challenging to objectively measure. In response, Barrett (2005) suggests that PBL should be considered as an education strategy, and thus, PBL may be just *one* of many viable approaches to enriching teaching and learning experiences. Through incorporating PBL approaches within technology education, students are afforded opportunities to advance independent and collaborative inquiry to devise, design, and develop authentic outcomes to meet perceived needs and/or wants.

Although much support has been garnered for PBL in the fields of education and beyond, there are several considerations to note for both educators and learners, particularly in the area of technology education. In relation to educators, PBL necessitates tutors who can facilitate learning rather than directly teach content: such an approach requires a pedagogical shift to embrace the student-centered nature of PBL practices. In relation to learners, such a flexible and student-directed approach to learning, while fostering autonomy, can create uncertainty for students in regard to how much "self-direction" to assume, how much study to engage with, and how to be discerning with research and information (Wood 2002). Importantly however, these approaches foster student-centered thinking and design which further supports creativity and innovation in technology education.

There is a distinct need, therefore, to teach learners the requisite skills before engaging with PBL activities. While the skill-intensive nature of technology education often draws attention toward safety considerations and resource management, students must be specifically taught how to problem solve, self-direct learning, and work collaboratively to the extent that the educator becomes the facilitator of learning (Savery 2006). That is not to argue that both educator and learner roles are automatically, or indeed immediately assumed, but in order for effective PBL to occur, educators and learners must be afforded time and opportunity to trial, experience, and experiment with alternative practices to the teaching and learning process.

PBL approaches facilitate teaching and learning in which learners have greater input in to how and what they learn. As Savery and Duffy (2001) explained in their discussion of constructivist principles evident in PBL, such an approach provides immense opportunity for students to be the "constructors of their own knowledge in a context which is similar to the context in which they would apply that knowledge" (Savery and Duffy 2001, p. 14). This exposes a particularly pertinent link to technology education where a key attribute is the promotion of critical and creative thinking and connection to real-world settings. That is, fundamental to the learning area of technology education, the "problem" is what drives thinking toward possible solutions.

Conclusion

The focus of this chapter has been on problem-based learning and the possibilities it presents within technology education as a means for learners to explore, collaborate, research, and respond to authentic, real-world problems and situations. In particular, this chapter has drawn attention to the characteristics and processes associated with PBL and how educators may incorporate such practices to encourage learners to develop their knowledge base, scaffold self-directed learning, work collaboratively, and foster intrinsic motivation. However, this chapter has likewise highlighted the tensions that PBL approaches raise in an educational system where standardized testing is common. Given that PBL has an established foundation as both an instructional and curricular approach to education, it appears to be more than a passing trend in education (Savery 2006). It is therefore at the discretion of technology educators to challenge educational curriculum, pedagogy, and practice and collectively embrace authentic approaches to teaching and learning. As such, this chapter has highlighted the ways in which PBL can be a valid approach in technology education to support students to be lifelong learners and inquirers, vital dispositions in a rapidly changing world.

Therefore, as this chapter has raised, the self-directed nature of PBL experiences in technology education serves to foster the skills and ability for learners to autonomously problem solve while at school and beyond. It has likewise emphasized the collaborative nature of learning. That is, PBL provides immense scope to develop students' disposition to work in autonomous and collaborative situations, drawing on their knowledge, and learning from the knowledge of others. PBL is not simply about problem solving, but using problems as a stimulus to increase learners' knowledge and understanding. This, it is argued, is fundamental to rich technology education experiences. As mentioned in the introduction to this chapter, PBL has been positioned as "perhaps the most innovative instructional method conceived in the history of education" (Hung et al. 2008, p. 486). And while this remains an arguably contentious claim within the educational community, it cannot be argued that PBL provides immense opportunities for students to think innovatively, critically, and creatively and to be more than just effective problem solvers within technology education.

References

Allen, D., Donham, R., & Bernhardt, S. (2011). Problem-based learning. *New Directions for Teaching and Learning, 128*, 21–29.

Angeli, C. (2002). Teachers' practical theories for the design and implementation of problem-based learning. *Science Education International, 13*(3), 9–15.

Barlex, D. (2011). Dear Minister, This is why design and technology is a very important subject in the school curriculum. *Design and Technology Education: An International Journal, 16*(3), 1–10.

Barr, R., & Tagg, J. (1995). From teaching to learning: A new paradigm for understanding education. *Change, 27*(6), 12–25.

Barrett, T. (2005). Understanding problem-based learning. In T. Barrett, I. Mac Labhrainn, & H. Fallon (Eds.), *Handbook of enquiry and problem based learning*. Galway: Creative Commons.

Barrows, H. (1985). *How to design a problem-based curriculum for preclinical years*. New York: Springer.

Barrows, H. (1986). A taxonomy of problem-based learning methods. *Medical Education, 20*, 481–486.

Barrows, H. S. (1992). *The Tutorial Process*. Springfield, IL: Southern Illinois University School of Medicine.

Barrows, H. (1996). Problem-based learning in medicine and beyond: A brief overview. In L. Wilkerson & W. Gijselaers (Eds.), *Bringing problem-based learning to higher education: Theory and practice*. San Francisco: Jossey-Bass.

Barrows, H. (2000). Foreword. In D. Evenson & C. Hmelo (Eds.), *Problem-based learning: A research perspective on learning interaction*. Mahwah: Lawrence Erlbaum Associates.

Barrows, H., & Tamblyn, R. (1980). *Problem-based learning: An approach to medical education*. New York: Springer.

Best, M., & MacGregor, D. (2015). Transitioning design and technology education from physical classrooms to virtual spaces: Implications for pre-service teacher education. *International Journal of Technology and Design Education, online*, 1–13.

Best, M., Price, D., & McCallum, F. (2015). 'Go over there and look at the pictures in the book': A case study exploring the relationships between educational marginalisation, social interactions and achievement motivation in an alternative school setting. *International Journal of Inclusive Education, 19*(4), 422–434.

Best, M., MacGregor, D., & Price, D. (2017). Designing for diverse learning: Case study of place-based learning in Design and technologies pre-service teacher education. *Australian Journal of Teacher Education, 42*(3), 91–106.

Boud, D., & Feletti, G. (1997). *The challenge of problem-based learning* (2nd ed.). London: Kogan Page.

de Vries, M. (2005). The nature of technological knowledge: Philosophical reflections and educational consequences. *International Journal of Technology and Design Education, 15*, 149–154.

Dennen, V. (2004). Cognitive apprenticeship in educational practice: Research on scaffolding, modeling, mentoring, and coaching as instructional strategies. In D. Jonassen (Ed.), *Handbook of research on educational communications and technology* (2nd ed., pp. 3–36). New Jersey: Lawrence Erlbaum Associates.

Dewey, J. (1938). *Experience and education*. New York: Macmillan.
Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction, 13*, 533–568.
Dolmans, D., Snellen-Balendong, H., Wolfhagen, I., & Van der Vleuten, C. (1997). Seven principles of effective case design for a problem-based curriculum. *Medical Teacher, 19*, 185–189.
Donnelly, R. (2010). Harmonizing technology with interaction in blended problem-based learning. *Computers and Education, 54*, 350–359.
Donner, R., & Bickley, H. (1993). Problem-based learning in American medical education: An overview. *Bull Medical Library Association, 81*(3), 294–298.
Duch, B., Groh, S., & Allen, D. (2001). Why problem-based learning? A case study of institutional change in undergraduate education. In B. Duch, S. Groh, & D. Allen (Eds.), *The power of problem-based learning*. Sterling: Stylus.
Etherington, M. (2011). Investigative primary science: A problem-based learning approach. *Australian Journal of Teacher Education, 36*(9), 53–74.
Graube, G., & Theuerkauf, W. (2005). Technological development and development of technology education. In L. Lindstrom (Ed.), *Technology education in new perspectives*. Stockholm: HLS Forlag.
Hmelo-Silver, C. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266.
Hmelo-Silver, C., & Barrows, H. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction, 26*, 48–94.
Hmelo-Silver, C., Duncan, R., & Chinn, C. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107.
Hung, W. (2011). Theory to reality: A few issues in implementing problem-based learning. *Educational Technology Research Development, 59*, 529–552.
Hung, W., Jonassen, D., & Liu, R. (2008). Problem-based learning. In J. Spector, J. van Merriënboer, M. Merrill, & M. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed.). New Jersey: Erlbaum.
Jonassen, D., & Hung, W. (2008). All problems are not equal: Implications for problem-based learning. *Interdisciplinary Journal of Problem-Based Learning, 2*(2), 6–28.
Kimbell, R. (2005). Assessing design innovation. In L. Lindstrom (Ed.), *Technology education in new perspectives*. Stockholm: HLS Forlag.
Kolodner, J., Camp, P., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design into practice. *Journal of the Learning Sciences, 12*(4), 495–547.
Kwan, C. (2000). What is problem-based learning? It is magic, myth and mindset. *Centre for Development of Teaching and Learning, CDTL Brief, 3*(3), 1–4.
Lieux, E. (2001). A skeptic's look at PBL. In B. Duch, S. Groh, & D. Allen (Eds.), *The power of problem-based learning: A practical 'how to' for teaching undergraduate courses in any discipline*. Sterling: Stylus Publishing.
Loyens, S., Kirschner, P., & Paas, F. (2011). Problem-based learning. In K. Harris, S. Graham, & T. Urdan (Eds.), *APA educational psychology handbook* (Vol. 2nd). Washington, DC: American Psychological Association.
Middleton, H. (2005). Creative thinking, values and design and technology education. *International Journal of Technology and Design Education, 15*, 61–71.
Mills, J., & Treagust, D. (2003). Engineering education – Is problem-based or project-based learning the answer? *Australasian Journal of Engineering Education, 3*(2), 2–16.
Neufeld, V., & Barrows, H. (1974). The "McMaster philosophy": An approach to medical education. *Journal of Medical Education, 49*, 1040–1050.
Pagander, L., & Read, J. (2014). Is problem-based learning (PBL) an effective teaching method? A study based on existing research. *Institutionen För Kultur Och Kommunikation, 581*(83), 1–45.

Savery, J. (1999). Enhancing motivation and learning through collaboration and the use of problems. In S. Fellows & K. Ahmet (Eds.), *Inspiring students: Case studies in motivating the learner*. London: Kogan Page.
Savery, J. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 9–20.
Savery J., & Duffy, T. (2001). Problem Based Learning: An instructional model and its constructivist framework, CRLT Technical Report, Indiana University, No 16-01.
Savery, J., & Duffy, T. (2005). Problem based learning: An instructional model and its constructivist framework. *Educational Technology, 35*(5), 31–38.
Schmidt, H. (1983). Problem-based learning: Rationale and description. *Medical Education, 17*, 11–16.
Schmidt, H., Loyens, S., Van Gog, T., & Paas, F. (2007). Problem-based learning is compatible with human cognitive architecture: Commentary on Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*, 91–97.
Scott, K. (2014). A multilevel analysis of problem-based learning design characteristics. *Interdisciplinary Journal of Problem-Based Learning, 8*(2), 533–568.
Smith, G. (2002). Going local. *Educational Leadership, 60*(1), 30–33.
Snape, P., & Fox-Turnbull, W. (2013). Perspectives of authenticity: Implementation in technology education. *International Journal of Technology and Design Education, 23*(1), 51–68.
Wood, D. (2002). Problem based learning. In C. Cantillon, L. Hutchinson, & D. Wood (Eds.), *ABC of learning and teaching in medicine*. London: BMJ.

Emotion and Technology Education 36

David Spendlove

Abstract

The link between emotion and technology education may not be an obvious one, however our emotions are central to our everyday decision making and responses to stimuli. As such it is essential that all learners develop an emotional literacy in order to better understand their emotions, and this can be achieved through technology education. More specifically within technology education, and through this chapter, the link between emotion and creativity will be explored. In addition how our emotions link to the concepts of agency and metacognition will also be explored. Finally, emotion will be examined within three domains of Person, Process, Product, which allows us to conceptualise the contribution and location of emotion within technology education.

Keywords

Emotion • Creativity • Agency • Metacognition

Contents

D. Spendlove (✉)
University of Manchester, Manchester, UK
e-mail: David.Spendlove@manchester.ac.uk

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_38

Introduction

If you are not familiar with the discourse connecting emotion to learning, then you may be surprised to see a chapter in this book focusing on the relationship of emotion to learning through technology education. Many would associate "emotion" within a school context as closely linked to those aspects of the curriculum related to personal health and wellbeing. As such, the link between emotions being a product of learning and the extent to which emotions impede or facilitate learning may not have been considered. Immordino-Yang and Demasio (2007) describe the profound effect of emotion on a multitude of cognitive processes within the classroom including attention, memory, and decision-making. Accordingly, they promote the need for educators to acknowledge how emotion is fundamental for the transference of skills and knowledge learned in the classroom into a real-world environment.

As a starting point, I will therefore highlight two points that will hopefully facilitate navigation through this chapter. Firstly, I believe that developing "emotional literacy" should be a central feature of education, particularly within the learning and "wellbeing" domains, and that subsequently there are additionally strong opportunities for us to consider "emotion" in the context of technology education, specifically within the associated areas of design and creativity. Secondly, the landscape of emotion is not a clear one in relation to whether emotions are naturally embodied in our biology, as part of our evolutionary psychology, or whether emotions are learned and socially and culturally constructed and mediated. However, there is sufficient evidence to suggest that both a combination of socially "nurtured" and evolutionary "natured" emotions, and more specifically through the concept of behavioral epigenetics (Weaver 2007), ultimately shape our everyday being, and this will form the basis of how emotions are considered within this chapter.

To further help navigate the complex and convoluted topic of emotion, located within a technology education context, this chapter will therefore focus upon exploring key areas as follows:

- Emotion within technology education
- Emotion and creativity
- Emotion, agency, and metacognition
- Locating emotion in technology education: person, process, and product

As a precursor to the above, it is worth identifying that the presence of emotion as a topic within education is ultimately nothing new as Plato, some 2,000 years ago, is believed to have stated that all education has an emotional basis (Hinton et al. 2008) building upon Aristotle's view of pathos being persuasion based upon emotion. Within a schooling context, where often increasingly a narrower view of education has become prevalent and where the intellectual and academic are often increasingly prioritized over the emotional, physical, and personal development of children, it is noted how emotional development, wellbeing, and resilience have gradually become increasingly politicized and predominantly located within a progressive education discourse. Nevertheless, many teachers will have been introduced through their teacher preparation programs to the often abstract theories of emotion through concepts such as emotionally conditioned stimuli (Pavlov 1927), emotion-led motivation and hierarchical needs (Maslow 1954, 1968), the unconscious dimensions of emotions (Freud 1984) or Piaget's (1964, 1981) concepts of emotion providing the motivation for cognitive processing and development. Such child-centered theories were also enshrined in policy, for example, in the UK the influential Plowden report (1967) that focused on prioritizing children's emotional and intellectual development.

While many of the above theories of emotion and policy would remain relevant within teacher education programs, new emotionally oriented terminology such as "emotional literacy" (Spendlove 2009), emotional intelligence (Mayer and Salovey 1997), "emotional resilience" (Goldstein and Brooks 2012), "emotional and social competence" (Elias et al. 1997), "emotional and social wellbeing" (Stewart-Brown 2000), and "emotional wellbeing" (McLaughlin 2008) have entered the broader educational (and often business world) discourse. The growth of such discourse recognizes an interrelationship of the intellectual and personal wellbeing consistent with the World Health Organization's (2014) acknowledgment of mental health and wellbeing being fundamental to our "collective and individual ability as humans to think, emote, interact with each other, earn a living and enjoy life." Equally the increasing interest also confirms growing concerns as illustrated by the World Federation for Mental Health who suggest that unipolar depressive disorders will become the leading global burden of disease by 2030 (World Federation for Mental Health 2012). As such governments around the world recognize the increasing demand for social and emotional wellbeing in education, perversely often as an antidote to the associated demands from high stakes testing that they often advocate.

Recognizing and nurturing "emotional resilience" (Masten et al. 1990) and "character" are therefore seen as promoting the ability to cope with the intense demands of twenty-first century living, high-pace consumerism, while maintaining work-life balances alongside the emergence of fragile economies and global and political uncertainties. Such a shift in emphasis is identified as prioritizing a movement from Piagetian models of cognition to broader social and psychobiological concepts of socio-emotional learning and development. In acknowledging a broader conception of emotion, it is therefore useful to adopt the Salovey and Mayer (2004, p. 2) definition of emotions as:

> . . .crossing the boundaries of many psychological subsystems, including the physiological, cognitive, motivational, and experiential systems. Emotions typically arise in response to an event, either internal or external, that has a positively or negatively valenced meaning for the individual.

The implementation and unravelling of this definition will be explored throughout this chapter, but it is worth for a moment considering the emerging alternative viewpoint related to rejecting the embedding of emotions within the curriculum at the expense of academic development. Such calls have come from some aligned with antiprogressive, neo-traditionalists' viewpoints who would advocate a curriculum that acknowledges the attention given to emotional development as fostering unnecessary introspection and emotional dependence within an instrumental curriculum (Ecclestone and Hayes 2009). This alternative position considers emotional education as profoundly dangerous while Furedi (2004) has warned of the dangers of an emergence of a therapy culture willing to burden others with their feelings. In such "vulnerability zeitgeist" contexts (Ecclestone and Rawdin 2016), the attention given to recognition of emotion is seen as distracting and a move away from an education built around subject knowledge toward a "curriculum of the self" (Ecclestone 2011).

Trying to empirically map the growth of emotional wellbeing initiatives in response to an emerging "childhood crisis" narrative is inevitably complex although increasing data would suggest that certain emotional outcomes and manifestations can be mapped to propose changing dispositions across nations and within nations. For example, the "The Good Childhood Report" identified children in England as being among the unhappiest at school while children in Algeria were among the most satisfied (Pople et al. 2015). Equally groups within groups seem to becoming more susceptible to certain forms of emotional and mental health issues as evidenced by a significant increase in self-harm among female adolescents and a rise in suicide among young males. As such Myers et al. (2012) identifies that complexity in comprehending such matters resides in understanding the changing policy and political space and consequently the therapeutic and pedagogical models that are in response to such policies. Therefore, concepts such as emotion and wellbeing are not stable concepts, as they cannot be delineated from the social conditions they operate in which are equally often rapidly changing. Ultimately how we think about emotion and wellbeing is shifting as part of a complex ecosystem which therefore requires more critical and reflexive debate (ibid., p. 421).

In this broader context of education, emotions and cognition should not therefore be considered as opposing binaries as they are interdependent and an essential feature of epistemology and more specifically epistemic emotions (De Sousa 2009), as in feelings of doubt, certainty, and knowing. Such epistemic emotions, which according to Elgin (2008) can be "refined" in order increase their epistemic yield particularly through a process of metacognition are therefore not at the expense of the academic. Such introspection however requires reflection and critique of our own judgments and about one's own capacity and mental state to validate the emotional and cognitive processing. Therefore a focus on emotion has the dual effect on both intellectual and personal developments and rather than being perceived as a distraction or a deficit model should be considered as an integral feature of education. Within this context, I will now outline where and how emotion can be specifically located within technology education.

Emotion Within Technology Education

The translation of the previous section into the everyday practice of technology education will largely be dependent on what one views technology education to be; however, in this context it is worth emphasizing the important concept phronesis, which is pertinent to a broader macroview of the location of emotion within technology education. “Phronesis” is regarded as action and practically oriented and embodies concepts of wisdom, “sensitivity and attunement” (Dunne 1993 p. 256), being closely aligned to the concept of “techne.”

While technology is etymologically derived from “techne,” regarded as craftsmanship, factual, clinical, and instrumentalist with a ‘scientific’ basis, it is through the application of phronesis, which is not bound by a means-ends rationality, and specifically the emotional dimension of phronesis, that technology is mediated and harnessed for the benefit and needs of individuals and society. The macropoint being that the interrelationship of the technical and emotion (pathos) are significant concepts that Aristotle grappled with over 2,000 years ago yet which remain problematic within a broad activity such as technology education. Therefore, while having previously identified that I view emotional literacy and wellbeing to be an essential feature of a well-rounded general education, I would also advocate that technology education provides a unique opportunity to consider our emotions in some of the following ways:

- Technology education is not a neutral activity; we all have values, which are reflected, in our emotions. Something as basic as a choice of color for a product will psychologically, culturally, and physically make us “feel” something in a particular way, and as a consequence, technology education provides a unique context to consider the applied use and potential misuse of such emotional responses.
- Designing is an emotion-led “human focused” activity, and subsequently there needs to be opportunities to understand how our emotions influence our decisions, ideas, and instincts. Accordingly, our emotions drive us to think and behave in a particular way, and as such when designing, we often need to reflect upon such “gut feelings” and think counterintuitively in order to achieve more “considered,” less instinctive outcomes.
- Students can develop a contextualized understanding of emotion within technology as part of the development of their own emotional literacy. As such through designing for others in technology education has a valuable role to play in understanding other people’s physical and emotional needs within the designed and manufactured world.
- While I do not necessarily completely subscribe to the broader concept of emotional intelligence (as our emotions are far from intelligent), I do think that developing intelligence of our emotions through developing emotional literacy is central to making decisions for ourselves and on behalf of others. This would apply to students who may be making decisions on behalf of others when notionally trying to “improve the world” that they and others operate in.
- As part of a broader emotional literacy, technology students need to both understand how users’ and consumers’ emotions interact with their “needs and wants” of products that they design. Equally as emotionally informed consumers, students need to develop an understanding of how they are emotionally targeted, seduced, engaged, and manipulated by the media and marketing, in order that they can become more discerning in their decision-making.

It can be seen from the brief list above that there are significant opportunities to develop both an understanding and application of the concept of emotion through the development of emotional literacy within technology education. However, while much of the above is about developing students' understanding of emotion, it is also essential that all teachers develop an understanding their own emotions. Within technology education, this would relate to teachers' understanding of emotion within a broader construct of pedagogy, their understanding of students' emotional needs, their understanding of their own emotional needs and wellbeing, and understanding of the nuances and opportunities, which will be explored in further detail later, for developing emotional understanding within technology education.

Emotion and Creativity

Having established a broad perspective of the relationship of technology education and emotion, I will now endeavor to focus more specifically on the creative element of technology and the essential relationship with emotion. The literature on creativity within technology education is significant (Atkinson 2000; Barlex 2003; Davies et al. 2014; Kimbell 2009; Lu 2016; McLellan and Nicholl 2011; Spendlove 2005; Spendlove and Cross 2013; Spendlove and Wells 2013; Stables 2009); however, the extent to which the relationship between creativity and emotion has been explored is at times variable due to an often narrow conception of both creativity and technology education. The starting point is therefore to locate creativity within technology education and more specifically within the field of design.

In this context, I would contend that creativity is an integral part of design, but design is not integral to creativity. I would also advocate that the societal benefits of being creative within a technological experience provides a strong rationale for technology education as a significant force for children in enabling them to use their powers of creation to mold their environment, ultimately strengthening the stability of their own and future societies. Thus creativity, and by association emotion, is more than merely embellishment of products or the associated aesthetics but is an integral aspect of a sustainable economy, ethical lifestyle, and the shaping of communities. As Chomsky (2000) noted, "Citizenship and creativity leads to liberty and enlightenment. It offers new ways of radical thinking, empowerment, autonomy, future shaping, and the challenging of static hegemonies" (p. 38).

A central feature of creativity also entails scenario visualization (Arp 2008) which involves recognizing often serendipitous opportunities, synthesizing unrelated concepts, hypothesizing cause and effects while investigating and engaging in abstract and creative opportunities. As such the deficit between an existing experience and a preferred alternative, often triggered by an emotional response, is identified. Such creative visualization requires an emotional empathy to understand the needs of others and an emotionally motivated behavior to do something to address the issue. The acknowledgment and development of emotional empathy in the creative process is therefore seen as incredibly important aspect of learning, both within and beyond the classroom as it plays a fundamental role in social cohesion and interaction, and arguably such dispositions should be nurtured within technology education environments. The presence of empathy (Graydon 2009) in the classroom also appears to be important not only for social learning but for the development of creative thinking through making emotional empathetic connections with others and being open to new ideas providing students with an increasing accessibility to and appreciation of technological artifacts and artwork from around the globe (Feenberg 2010). Jeffers (2008) contends that teachers dedicated to preparing students for the future should grant a high priority to empathy, by encouraging activities which build connections between students and cultural objects, as well as between students themselves. The development of emotional empathy therefore allows students an insight into the minds of others, which in turn helps them to engage in the creative process and produce something other people will hopefully engage with in a positive emotional manner. Such meta-emotion (Gottman et al. 1996) or epistemic emotion (Goldie 2009) validates our behavior to challenge existing situations and to take action while dealing with uncertainty. Such uncertainty therefore inevitably involves engaging in risk, as without risk and uncertainty, creativity does not exist. However, to take risks and deal with uncertainty in order to be innovative requires the management of the emotional discomfort that comes with not always knowing how to proceed.

Creativity ultimately requires an emotional capacity in order to take a "leap of faith." Therefore, creativity has to be risky, and the returns from engaging in precarious endeavors can be low (as in the failure of an idea) as well as high (success of an idea); in its simplest form, this means a risky, creative, idea succeeds or fails. Unfortunately, teachers who are highly accountable, whose reputation and performance are measured through the perceived success of their students' assessed performance, will often, despite their best intentions, provide their students with a benign, safe, and impoverished creative experience through being risk averse. Such constraining of creative opportunities in learning experiences can lead to oppressive experiences where students are conditioned into a notionally "correct" response necessary for the achieving of predetermined view of success. This modus operandi has increasingly dominated much of teachers' pedagogic practice, when one of our core goals as educators should be to maximize the potential for students to be creative and successful learners. Therefore it is not only students who need to have their emotional capabilities to be creative nurtured, but also teachers in order for them to be able to facilitate and cultivate creative responses from their students. Effectively teachers have to walk the talk.

Unfortunately, certain forms of assessment, school culture, and pedagogical strategies can each also present significant barriers to creativity (Spendlove and Wyse 2008) in a formal education setting, and Keirl (2004) contextualizes these concerns, calling for a "culture of creativity" but emphasizing that "it is much easier to facilitate a culture of risk taking, questioning and being different if such behaviours are both valued and well managed" (p. 155). Accordingly, both students and their teachers need to be emotionally liberated as unfortunately the concept of teachers "playing safe" resulting in contrived experiences for the learner (Spendlove and Hopper 2005; Spendlove and Rutland 2007; Spendlove and Wells 2013) has become the norm in those schools where performativity overrides authentic learning opportunities. While many teachers may want to take risks and want to encourage their students to take risks and be creative, the effects of accountability are often felt to constrain their practice; Davies (2000) concluded that teachers may ultimately be impeding creativity in their students, particularly if they themselves lacked confidence in their understanding of creativity and were unwilling to take risks due to the legislative and institutional framework they operated in.

Consequently, both students and teachers need to be emotionally literate and emotionally liberated to harness their creativity and risk taking. Teachers ultimately have the responsibility to cultivate an emotionally supportive environment and to demonstrate what Tolstoy et al. (1995) calls "infectiousness," in order to generate the passion and feeling to enable the disparity between "what is" and "what could be" to be bridged.

Emotion, Agency, and Metacognition

Human instinctive feelings have been shown (Damasio 2006) to inform us what we think (and not as is often perceived as the other way around as thinking informing our feelings); therefore, intuition is considered as when we operate semi-autonomously. Such instinctive senses and accompanied responses (through adoption of heuristic shortcuts) that "something does or doesn't feel right" can however be highly misleading as our emotional responses are prone to errors particularly when engaged in complex and often stressful decision-making as part of technology education.

In effect such responses are both emotional and cognitive frailties; they are key survival properties that can be incredibly important in dangerous circumstances while highly misleading when relied upon in the wrong contexts. As such, we need to develop an emotional literacy through a process metacognitive debiasing (Fischoff 1982). The resultant metacognitive experiences (Efklides 2006) can be considered different from metacognitive skills, as in when dealing with procedural knowledge, or metacognitive knowledge (Pintrich 2002) when dealing with declarative knowledge, in that metacognitive experiences are recognized as dual character in that they are located in cognitive and an affective domains. Therefore, metacognitive feelings arise from monitoring one's own experiences of cognition and the resulting volition (Mitcham 1979). Through recognition of such constructs, it can be seen that technology education offers a unique opportunity to both expose such cognitive and emotional constraints and most significantly, given the educational context, offer the opportunity learn from such limitations in order to improve future decision-making particularly when designing in human contexts. Such "agency" (Bandura 2001, p. 1) is achieved through "intentionality and forethought, self-regulation by self-reactive influence, and self-reflectiveness about one's capabilities." As previously indicated such qualities, I would argue, are essential when engaging in technology education and more specifically when challenged by genuine critical "design thinking" processes. In this context, the explicit nature of such metacognition is unequivocally linked to understanding the extent to which we are responsible for our actions through understanding our emotions; we therefore use our "agency" to make "metacognitive judgments about whether or not we were in control" (Miele et al. 2011, p. 3620).

Agency therefore involves self-reflection (Schön 1987) and metacognition but also requires a reflection of the culture and social context of the decision-making. Within this paradigm Bourdieu's concept of "habitus" provides a further dimension in which to consider the perceived "autonomous" decision-making of agents, as in the teachers and students within a technology education context. Habitus (Bourdieu 1985) is therefore manifested through the adoption of socialized norms and psychological tendencies that guide our behavior and everyday thinking. Accordingly, habitus can be considered as how culturally society becomes "deposited in persons in the form of lasting dispositions, or trained capacities and structured propensities to think, feel and act in determinant ways, which then guide them" (Navarro 2006, p. 16).

Agents (within this context teachers and students) therefore have a habitus manifested psychologically and emotionally in their intuitive "feel for the game." This is not so much a "state of mind as a state of the body, a state of being. It is because the body has become a repository of ingrained dispositions that certain actions, certain ways of behaving and responding, seem altogether natural" (Bourdieu and Thompson 1991, p. 13). Such intuition can be misleading and ultimately constraining particularly when operating in complex, creative, and designerly contexts. As indicated by Stevens (1995), a paradox occurs as habitus "does not determine, but it does guide. Individuals are both completely free and completely constrained..." (p. 112). As a consequence, the very act of students designing and notionally problem-solving in a technology context is constrained by a whole range of emotional, cultural, historical, and psychological factors that are both institutionally and biologically manifested as tacit or intuitive thinking. Such tacit preconceptions and unconscious cueing relate to "self-evident" and often perceived common sense (Watts 2011) which offers an unreliable guide to problem resolution, yet we rely on this mode of thinking virtually all the time to the exclusion of other methods of thinking. The perceived overcoming of such limitations can be notionally achieved through the adoption of purely optimistic strategies that manifest as an "optimism bias" (Sharot et al. 2007), used as a key survival strategy in that we mentally project forward and identify our future position with little interrogation of such optimism.

Locating Emotion in Technology Education: Person, Process, and Product

Emotions are subconscious directors of our attention that occur prior to our feelings; they are the drivers of our cognitive and physiological attention and are ultimately complex, primitive, and difficult to define yet they provide a reflexive ordinance system which influences our behavior, decision-making, and creative thinking. As previously outlined, there is a need to understand the complexity of the discourse

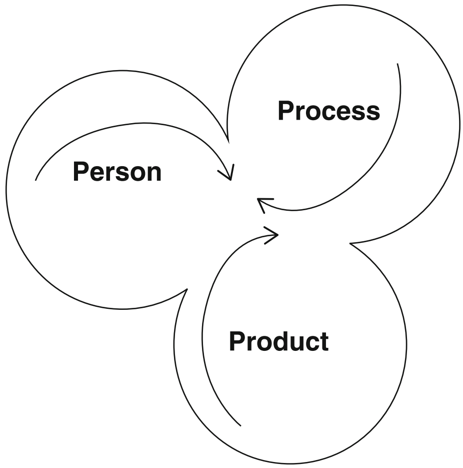


Fig. 1 Person, process, product domain

relating to emotion and to understand the implications and application within a technology education context. Therefore, in order to conceptualize this complexity more readily, I have established a three-stage (triadic) model (Spendlove 2008), which locates the appropriate emotional elements within three "emotional" domains of the "person," the "process," and the "product" (Fig. 1), which will be briefly examined.

Person Domain

Kress (2000) has argued for a curriculum for instability where risk and uncertainty are both welcome. Without both elements, education becomes orientated toward the reproduction of existing practice and defines itself as content with existing benign practices. As such, when considering a learner in technology education, there is an implicit expectation for them to be capable of dealing with uncertainty and risk taking while reflecting upon their own performance, learning in different contexts, and interrogating and creating products, systems, and services within a creative process. The personal attributes and dispositions required by a learner are therefore hugely ambitious and emotionally challenging to the individual.

When the context of that creative endeavor is an educational one, it can be further argued that the uncertainty and risk taking are doubled (rather than shared), as the teacher and the learner will be equally uncertain of the outcome of any given creative challenge, therefore requiring a significant emotional investment on both parts. Indeed, as previously stated, creativity can only occur in such circumstances and that uncertainty and risk taking are essential prerequisites in order for creativity to take place. For the teacher and student to exist in such an uncertain state and to be willing to take risks in pursuit of engaging in an authentic process requires the emotional capacity to do so. Therefore, by being creative, novel, the creator (in this case the student) is expressing a set of values and beliefs about the gap between the existing and the imagined alternative world.

Ultimately to be creative "is an expression of the self" (Morgan and Averill 1992) and such expressions and convictions require an emotional capacity, self-efficacy (Bandura 1997) or "creative self-efficacy" (Tierney and Farmer 2002) to take action. Henderson (2004) has identified that inventors expressed a profound level of emotional experience as part of their creative process. Though many emotions were mentioned, the inventors spoke repeatedly and consistently about their enjoyment of innovation work. Shaw (1994) also emphasized that negative emotions are a normal part of the creative process. One theory relating to this level of emotional discomfort is proposed by Runco (1994, 1999) who has identified that creative tensions can exist when one experiences the emotional discomfort of attempting to reconcile a problem. Therefore, within the person domain, it can be argued that emotion and self-esteem are inexorably intertwined within the creative process. As such full regard has to be considered in facilitating sufficient emotional underpinning that engenders a genuine spirit of agency, empathy, reflection, and metacognition while engaging in uncertainty, risk taking, and creative endeavor. Without an overt recognition or facilitation of the demands of emotion, self-reflection and agency within any activity intended to develop creative capability, that learning will ultimately be inhibited and lack true effectiveness in terms of developing capacity through the nurturing of genuine creative responses.

Process Domain

Learning is a dynamic, complex, and multifaceted process in which a vast array of factors has to be considered in position to ensure learning is effective. While acknowledging this within the context of the second domain of the model, the emotional "process" of learning in technology education, attention is drawn to Vygotskian principles of meaning and sense, both being tied to emotional experience and where "emotion-infused" mental images and "inner speech" become the learner's focus of attention (Vygotsky 1971). Within this context, two specific areas of the emotional dimension of learning are considered: firstly, the emotional climate of the learner and secondly the context of emotional engagement within the learning process in technology education.

Jeffrey and Woods (1997) draw attention to the need for trust in a creative classroom. They believe that the emotional climate of the classroom needs to offer each learner personal confidence and security. Ahn (2005) suggests this is partially achieved through the exemplification of teacher modelling through emotional expression, reaction, and regulation, whether intentional or unintentional, teaches the learner the nature of emotions, their expressions, and how to regulate negative and positive emotions. This is consistent with the emerging evidence of mirror neurons (Rizzolatti et al. 1996; Iacoboni and Dapretto 2006) and the teacher's modelling of their emotional capacity to deal with both uncertainty and risk and their emotional engagement with the topics they teach and students engage with. Since the initial discovery of mirror neurons many functions in humans, including empathy, action understanding, and language acquisition (Blakemore and Decety

2001; Carr et al. 2003; Rizzolatti 2005) have been increasingly explored from an education perspective. Specifically, new understanding is emerging of creative subjects such as art and music (Gadberry 2010; Jeffers 2008), as well as general teaching practice, for considering the potential connection between mirror neurons (Hadjikhani et al. 2006), creativity, emotion, and consciousness. In particular connections between mirror neurons, empathy, emotion, and creativity have significant implications for "process pedagogy" through the benefits of encouraging empathy and exposure to creativity and modelling positive emotions alongside learning. Important implications are therefore emerging for the concept of modelling in teaching, not only for modelling specific actions or skills but actually for explicitly modelling the process of learning, with both teacher and learners acknowledging what particular learning is happening, how, and why.

Unfortunately, within many traditional classroom environments insufficient attention is given to the creative and emotional process aspects of learning as learners are often "cognitively, emotionally, and socially dependent on their teachers who formulate the learning goals, determine which type of interaction is allowed, and generally coerce their students to adjust to the learning environment they have created" (Boekaerts 2001, p. 589). Significant research has also shown that negative emotions, such as anxiety, fear, irritation, shame, and guilt further hinder learning, as they temporarily narrow the scope of attention, cognition, and action (Pekrun et al. 2002), yet many traditional classroom orientations are built upon these principles.

Product Domain

Emotional ergonomics (Seymour and Powell 2003), emotional usability (Leder et al. 2004), aesthetic emotion (Kim and Yun Moon 1998), emotional products (Demirbilek and Sener 2003), and emotional design (Norman 2004) are some examples from the professional world of design of the growing recognition, acknowledgement, and awareness of the emotional dimension within the design world (Thackara 2005). Such acknowledgments are not merely generating an emotional momentum from purely commercial expectation but from increasing demand for designers to acknowledge the full environmental, social, and physical engagement of their products on users and consumers emotions. This is consistent with the need for emotionally informed decision-making in the form of empathy through the acquiring of "habitus" (Bourdieu 1990), as in development of an understanding of another's world through developed and informed perception in order to apply that insight.

By using the term "product" in this domain deliberately aligns the "outputs" of a creative and learning process with such outcomes and intentionally associates the products with physical responses, systems, services, performances, and artifacts that may be produced and that may be available for both the creator, user, and consumer to interface and engage with. In doing this, it is recognized that the output from a creative process may not always be a "physical" product and may be an output that results in new thinking, feelings, or the development of a new skill, attitude, concept, or knowledge.

It must, however, be acknowledged that tensions clearly do exist when focusing purely on outcomes or products (Barlex 2003; Spendlove 2005) at the expense of true engagement with or even bypassing of different creative processes. Poor practice within technology education has often focused, for reasons of expediency, purely on the product stages of the creative process and in doing so circumvents the essential creative (person) and learning (process) emotional domains, resulting in embellished, rather than creative, novel, and inspiring outcomes with limited contextualized learning, emotional engagement, or opportunities to engage in empathy, risk taking, and uncertainty. In conceiving of the product domain as an emotional-oriented activity reframes the outcomes more specifically on informed and intelligent technology education that interplays with the process and person domains and more specifically prioritizes learning in multiple ways.

Conclusion

This chapter has attempted to begin to address the shortfall in the discourse of emotion within a technology education context. In doing so, it is acknowledged that there is still much to explore on this topic but that there is equally much to be gained from engaging with and questioning the emerging and dominant assumptions relating to emotion within an equally slippery concept of technology education. By theorizing emotion as a topic, we can recognize that emotion is symbiotically intertwined with creative practice, designing, thinking, and learning, each of which are further interwoven with the concepts of agency and metacognition.

Accordingly, the complexity of the discourse in this chapter has been reduced through conceiving of emotion within the person, process, and product domains. However, to reduce further I would posit that the essential feature of emotion within technology education is that the application of emotional understanding has an inherent value in developing one's own emotional literacy. As such:

- Learners need to understand how their own emotions influence their own thinking and behavior.
- Learners should be able to critique how their emotions are manipulated in the designed and made world (including social, political, marketing, and media messaging).
- Learners should understand the implication of their emotionally informed decisions on other people's emotions through the design and made world.

References

Ahn, H. J. (2005). Child care teachers' strategies in children's socialisation of emotion. *Early Child Development and Care, 175*, 1–49.

Arp, R. (2008). *Scenario visualization: An evolutionary account of creative problem solving*. Cambridge, MA: MIT Press.

Atkinson, S. (2000). Does the need for high levels of performance curtail the development of creativity in design and technology project work? *International Journal of Technology and Design Education, 10*(3), 255–281.
Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: W. H. Freeman.
Bandura, A. (2001). Social cognitive theory: An agentic perspective. *Annual Review of Psychology, 52*(1), 1–26.
Barlex, D. (2003). *Creativity in crisis?: Design & technology at KS3 and KS 4*. Design and Technology Association. Wellesbourne, England.
Blakemore, S., & Decety, J. (2001). From the perception of action to the understanding of intention. *Neuroscience, 2*, 561–567.
Boekaerts, M. (2001). Bringing about change in the classroom: Strengths and weaknesses of the self- regulated learning approach – EARLI presidential address, 2001. *Learning and Instruction, 12*(2002), 589–604.
Bourdieu, P. (1985). The genesis of the concepts of habitus and of field. *Sociocriticism, 2*, 11–24.
Bourdieu, P. (1990). *The logic of practice*. Stanford: Stanford University Press.
Bourdieu, P., & Thompson, J. B. (1991). *Language and symbolic power*. Cambridge, MA: Harvard University Press.
Carr, L., Iacoboni, M., Dubeau, M., Mazziotta, J., & Lenzi, G. (2003). Neural mechanisms of empathy in humans: A relay from neural systems for imitation to limbic areas. *Proceedings of the National Academy of Sciences of the United States of America, 100*(9), 5497.
Chomsky, N. (2000). *Chomsky on mis-education* (Edited and introduced by D. Macedo). New York: Rowan and Littlefield.
Damasio, A. R. (2006). *Descartes' error*. New York: Random House.
Davies, T. (2000). Confidence! Its role in the creative teaching and learning of design and technology. *Journal of Technology Education, 12*(1), 18–31.
Davies, D., Jindal-Snape, D., Digby, R., Howe, A., Collier, C., & Hay, P. (2014). The roles and development needs of teachers to promote creativity: A systematic review of literature. *Teaching and Teacher Education, 41*, 34–41.
De Sousa, R. (2009). Epistemic feelings. *Mind and Matter, 7*(2), 139–161.
Demirbilek, O., & Sener, B. (2003). Product design, semantics and emotional response. *Ergonomics, 46*(13/14), 1346–1360.
Dunne, J. (1993). *Back to the rough ground: 'Phronesis' and 'techne' in modern philosophy and in Aristotle*. Notre Dame: University of Notre Dame Press.
Ecclestone, K. (2011). Emotionally-vulnerable subjects and new inequalities: The educational implications of an 'epistemology of the emotions'. *International Studies in Sociology of Education, 21*(2), 91–113.
Ecclestone, K., & Hayes, D. (2009). *The dangerous rise of therapeutic education*. London: Routledge.
Ecclestone, K., & Rawdin, C. (2016). Reinforcing the 'diminished' subject? The implications of the 'vulnerability zeitgeist' for well-being in educational settings. *Cambridge Journal of Education, 46*, 1–17.
Efklides, A. (2006). Metacognition and affect: What can metacognitive experiences tell us about the learning process? *Educational Research Review, 1*(1), 3–14.
Elgin, C. Z. (2008). Emotion and understanding. In G. Brun, U. Doğuoğlu, & D. Kuenzle (Eds.), *Epistemology and emotions* (pp. 33–50). Ashgate Publishing.
Elias, M., Zins, J., Weissberg, R., Frey, K., Greenberg, M., Haynes, N., Kessler, R., Schwab-Stone, M., & Shriver, T. (1997). *Promoting social and emotional learning*. Alexandria: ASCD.
Feenberg, A. (2010). *Between reason and experience: Essays in technology and modernity.* Cambridge: MIT Press.
Fischhoff, B. (1982). Debiasing. In D. Kahneman, P. Slavic, & A. Tversky (Eds.), *Judgment under uncertainty: Heuristics and biases*. New York: Cambridge University Press.
Freud, S. (1984) The unconscious. In *On metapsychology: The theory of psychoanalysis* (Vol. 11, pp. 159–222). Harmondsworth: Pelican Freud Library, original work published 1915.

Füredi, F. (2004). *Therapy culture: Cultivating vulnerability in an uncertain age*. London: Psychology Press.

Gadberry, A. (2010). Modeling and the mirror neuron system. *Kodaly Envoy, 37*(1), 21.

Goldie, P. (Ed.). (2009). *The Oxford handbook of philosophy of emotion*. Oxford: Oxford University Press.

Goldstein, S., & Brooks, R. B. (Eds.). (2012). *Handbook of resilience in children*. New York: Springer Science & Business Media.

Gottman, J. M., Katz, L. F., & Hooven, C. (1996). Parental meta-emotion philosophy and the emotional life of families: Theoretical models and preliminary data. *Journal of Family Psychology, 10*(3), 243.

Graydon, K. (2009). Roots of empathy. *The Educational Forum, 35*(3), 26–30.

Hadjikhani, N., Joseph, R., Snyder, J., & Tager-Flusberg, H. (2006). Anatomical differences in the mirror neuron system and social cognition network in autism. *Cerebral Cortex, 16*(9), 1276.

Henderson, J. (2004). Product inventors and creativity: The finer dimensions of enjoyment. *Creativity Research Journal, 16*(2&3), 293–312.

Hinton, C., Miyamoto, K., & Della-Chiesa, B. R. U. N. O. (2008). Brain research, learning and emotions: Implications for education research, policy and practice. *European Journal of Education, 43*(1), 87–103.

Iacoboni, M., & Dapretto, M. (2006). The mirror neuron system and the consequences of its dysfunction. *Neuroscience, 7*, 942–951.

Immordino-Yang, M. H., & Damasio, A. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. *Mind, Brain, and Education, 1*(1), 3–10.

Jeffers, C. (2008). Empathy, cultural art, and mirror neurons: Implications for the classroom and beyond. *Journal of Cultural Research in Art Education, 26*, 65–71.

Jeffrey, R., & Woods, P. (1997). The relevance of creative teaching: Pupils views. In A. Pollard, D. Thiessen, & A. Filer (Eds.), *Children and their curriculum*. London: Falmer Press.

Keirl, S. (2004). Creativity, innovation and life in the Lilly Pond: Nurturing the design and technology family while keeping the alligators fed. *The Journal of Design and Technology Education, 9*(3), 145–157.

Kim, J., & Yun Moon, J. (1989). Designing towards emotional usability in customer interfaces-trustworthiness of cyber-banking system interfaces. *Interacting with Computers, 10*(1998), 1–29.

Kimbell, R. (2009). Creativity in crisis. *Journal of Design & Technology Education, 5*(3), 206–2011.

Kress, G. (2000). A curriculum for the future Cambridge. *Journal of Education, 30*(1), 133–145, Cambridge.

Leder, H., Benno, B., Oeberst, A., & Augustin, D. (2004). A model of aesthetic appreciation and aesthetic judgments. *British Journal of Psychology, 95*, 489–508.

Lu, C. C. (2016). Interactive effects of environmental experience and innovative cognitive style on student creativity in product design. *International Journal of Technology and Design Education, 142*, 1–18.

Maslow, A. (1954). *Motivation and personality*. New York: Harper.

Maslow, A. (1968). *Toward a psychology of being*. New York: D. Van Nostrand Company.

Masten, A. S., Best, K. M., & Garmezy, N. (1990). Resilience and development: Contributions from the study of children who overcome adversity. *Development and Psychopathology, 2*(04), 425–444.

Mayer, J. D., & Salovey, P. (1997). What is emotional in- telligence? In P. Salovey & D. Sluyter (Eds.), *Emotional development and emotional intelligence: Implications for educators* (pp. 3–31). New York: Basic Books.

McLaughlin, C. (2008). Emotional well-being and its relationship to schools and classrooms: A critical reflection. *British Journal of Guidance & Counselling, 36*(4), 353–366.

McLellan, R., & Nicholl, B. (2011). “If I was going to design a chair, the last thing I would look at is a chair”: Product analysis and the causes of fixation in students’ design work 11–16 years. *International Journal of Technology and Design Education, 21*(1), 71–92.

Miele, D. B., Wager, T. D., Mitchell, J. P., & Metcalfe, J. (2011). Dissociating neural correlates of action monitoring and metacognition of agency. *Journal of Cognitive Neuroscience, 23*(11), 3620–3636.

Mitcham, C. (1979). Philosophy and the history of technology. In G. Bugliarello (Ed.), *The history and philosophy of technology* (pp. 163–189). Champaign- Urbana: University of Illinois Press.

Morgan, C., & Averill, J. R. (1992). True feelings, the self, and authenticity: A psychosocial perspective. In D. D. Franks & V. Gecas (Eds.), *Social perspectives on emotion* (Vol. 1, pp. 95–124). Greenwich: JAI Press.

Myers, T.A., Nisbet, M.C., Maibach, E.W. and Leiserowitz, A.A., 2012. A public health frame arouses hopeful emotions about climate change. *Climatic Change, 113*(3–4), pp.1105–1112.

Navarro, Z. (2006). In search of a cultural interpretation of power: The contribution of Pierre Bourdieu. *IDS Bulletin, 37*(6), 11–22.

Norman, D. (2004). *Emotional design: Why we love (or hate) everyday things*. New York: Basic books.

Pavlov, I. P. (1927). *Conditioned reflexes*. London: Oxford University Press.

Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Positive emotions in education. In E. Frydenberg (Hrsg.), *Beyond coping: Meeting goals, visions, and challenges* (S. 149–173). Oxford: Oxford University Press.

Piaget, J. (1964). Part I: Cognitive development in children: Piaget development and learning. *Journal of Research in Science Teaching, 2*(3), 176–186.

Piaget, J. (1981). *Intelligence and affectivity.* Palo Alto: Annual Reviews.

Pintrich, P. R. (2002). The role of metacognitive knowledge in learning, teaching, and assessing. *Theory into Practice, 41*(4), 219–225.

Plowden. (1967). *Children and their primary schools: Report of the Central Advisory Council for Education (England)*. London: HMSO.

Pople, L., Rees, G., Main, G., & Bradshaw, J. R. (2015). *The good childhood report 2015.* London: The Children's Society. Retrieved from: http://www.childrenssocie ty.org.uk/what-we-do/research/the-good-childhood- report-2015

Rizzolatti, G. (2005). The mirror neuron system and its function in humans. *Anatomy and Embryology, 210*(5), 419–421.

Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research, 3*(2), 131–141.

Runco, M. A. (1994). Creativity and its discontents. In M. P. Shaw & M. A. Runco (Eds.), *Creativity and affect* (p. 102). Norwood: Ablex.

Runco, M. A. (1999). Tension, adaptability, and creativity. In S. W. Russ (Ed.), *Affect, creative experience, and psychological adjustment* (pp. 165–194). Philadelphia: Brunner/Mazel.

Salovey, P., & Mayer, J. D. (2004). Emotional intelligence. In P. Salovey, M. A. Brackett, & J. D. Mayer (Eds.), *Emotional intelligence: Key readings on the Mayer and Salovey model* (pp. 1–28).New York: Dude.

Salovey, P., Caruso, D., & Mayer, J. D. (2004). Emotional intelligence in practice. In P. A. Linley & S. Joseph (Eds.), *Positive psychology in practice* (pp. 447–463). Hoboken: Wiley.

Schön, D. (1987). *Educating the reflective practitioner.* San Francisco: Jossey-Bass Publishers.

Seymour, R., & Powell, R. (2003, December 11). Emotional ergonomics. *Design Week.*

Sharot, T., Riccardi, A. M., Raio, C. M., & Phelps, E. A. (2007). Neural mechanisms mediating optimism bias. *Nature, 450*(7166), 102–105.

Shaw, M. P. (1994). Affective components of scientific creativity. In M. P. Shaw & M. A. Runco (Eds.), *Creativity and affect* (pp. 3–43). Norwood: Ablex.

Spendlove, D. (2005). Creativity in education: A review. *Design and Technology Education: An International Journal, 10*(2), 9–18.

Spendlove, D. (2008). The locating of emotion within a creative, learning and product orientated design and technology experience: Person, process, product. *International Journal of Technology and Design Education, 18*, 45–57.

Spendlove, D. (2009). *Emotional literacy.* London: Bloomsbury Publishing.

Spendlove, D., & Cross, A. (2013). Design and technology. In R. Jones & D. Wyse (Eds.), *Creativity in the primary curriculum* (pp. 66–82). Routledge.

Spendlove, D., & Hopper, M. (2005). *Coping with uncertainty: An exploration of the place of emotion within the creative curriculum*. Paper presented at the British Education Research Association annual conference, Glamorgan University.

Spendlove, D., & Rutland, M. (2007). Creativity in design and technology. In D. Barlex (Ed.), *Design and technology: For the next generation*. Whitchurch: Cliffe & Company.

Spendlove, D., & Wells, A. (2013). Creativity for a new generation. In G. Owen-Jackson (Ed.), *Debates in design and technology education* (pp. 166–179). Routledge.

Spendlove, D., & Wyse, D. (2008). Creative learning: Definitions and barriers. *Creative Learning, 3* (11), 11–18.

Stables, K. (2009). Educating for environmental sustainability and educating for creativity: Actively compatible or missed opportunities? *International Journal of Technology and Design Education, 19*(2), 199–219.

Stevens, G. (1995). Struggle in the studio: A Bourdivin look at architectural pedagogy. *Journal of Architectural Education, 49*(2), 105–122.

Stewart-Brown, S. (2000). Parenting, wellbeing, health and disease. In A. Buchanan & B. Hudson (Eds.), *Promoting children's emotional well-being* (pp. 28–47). Oxford: Oxford University Press.

Thackara, J. (2005). *In the bubble: Designing in a complex world*. Cambridge, MA: The MIT Press.

Tierney, P., & Farmer, S. M. (2002). Creative self-efficacy: Its potential antecedents and relationship to creative performance. *Academy of Management Journal, 45*, 1137–1148.

Tolstoy, L., Pevear, R., & Volokhonsky, L. (1995). *What is art?* Harmondsworth: Penguin.

Vygotsky, L. S. (1971). *The psychology of art*. Cambridge, MA: MIT Press (Not published in lifetime, 1925 dissertation, worked on 1917–1922).

Watts, D. J. (2011). *Everything is obvious once you know the answer: How common sense fails*. London: Atlantic Books.

Weaver, I. C. (2007). Epigenetic programming by maternal behavior and pharmacological intervention nature versus nurture: Let's call the whole thing off. *Epigenetics, 2*(1), 22–28.

World Federation for Mental Health. (2012, October 10). *Depression: A global crisis world mental health day.*

World Health Organization. (2014). *Mental health: Strengthening our response* (Fact sheet no. 220). Retrieved from: http://www.who.int/mediacentre/factsheets/fs220/en/

Technology Education as a Practice-Based Discipline

37

Johannes Strobel

Abstract

The existing literature suggests a mismatch between what and how engineering and technology students are learning in the classroom and what employers and society in general are demanding from them in their careers. This mismatch between engineering learning and practice is rooted in a fundamental dissonance between what technology is and how it is taught; engineering and technology education programs continue to portray engineering through building the curricula and infrastructure upon the notion that engineering is more of a platform for conceptual understanding than a complex and contextualized practice of solving problems, achieving sustainable design, and/or employing creative skills, such as design. The purpose of this chapter is to provide a model that conceptualizes engineering as a complex and contextualized activity and to consequently argue for a new positioning of the role of conceptual understanding. First, this chapter briefly discusses the existing prevalent model of technology and engineering that focuses on the attainment of conceptual knowledge, giving primarily attention to its main assumptions, limitations, and implications in the context of engineering/technology education and practice. Then, the discussion proceeds to some precursor frameworks of the proposed model that already exist in a more fragmented form, including frameworks developed in the form of theoretically derived rationales, as well as those models that have drawn from naturalistic approaches of inquiry. Finally, this new model of engineering and technology is introduced as a complex and contextualized practice along with its main tenets, how it reframes

J. Strobel (✉)
School of Information Science and Learning Technologies, University of Missouri, Columbia, MO, USA
e-mail: strobelj@missouri.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_39

the fundamental questions of technology and engineering and technology/engineering practice, and the possible implications for technology/engineering education and practice.

Keywords
Practice • Work • Non-conceptual • Tacit

Contents

Introduction

What differentiates engineering, technology, and science? In the early years of undergraduate curricula, one could not tell the difference. Students' schedules were dominated by physics, chemistry, English composition, and mathematics, and the curriculum focused on remediation and the preparation for engineering practice. The standard definitions of *engineering*, such as "applied mathematics and science" or "using math and science to solve problems," reinforced the supremacy of scientific concepts and mathematical knowledge as the basis for the education of engineers. As Jonassen et al. (2006) pointed out, "Practicing engineers are hired, retained, and rewarded for solving problems, so engineering students should learn how to solve workplace problems" (p. 139). This utilitarian view of the role of engineers supports the assertion that the engineering/technology paradigm should be conceived as a set of complex and contextualized activities including real-world problem-solving as opposed to solving story problems in textbooks, designing, modeling, optimizing, and participating in other creative activities (Holt et al. 1985). Concordantly with these statements, the role of engineering education should be that of providing would-be engineers with the necessary conditions (e.g., adequate infrastructure, well-qualified faculty, and comprehensive curriculum structures) and training to help them become creative problem solvers and designers who actively and positively transform the way in which we live.

Most engineering educators today would agree that providing the best of those conditions to engineering students should be the primary goal of engineering education. Regardless of how engineering education programs decide which conditions are essential for training future engineers, a strong case can be made for what is more important: how these conditions are framed (both conceptually and operationally) so that they account for a practice of engineering that suitably responds to the demands of real-world problems. Following this line of thought, I argue that there should be a close correspondence between the real-world *demands*, the *practice* of engineers, and the academic *conditions* that engineering education programs offer to engineering students. Unfortunately, it seems that these three elements are not always in close correspondence with each other. Whether or not engineering education programs provide future engineers with all the necessary conditions during their training, a gap exists, generally, between what professional engineers are called to do in the field and the academic experiences they encounter in engineering preparation programs and in precollege settings (Tuncer 2003; McNeill et al. 2016; Martin et al. 2005; Singer and Edmondson 2008; Splitt 2003; Wulf and Fischer 2002). In other words, in most parts of the world, there is a mismatch between what and how would-be engineers are learning in the classroom and what employers and the society in general are demanding from them as engineers. I argue that this mismatch between engineering learning and practice is rooted in a fundamental dissonance between *what engineering/technology is* and *how it is taught*; engineering/technology education programs continue to portray engineering and build up their curricula and infrastructure upon the notion that engineering/technology is more of a platform for conceptual understanding than a complex and contextualized practice of problem-solving, sustainable design, and/or the employment of creative skills (Gattie et al. 2011). Thus, a sensible step forward in bringing a solution to this mismatch and reducing the gap between engineering learning and practice is to conceptually reformulate how we understand engineering.

The purpose of this chapter is to provide a model that conceptualizes engineering as a *complex and contextualized activity* and consequently an argument for a new positioning of conceptual understanding as an outcome of engineering education. I first briefly discuss the existing prevalent model of engineering that focuses on the attainment of conceptual knowledge (e.g., Sheppard et al. 2006; Streveler et al. 2008), primarily giving attention to its main assumptions, limitations, and implications in the context of engineering education and practice. I then discuss some precursor frameworks of the proposed model that already exist in a more fragmented form, including frameworks developed in the form of theoretically derived rationales (e.g., Evans 2010; Evans and Gabriel 2007; Singer and Edmondson 2006), as well as those models that have drawn from naturalistic approaches of inquiry (e.g., Itabashi-Campbell et al. 2012; Trevelyan 2010). Finally, I describe the model, its main tenets, and how it reframes the fundamental questions of engineering and its practice, along with its possible implications for engineering education and practice. The chapter will not be addressing existing approaches and research on internships, co-op programs, or industry placements of students as these represent obvious and deliberate attempts to provide students with practice experiences.

Modeling Engineering

Engineering as the Acquisition and/or Application of Conceptual Knowledge

The Conceptual Understanding (CU) Model

According to the CU model, conceptual knowledge determines how engineering students identify the essential elements in establishing correct procedures and how they evaluate whether new alternative procedures might work in terms of finding solutions to problems (Streveler et al. 2008). This model draws from the thesis held by cognitive psychologists suggesting that concepts act as organizers that help us make sense of the world around us (for a review, see Thagard 2002). This particular psychological perspective also postulates that conceptual knowledge, in its most basic form (i.e., concepts), is necessary for developing more complex forms of declarative knowledge (e.g., schemas and theories), procedural knowledge (e.g., scripts and algorithms), and behaviors. For example, if one wants to learn the correct procedures that are necessary to design a car, one first needs to have an understanding (most often implicitly) of basic concepts such as acceleration and rotation. Thus, according to the CU model, the acquisition of science-, mathematics-, and engineering-related concepts is the most essential component in the context of engineering education and practice. As put by Streveler and her colleagues, “The construction of conceptual knowledge is a key element in the development of competence and expertise in engineering” (Streveler et al. 2008, p. 280).

Another important tenet of the CU model is that students come to engineering education programs with misconceptions about both scientific (e.g., force) and engineering (e.g., the automatization of processes) concepts, which make it difficult for them to learn other concepts and theories and how to use them to solve engineering-based problems. It is then postulated that the role of engineering education is that of providing the conditions that could allow students to transform those misconceptions into new, correct conceptions. This implies that in its initial stage, learning engineering basically consists of a process of conceptual change, which means that engineering students’ conceptual knowledge is always under development and the role of the instructor should be to help them identify and reconstruct incorrect conceptual structures. According to Streveler et al.:

> The first pedagogical challenge is to discover what conceptual knowledge students bring to a course and how it is structured in their conceptual framework. Once that is understood, instructors can begin to craft appropriate teaching and learning methods to help the students construct, or perhaps reconstruct, their conceptual knowledge into a correct framework. (2008, p. 290)

In sum, according to the CU model, engineering is mainly conceptualized as a theoretical enterprise in which engineers are conceptual knowledge administrators and operators. Expert engineers are those who know more and have a better grasp of the relevant science and mathematics and engineering concepts and who are able to proceed in their practice according to those concepts. Therefore, according to the CU model, the main achievement of engineering education is to help engineering students develop more expert-like conceptual knowledge structures (Streveler et al. 2008; Meyer and Land 2006; Meter et al. 2016).

The Problem-Based Learning (PBL) Model

Although the CU model does not deny that the application of conceptual knowledge to solve problems is an important step in engineering learning and practice, its main tenets give more weight to the importance of conceptual understanding than to the development of problem-solving skills. Other scholars, however, have suggested that engineering should be conceived as the integration of problem-solving processes and conceptual knowledge, with the latter acting as an activator of the former (e.g., Sheppard et al. 2006). This particular view of engineering as the integration of conceptual knowledge and problem-solving draws from the theories of problem-based learning (PBL). According to the PBL model, (a) knowledge is individually and socially constructed from interactions with the environment, which implies that knowledge cannot be simply transmitted; (b) meaning and thinking are culturally distributed in the form of tools (e.g., language and narratives); and (c) knowledge is contextually anchored. In operational terms, the PBL model is defined as a problem-focused instructional method in which groups of students organize the content to be learned by working on simulations of ill-structured problems.

With this view, expert engineers consequently need to organize their knowledge around conceptual structures that facilitate their understanding of problems and the creation of possible solutions, and they need to know the means to contextualize conceptual understanding when attempting to solve engineering-based problems (Yadav et al. 2011). Engineering learning is then understood as a problem-solving activity that requires the contextual application of conceptual knowledge. For a more detailed description of PBL, see the chapter by Best in this volume. For examples of PBL models in engineering education and associated research, see CDIO (Edström and Kolmos 2014), EPICS (Huff et al. 2016), and the two edited volumes *Research on PBL Practice in Engineering Education* (Du and Kolmos 2009) and *Management of Change* (de Graaff and Kolmos 2007).

Limitations and Implications for Conceptual-Centered Education Models

These two models of engineering education (CU and PBL) draw from completely different assumptions regarding the nature of the practice of engineering. According to the PBL model, engineering practice involves a dialectical interaction between the concepts that the engineer is supposed to individually and socially construct and the possible problems in which those concepts could be applied. However, according to the CU model, engineering practice involves a linear relationship between concepts and problems (not a dialectical interaction), giving priority to the acquisition of conceptual knowledge and not to the solution of the problem. There is, however, one key assumption that is shared by these models: Conceptual knowledge has supremacy in engineering education, meaning that conceptual understanding is the goal and end. Both characterize engineering practice as the *use of concepts to solve problems.*

But then, is there a problem with applying conceptual knowledge to solve engineering-based problems? Is conceptual knowledge necessary to make things work better, more efficiently, and less expensively? Could it be possible that other forms of knowledge (e.g., procedural, situational, and kinesthetic) are more fundamental for solving engineering-based problems? Does a person need specific conceptual knowledge of engineering (e.g., automatization) or, for instance, of physics (e.g., electromagnetism) or chemistry (e.g., biochemistry) to solve an engineering-based problem? Could a person with training in a different domain (e.g., music) and who does not have any previous knowledge in engineering be able to solve an engineering-related problem as well as a professional engineer or someone who has advanced conceptual knowledge in physics and/or chemistry?

At first glance, one could argue that it would be very difficult, if not impossible, for a musician with no background knowledge in electrical engineering to solve a problem that requires a conceptual understanding of electromagnetism (e.g., designing and making a tube amplifier to work better by correctly setting up the bias). Perhaps, this is not always the case. Take for example a hobbyist guitarist with no background in engineering. She recently bought a tube amplifier to improve the quality of the sound of her electric guitar. To her surprise, after playing the guitar through the amplifier, the results were not as expected. After doing some research on the Internet (20–30 min), she found out that the tubes inside the amplifier were causing the problem. She then had a problem to solve: Find a way to replace the tubes and make the amplifier work better (as it should). Additionally, she found out that to make the new tubes work properly and improve the performance of the amplifier, she would have to do something called, “bias setup.” At this point, she did not have any knowledge about how an amplifier works internally (how it amplifies the signal that comes out of the electric guitar), nor did she have any knowledge of the structure and functionality of its components (e.g., transistors, capacitors, and transformers) or what “bias setup” meant. In electrical engineering, *bias* refers to a voltage, current, or other input applied to a device or system as a reference or to set its conditions of operation. In the case of tube amplifiers, it is used to keep the input voltage constantly within the conductive region of the tubes. During her research, she also found out that this process should be done by a skilled professional with advanced knowledge of the internal components and functionality of tube amplifiers. However, she decided to try to set up the bias herself. She found a short video on the Internet where someone was showing, *step-by-step*, how to set up the bias of a similar tube amplifier. All she needed was to buy the new set of “matched” tubes and a multimeter (a device she did not know anything about). After watching the video twice and without understanding any of the technical concepts that the person in the video was using to explain the process (e.g., plate voltage, ground lead, millivolts, DC, and AC), she was finally able to correctly set up the bias of the amplifier; she appropriately set up the multimeter, connected the “red” and “black” cables inside the amplifier, and turned the calibration knob until the multimeter showed “the numbers she needed to see" according to a bias reference table. At the end, she successfully solved the problem without knowing anything about the concepts of electromagnetism or how to use a multimeter. Perhaps the only vital piece of conceptual knowledge she learned was that there are some things inside the amplifier called "capacitors" and that touching them can cause imminent death.

Going back to the questions from above, I could conclude the following: (a) Mathematics-, science-, and engineering-based knowledge was not necessary to solve the problem and make the amplifier work better, neither at the conceptual nor at the skill level (e.g., knowing how to operate the multimeter); (b) apparently, knowing the step-by-step process in the video (procedural knowledge) was sufficient to solve the problem; (c) a person with training in a different domain and no background knowledge in engineering was able to solve an electrical engineering-related problem as well as someone who has advanced conceptual knowledge of the concepts of electromagnetism.

I believe that this and other similar cases directly question whether engineering knowledge should always be necessary to solve engineering-based problems, and in this sense, the nature of engineering as a disciplinary domain is not unique. I do not claim, however, that conceptual knowledge is not important for engineering; for instance, designing and building a tube amplifier from scratch certainly demands more than following a step-by-step procedure. Rather, I argue that there could be many instances where solving an engineering-based problem only requires knowledge of specific sequences of actions that ultimately convey the existence of a contextualized construction of general heuristics and scripts that could be used to solve similar problems. In addition, I do not argue that scripts and step-by-step processes are sufficient in engineering and technology. Engineering is rather a complex and contextualized set of activities that need to be honed as much as a cellist needs to hone playing the cello. Before going any further in explaining this argument, I present a brief overview of existing models of engineering education which could be thought of as precursors of this model.

Engineering as Performance/Action

Theoretically Derived Models

Other scholars have proposed alternative views regarding engineering and engineering education. Michael Evans and his colleagues (Evans 2010; Evans and Gabriel 2007) suggested that engineering should be conceptualized as a *performance* or *performing*. Evans (2010) defined performance as doing, redoing, and showing doing. By *doing*, Evans refers to the importance of action and acting in engineering, particularly in terms of how an engineer engages in activities directed to a particular purpose. In terms of performance as *redoing,* he states that performance is "acting with an appreciation of the history of past action and of the conventions that direct current action" (Evans 2010, p. 6). In this sense, we never talk of new or original performances; engineers follow sequences of actions that have been shown to be effective and efficacious. Finally, Evans refers to *showing* *doing* as having three types of awareness: awareness of the engineer's distinctive agency, awareness that what the engineer does is redoing, and awareness of the engineer as a performer doing and redoing. Even though the model of engineering we attempt to propose here may concur with some premises of Evans' model, one critical issue in his framework needs to be carefully evaluated: Redoing implies that there are *not* new or original performances. We believe this notion of performance in engineering is problematic. For example, what happens then when an engineer engages in the solution of a new ill-structured problem that demands different sequences of action? Or what happens when an engineer engages in the solution of a known problem, but the problem is situated in a new unknown context that involves new variables? Does redoing then imply the absence of creativity in engineering practice? We believe this issue clearly contradicts one of the assumptions that Evans and his colleagues had previously formulated (Evans and Gabriel 2007). This assumption was that the nature of performance is situated and context bounded. Thus, from this position, one should also have to assume that the context is dynamic in nature, so it involves reconstruction (Bruner 2006; Miller 2011), not reproduction (or redoing). Despite this caveat, we believe Evans' model of engineering as a performance posits an interesting challenge for engineering education.

Naturalistic Models

The model proposed by Trevelyan (2010) of the University of Western Australia does however address these issues. The unifying model of engineering practice sees engineering as a social system involving a sequence of steps common to most engineering activities that are enclosed within a scaffold that continually guides the implementation steps toward the intended objectives. The scaffold in turn involves continual interaction between all the participants, including the client, financiers, engineers, contractors, suppliers, production and service delivery workers, technicians, regulators, government agencies, and local community and special interest groups.

Trevelyan's article concurs with other studies suggesting that engineering needs to be understood as a much broader human social performance than the traditional narratives that focus just on technical design and problem-solving (Johri and Olds 2011; Allie et al. 2009; Stevens et al. 2008; Zitter et al. 2016). The article by Trevelyan proposes a model of practice based on observations from all the main engineering disciplines and diverse settings in Australia and South Asia. The observations reveal that engineers tend to relegate the social aspects of their work to a peripheral status, and many critical technical aspects (e.g., design checking) are also omitted from the prevailing narratives. Therefore the foundation of engineering practice is distributed expertise enacted through social interactions between people: Engineering relies on harnessing the knowledge, expertise, and skills carried by many people, much of it being implicit and unwritten knowledge. Therefore, social interactions lie at the core of engineering practice, and therefore engineering studies need to relocate engineering studies from the curricular margins to the core of engineering teaching and research and open new ways to resolve contested issues in engineering education.

Engineering faculty who help students construct the discipline center their view of practice on problem-solving and design. An extensive study of faculty and students at several American universities (Stevens et al. 2008; Atman et al. 2010) revealed that they describe engineering practice in terms of (1) problem-solving, a systematic process that engineers use to define and resolve problems, often ill-defined ones; (2) specialized knowledge, both theoretical and contextual; and (3) the integration of process and knowledge to resolve some particular problem, involving judgment, creativity, and uncertainty.

Several aspects of engineering practice are missing or are inconspicuous in these accounts. The main finding of the analysis, though only part of the evidence has been presented here, is that we can better understand engineering practice by reframing engineering as a human social performance. We can only fully understand engineering if we understand how people think, feel, act, and interact as they perform it. Engineers use their special knowledge of materials and physical and abstract objects to work out how to rearrange them, so they can perform some required function with desirable properties, yielding economic or social benefits for people. We can describe this thinking as *technical*. Thinking is human, and we need to recognize that even technical accomplishment is limited by human capabilities. Engineering performance, as with most human performance, is time, information, and resource constrained. In engineering practice, therefore, people have to allocate time and attention to satisfy many diverse demands.

One analysis of data from interviews and observations of practicing engineers provided a description of engineering practice based on distributed expertise (Pan 2014). The description revealed that human performance and social interactions lie at the core and constrain engineering outcomes just as material properties constrain the feasible height of buildings. The description captures many aspects of engineering practice omitted from contemporary narratives that restrict *engineering* to design and problem-solving.

Improving the understanding of how people learn has close parallels with understanding the way that people interact in engineering practice. Therefore, we may be able to improve the understanding of both and also improve technical learning at the same time.

Because learning tends to be triggered by problems, problem-solving is a dominant form of learning. Nonaka (1991) theorizes that organizational learning processes are facilitated by bidirectional conversions of two types of knowledge: tacit and explicit. *Tacit knowledge* (e.g., individual skills and know-how gained through years of experience, training, and personal learning) is held by individuals and by its nature is not readily expressible. *Explicit knowledge* is “codified” in outwardly expressed forms such as product designs, procedures, manuals, and specifications. In Nonaka’s model, knowledge can be converted in four ways: tacit to tacit (socialization), tacit to explicit (externalization), explicit to explicit (combination), and explicit to tacit (internalization).

Remodeling Engineering as a Complex and Contextualized Activity

Following Dewey's view of learning and education, as well as partially Evans' model, engineering needs to be conceptualized as *doing*, and learning should be viewed as a contextualized and social experience in which students are actively engaged in all aspects (Dewey 1938). Some research programs in psychology and education have drawn from and empirically support important elements of this view of learning. Some scholars have advocated for situated perspectives of action, cognition, and learning (see Johri and Olds 2011). According to this view, learning is seen as doing (Greeno 2005). Sawyer and Greeno (2009) further asserted that the situative perspective seeks an analysis of individuals' performances and the transformation of activities rooted in complex social environments. In this sense, learning is not seen as the acquaintance of conceptual knowledge in a vacuum, but as a *contextualized action* in which the individuals acquire knowledge about how to perform in particular circumstances.

In this regard, Brown et al. (1989) pointed out that unless students develop knowledge in the context in which it is to be used, they will only gain an understanding of abstract concepts and procedures that they will not be able to use in real situations. This account of learning as a contextualized action also has its roots in sociocultural psychology theories. From a sociocultural perspective, learning could be seen as a process of reconstruction in which the individual develops repertories of culturally and socially accepted practices and ways of engaging in activities that are linked to past practices supported by a specific culture and social network (Bruner 2006). Recently, more and more cognitive scientists have come to recognize that it is essential to take into account the effects of context on thinking and action (e.g., Bruner 2006; Ferrari and Sternberg 1998).

But what is *context*? If learning (and in this particular case, engineering learning) is assumed to be a contextualized action, it seems reasonable to define what is meant by context. Alexander (1992) suggested that the meaning and boundaries of constructs such as domains and contexts are problematic, in large part, because researchers usually do not thoroughly define these constructs in their theoretical frameworks. For instance, we could refer to knowledge in particular contexts as knowledge in disciplinary domains, and disciplinary domains could be defined as a collection of fields of study. In addition, we can refer to contexts in terms of academic-related (e.g., a classroom or laboratory) and nonacademic places or situations (e.g., an interview room or office) or, in a broader sense, in terms of sociocultural environments. According to Westbury, Wilensky & Resnick (2001), it seems that many current scholars in psychology and cognitive science would agree that there are at least three fundamental types of context: the *biological* context, which basically refers to biological predispositions; the *environmental* context, which corresponds to where the individual lives and learns and the interactions that take place within his or her social environment; and the *mental/epistemological* context, also known as the *domain context*, which refers to an individual's previous knowledge and thinking. Additionally, scholars in the field of developmental psychology have proposed interesting theoretical frameworks to explain the relation between development and context. For example, Bronfenbrenner and Ceci (1994) suggested that individual adaptation is greatly determined by the interaction of personal development and both proximal (e.g., family environment) and remote contexts (e.g., sociohistorical contexts). By considering this ecological framework, we could think of learning as a contextualized action in terms of the interaction between an individual's characteristics, his or her proximal and remote contexts, and the particular sociohistorical circumstances that surround him or her.

Also, according to a sociocultural framework, the object of study should not be individual learning in a vacuum; rather, it should be what some sociocultural psychologists (such as Lev Vygotsky) have called the *individual-in-activity-in-cultural-context* (see Miller 2011). By *individual-in-activity*, we refer to the participation of the individual in culturally organized activities (e.g., studying with a group of friends in a coffee shop or listening to a lecture in the classroom). The *context* encompasses both the larger social context in which the individual is embedded and his or her immediate environment (i.e., the remote and proximal environments). Finally, we could assume Miller's (2011) definition of *culture* as "shared beliefs, values, knowledge, skills, structured relationships, ways of doing things (customs), socialization practices, and symbol systems (. . .), [which] also incorporates physical and historical influences" (pp. 172–173). Thus, to understand engineering/technology learning as a contextualized action, researchers need to account for interactions among individuals, different levels of contexts, and the cultural and historical elements surrounding those contexts. Another important aspect of a conceptualization of engineering as a contextual action has to do with the definition of *action*. Is action a mechanical procedure that an individual performs without the use of any conceptual knowledge? Or perhaps an action implies the use of tacit conceptual knowledge operating at the same time it is taking place? I am not denying, however, that engineering understood as a contextualized action does not involve conceptual knowledge. As stated before, engineering learning is a reconstruction process in which the individual interacts with others while in a specific activity in particular proximal, remote, and larger cultural contexts. In agreement with Bruner (2006), conceptual knowledge cannot be seen outside its situated context. In other words, we need to accept the "cultural situatedness" of all mental activities and actions (p. x).

Conclusions

Engineering and technology education is dominated by a model that assumes the dominance of conceptual knowledge to the detriment of seeing engineering/technology as a complex and contextualized activity system and a performance. Learning to perform (while exhibiting complex and contextualized behaviors and reacting with agility), improve, and modify processes is the core of engineering and technology work. Years of engineering education are utilized to build a conceptual base without engaging students in practice, which does a disservice in precollege as well as in university education. Regrounding engineering and technology work to its own foundation will produce better adjusted and attuned engineering and technology workers in the future. For future research, we need to particularly explore the extent of engineering/technology work, features which separate it from other complex and situated practice, how to meaningfully teach to perform and improve processes as the core of the engineering/technology education agenda, how to set up systems of instruction and learning environments for the exploration and refinement of such competencies, and the socio-cognitive and cultural contexts in which these competencies are employed.

Cross-References

► Exploring the Relationship Between Technology Education and Educational Sloyd
► Philosophy of Technology: Themes and Topics
► Problem-Based Learning in Technology Education
► Technical Vocational Education: From Dualistic to Pluralistic Thinking

References

Alexander, P. A. (1992). Domain knowledge: Evolving themes and emerging concerns. *Educational Psychology, 27*(1), 33–51. doi:10.1207/s15326985ep2701_4.

Allie, S., Armien, M. N., Burgoyne, N., Case, J. M., Collier-Reed, B. I., Craig, T. S., et al. (2009). Learning as acquiring a discursive identity through participation in a community: Improving student learning in engineering education. *European Journal of Engineering Education, 34*(4), 359–367.

Atman, C. J., Sheppard, S. D., Turns, J., Adams, R. S., Fleming, L. N., Stevens, R., Streveler, R. A., Smith, K. A., Miller, R. L., Leifer, L. J., Yasuhara, K., & Lund, D. (2010). *Enabling engineering student success: The final report for the Center for the Advancement of Engineering Education* (p. 2010). San Rafael, CA: Morgan & Claypool Publishers.

Bronfenbrenner, U., & Ceci, S. J. (1994). Nature-nurture reconceptualized in developmental perspective: A biological model. *Psychological Review, 101*(4), 568–586. doi:10.1037/0033-295X.101.4.568.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42. doi:10.3102/0013189X018001032.

Bruner, J. S. (2006). *In search of pedagogy: Volume I*. New York: Routledge.

Collins, H. M. (1985). *Changing order: Replication and induction in scientific practice*. Chicago, IL: University of Chicago Press.

de Graaff, E., & Kolmos, A. (2007). *Management of change. Implementation of problem-based and project-based learning in engineering*. Rotterdam/Taipei: Sense Publishers.

Dewey, J. (1938). *Experience and education*. New York, NY: Collier Books, Macmilian.

Du, X., & Kolmos, A. (Eds.). (2009). *Research on PBL practice in engineering education*. Boston: Sense Publishers.

Edström, K., & Kolmos, A. (2014). PBL and CDIO: complementary models for engineering education development. *European Journal of Engineering Education, 39*(5), 539–555.

Evans, J. S. B. T. (2010). *Thinking twice: Two minds in one brain*. Oxford: Oxford University Press.

Evans, R., & Gabriel, J. (2007, October 10–13). Performing engineering: How the performance metaphor for engineering can transform communications learning and teaching. *Proceedings of the 37th ASEE/IEEE Frontiers in Engineering Education Conference*, 10–13 October 2007, Milwaukee, Wisconsin.

Ferrari, M., & Sternberg, R.J. (1998). The development of mental abilities and styles. In W. Damon (Series Ed.), & D. Kuhn and R. Siegler (Vol. Eds.), *Handbook of child psychology Vol. 2*: *Cognition, perception and language* (5th ed., pp. 899–946). New York: Wiley.

Gattie, D. K., Kellam, N. N., Schramski, J. R., & Walther, J. (2011). Engineering education as a complex system. *European Journal of Engineering Education, 36*(6), 521–535. doi:10.1080/03043797.2011.622038.

Greeno, J. G. (2005). Toward the development of intellective character. In E. W. Gordon & B. L. Bridgall (Eds.), *Affirmative development: Cultivating academic ability* (pp. 17–47). Lanham, MD: Rowman & Littlefield.

Holt, J. E., Radcliffe, D. F., & Schoorl, D. (1985). Design or problem solving – A critical choice for the engineering profession. *Design Studies, 6*(2), 107–110. doi:10.1016/0142-694X(85)90020-1.

Huff, J. L., Zoltowski, C. B., & Oakes, W. C. (2016). Preparing engineers for the workplace through service learning: Perceptions of EPICS alumni. *Journal of Engineering Education, 105*(1), 43–69.

Itabashi-Campbell, R., Gluesing, J., & Perelli, S. (2012). Mindfulness and product failure management: An engineering epistemology. *International Journal of Quality & Reliability Management, 29*(6), 642–665. doi:10.1108/02656711211245647.

Johri, A., & Olds, B. M. (2011). Situated engineering learning: Bridging engineering education research and the learning sciences. *Journal of Engineering Education, 100*(1), 151–185. doi:10.1002/j.2168-9830.2011.tb00007.x.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 139–151. doi:10.1002/j.2168-9830.2006.tb00885.x.

Martin, R., Maytham, B., Case, J., & Fraser, D. (2005). Engineering graduates' perceptions of how well they were prepared for work in industry. *European Journal of Engineering Education, 30* (2), 167–180.

McNeill, N. J., Douglas, E. P., Koro-Ljungberg, M., Therriault, D. J., & Krause, I. (2016). Undergraduate students' beliefs about engineering problem solving. *Journal of Engineering Education, 105*(4), 560–584.

Meter, P. N. V., Firetto, C. M., Turns, S. R., Litzinger, T. A., Cameron, C. E., & Shaw, C. W. (2016). Improving students, conceptual reasoning by prompting cognitive operations. *Journal of Engineering Education, 105*(2), 245–277.

Meyer, J., & Land, R. (2006). *Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge*. London: Routledge.

Miller, P. H. (2011). *Theories of developmental psychology* (5th ed.). New York, NY: Worth.

Nonaka, I. (1991). The knowledge-creating company. *Harvard Business Review Press, 69*, 96–104.

Pan, R. (2014). *Engineering students' experiences and perceptions of workplace problem solving* (Order No. 3636485). Available from ProQuest Dissertations & Theses A&I. (1615400888).

Sawyer, R.K. & Greeno, J.G. (2009) Situativity and learning (pp. 347–367) in Murat Aydede & P. Robbins (eds.), *The Cambridge Handbook of Situated Cognition*. Cambridge: Cambridge University Press.

Sheppard, S., Colby, A., Macantangay, K., & Sullivan, W. (2006). What is engineering practice? International Journal of Engineering Education, *22*(3), 429–438.

Singer, S. J., & Edmondson, A.C. (2006). When learning and performance are at odds: Confronting the tension. HBS working paper no. 07-032, Harvard University.

Singer, S. J., & Edmondson, A. C. (2008). When learning and performance are at odds: Confronting the tension. In P. Kumar & P. Ramsey (Eds.), *Learning and performance matter* (pp. 33–61). Hackensack, NJ: World Scientific Books.

Splitt, F. G. (2003). The challenge to change: On realizing the new paradigm for engineering education. *Journal of Engineering Education, 92*(2), 181–187. doi:10.1002/j.2168-9830.2003.tb00756.x.

Stevens, R., O'Connor, K., Garrison, L., Jocuns, A., & Amos, D. M. (2008). Becoming an engineer: Toward a three dimensional view of engineering learning. *Journal of Engineering Education, 97*(3), 355.

Streveler, R. A., Litzinger, T. A., Miller, R. L., & Steif, P. (2008). Learning conceptual knowledge in the engineering sciences: Overview and future research directions. *Journal of Engineering Education, 98*(3), 279–294. doi:10.1002/j.2168-9830.2008.tb00979.x.

Thagard, P. (2002). *Coherence in thought and action*. Cambridge: MIT press.

Trevelyan, J. (2010). Reconstructing engineering from practice. *Engineering Studies, 2*(3), 175–195. doi:10.1080/19378629.2010.520135.

Tuncer, C. (2003). Broadening the manufacturing practitioner's education. *Manufacturing Engineering, 130*(1), 16–17.

Westbury, C., Wilensky, U., & Resnick, M. (2001). *¿Sabemos cómo se aprende?: nuevos enfoques sobre el aprendizaje*. Perú. Ministerio de Educación.

Wulf, W. A., & Fischer, G. M. C. (2002). A makeover for engineering education. *Issues in Science and Technology, 18*(9), 35–39.

Yadav, A., Subedi, D., Lundeberg, M. A., & Bunting, C. F. (2011). Problem-based learning: Influence on students' learning in an electrical engineering course. *Journal of Engineering Education, 100*(2), 253–280. doi:10.1002/j.2168-9830.2011.tb00013.x.

Zitter, I., Hoeve, A., & de Bruijn, E. (2016). A design perspective on the school-work boundary: A hybrid curriculum model. *Vocations and Learning, 9*(1), 111–131.

Teaching the Language of Technology: Toward a Research Agenda

38

Gerald van Dijk and Maaike Hajer

Abstract

At all levels of technology education, language plays an important role. This chapter combines insights from applied linguistics, the philosophy of technology, and the pedagogy of technology to explore characteristics of the specific language requirements of technology and the way in which students can be guided in the intertwined development of subject and language. More than traditional grammar, Systemic Functional Linguistics offers tools to describe the language of technology as a multimodal resource for meaning making, including textual (oral and written) and graphical modes. Elaboration of writing tasks that are closely related to "designing" and "systems thinking" reveals that language demands can only be understood from a content perspective. These demands depend on choices for pedagogy and orientations to technology education: vocational skills training could ask for writing tasks describing procedures, while orientations toward technological literacy could result in texts that discuss the impact of technologies on societies.

The chapter further outlines content and language integrated approaches and discusses their potential for teaching technology, taking into account the specific position of learning at the edge of school and workplace. What these approaches have in common is that technology and engineering teachers need knowledge about language that can be considered part of pedagogical content knowledge. The chapter concludes with a broad outline for further multidisciplinary research and development.

G. van Dijk (✉)
HU University of Applied Sciences Utrecht, Utrecht, The Netherlands
e-mail: gerald.vandijk@hu.nl

M. Hajer
HU University of Applied Sciences Utrecht, Utrecht, The Netherlands

Malmö University, Malmö, Sweden
e-mail: maaike.hajer@hu.nl

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_40

Keywords
Design • Genre • Language • Systems

Contents

Introduction

Technology is often perceived as a school subject that has relatively little to do with language (Van der Velde 2010). Kimbell and Stables (2008), however, point out that designing, which is considered core content in technology, involves interaction between mind and hand. Thinking and learning in technology, as in other school subjects, involves language. This chapter first describes general key features of the language of technology in authentic contexts and school contexts. Secondly, approaches toward integration of language development in subject pedagogies are described, and their potential for technology teaching is being discussed. Finally a research agenda is proposed.

General Characteristics of the Language of Technology

A simple sentence can be used to clarify a few characteristics of knowledge in technology and the language that is used to construct such knowledge.

> The printer must be capable of printing A4 paper.

The artifact name "printer" says something about the purpose of the artifact, its functional nature. "A4" refers to a norm that has been collectively decided upon in the paper industry for reasons of efficiency (Vaesen 2013). Furthermore the description is only valid for this particular instance, where a printer needs to be designed for a specific context. In more general terms, this sentence represents knowledge in technology that is descriptive, normative, part of collective decision-making, and context dependent, rather than aiming for universal truths, which are all characteristics of knowledge in technology (Meijers and Kroes 2013). Rossouw et al. (2011) conducted a Delphi study and identified "design" as one of the core concepts in technology, along with systems, modeling, resources, and values. If this is indeed basic to technology's conceptual framework, then the language of technology should reflect this framework. This will be illustrated later in this chapter for "designing" and for "systems."

A fundamental question, which is addressed by philosophers of technology, is whether all knowledge in technology can be expressed in language. Arguably, "knowing how" can be seen as a kind of "knowing" that cannot be expressed in words, unlike "knowing that" (Ryle 1949). Ryle argues that the kind of "knowing" that is involved in tying a complex knot (p. 56) is nonpropositional, as it cannot fully and certainly not effectively be explained in words alone. Whether this assertion is true or not, it serves as a warning that language should not be foregrounded in all instances of learning in technology, even though "knowing how" and "knowing that" are often developed simultaneously (Norström 2014).

Language is not necessarily limited to verbal, written language. Linguists (Kress et al. 2001) and researchers in technology education (Banks and Barlex 2014; Kimbell and Stables 2008; Middleton 2013) would agree that the language of technology is multimodal in the sense that it includes graphic representations as a mode. Ferguson (1994) asserts that engineering heavily depends on nonverbal understanding and that graphic representations are equally, if not more important than text. In an example about the design of a "liquid level controller" for oil wells, Ferguson explains how parts working together realize the controlling function of the system. He uses a cross-sectional diagram and 106 words with numerical references to the diagram (Ferguson 1994, p. 33). Clearly a combination of text and graphic modes is needed to explain how the system works.

Another important mode is oral language, for instance, in face-to-face meetings between designers discussing qualities of a design (Allan 2013). Boundaries between different modes of communication are increasingly blurred as a result of the advent of new communication technologies (Lemke 2006), but for the purpose of this chapter, we distinguish between oral and written modes, the latter including graphic modes. In the next section, fundamentals of linguistics are used to present a more precise description of language demands inherent in technology education.

Linguistics and Subject-Specific Language

Often terminology is regarded as emblematic for the language of a subject (Phillips and Norris 2009). But there is more to language in technology than isolated technological words that denote tools, components, materials, or concepts. Traditionally, linguists distinguish between levels in language systems as phonology (sounds), morphology (word forms), syntax (sentence structure), and text structure. Semantics describes how meaning is expressed by using these grammatical elements. From the 1970s, the focus on language structure was criticized by linguists, who argued that communicative competence includes not only grammatical knowledge but also knowledge about how language systems are used in social contexts (De Oliveira and Schleppegrell 2015; Leung 2005). From this period, sociolinguistics studied the interplay between language use and its functions in educational, professional, and other contexts, often with regard to social class and power relations.

The attention to specific characteristics of subject-specific registers, as of technology and engineering, has been pushed by a need for professional language courses for adult professionals entering the English-speaking world. A different branch of applied linguistics, “English for Specific Purposes” (*ESP*) focuses on “needs of learners and analyses language demands in terms of grammar, lexis, register, study skills, discourse and genre” (Dudley-Evans and St-John 1998, p. 4). ESP-oriented research, for instance, yielded an analysis of communicative events that engineers face in high-tech industry (Spence and Liu 2013) and an analysis of how engineering students express affect and agency in their writing (Archer 2008).

A theory of language, less dominant than traditional grammar, is Systemic Functional Linguistics (*SFL*). It integrates language forms and meaning making with social contexts. SFL does so by starting from the functions or purposes for which people interact in different types of oral and written texts, called “genres” (Halliday 2004). Examples of genres include descriptions, narratives, explanations, and instructions. The way meaning is created is analyzed from three angles. First, “field” denotes what language in context is about. Second, “tenor” expresses how roles and relationships between writer or speaker and reader or listener shape the text. Third, “mode” describes choices for oral, written, or graphic representations and text coherence. SFL-based analyses have shown to be relevant for studying language in professional school contexts where specific genres can occur such as an instruction to make a kite (Derewianka 1990). Such instructional texts are described in terms of text organization, types of verbs and tense, “linking words,” and examples where such instructions are used (Rose and Martin 2012). SFL offers tools to grasp the specific characteristics in a more functional way, because of its focus on language use as a social practice. However, no comprehensive SFL-based studies in the field of technology have been found so far.

Language Demands in Technology Education

We need to distinguish language inherent in knowledge in technology from language demands in technology education. Orientations to technology education vary greatly (Norström 2014), and these orientations influence language demands. If vocational skills training is the primary orientation, writing tasks may primarily target describing procedures and relevant applications of the skill in particular situations as well as students’ insight into their own progress in mastering the skill. The latter would require the students to be able to write reflective texts in a highly personalized voice, most likely using the first-person singular form. Another orientation would be toward technological literacy (ITEA 2007) and could result in tasks involving discussing the impact of technologies on societies like reading texts on the use of drones by journalists.

Furthermore, technology education is a practice of its own, which comes with discourses and language demands reflecting educational as well as authentic technological practice. For writing in science, Hand and Prain (2012) distinguish in a review study between the genre perspective and the *writing to learn* perspective (p. 1376). In genre pedagogy, an induction perspective is emphasized, whereby students read, analyze, and produce authentic texts grounded in the sociocultural practices of the discipline. By doing so, they are enculturated, and at the same time, the language patterns in these prototypical texts serve as a model to organize thought in a disciplinary way. The "writing to learn" perspective results in writing diverse text types that do not necessarily resemble disciplinary genres. Drawing on research into effective conditions for learning, Hand and Prain (2012) state that "students need to write in diverse ways for different readerships to clarify understanding for themselves and others" (p. 1375). Distinguishing between these perspectives provides clarity for researchers and teachers, but in teaching, they may appear combined. The same distinction can be made for oral genres. Students in technology education are not only enculturated in ways of talking that are intrinsic to authentic practices. They are also expected to participate in pedagogic discourse unique to schools, such as exchanges between students and the teacher about a design problem, a discourse with its own linguistic demands (Christie 1998).

In spite of the acknowledgement of the importance of language in technology education, no linguistic analyses were found of language demands in specific content domains of technology. For the concept of "systems," for instance, Klasander (2010) mentions the existence of ontological, epistemological, environmental, and control language, but his work does not extend to linguistic analysis at the level of whole texts, paragraphs, sentences, and words. The same holds for "designing" (Kimbell and Stables 2008; Barlex 2007). These two core concepts (Rossouw et al. 2011), designing and systems, will now be used to illustrate how pedagogy of technology and linguistics can be used in combination, to achieve a better understanding of language development in technology education.

Designing

Kimbell and Stables (2008) developed models for design portfolios as a means to promote and assess "designerly thinking." The questions that students answer in their portfolios stimulate the interaction between mind and hands. Students are, for instance, required to explain how their design could be improved to cater for specific needs of potential users. As such, these portfolios fit the above-described "writing to learn" perspective. This approach to writing in design education has indeed proven to foster "designerly thinking" (Kimbell and Stables 2008). However, such portfolios can be seen as pedagogic genres, resembling professional designers' texts only to a limited extent. A student's entry in his digital design portfolio illustrates this point: "First thing tomorrow I will get my model out and then get some tubing [. . .]" (Kimbell and Stables 2008, p. 132). The student uses a highly personal voice (tenor), which is functional given the objectives behind the portfolio as mentioned above but which is not appropriate in, for instance, an architect's portfolio, meant to inform potential clients. Text organization in a student's design portfolio that forefronts the learning process will also be different from text organization in a professional design portfolio.

Barlex (2007) argues for "cultural authenticity" in design texts and for a "minimally invasive approach," in which writing tasks do not unnecessarily interrupt the design process. Culturally authentic components of a design portfolio can be a "job bag" and a product description. A job bag is a loose collection of sketches, photos, and notes that the student finds useful to retrieve ideas during later design activities. A product description could take the shape of a folder for an audience of potential customers for the product, in which the writer would be less visible than in Kimbell and Stable's design portfolio. To assess "designerly thinking," without interfering with the design process too strongly, Barlex suggests that writing tasks include short justifications of a few design decisions. A justification can be seen as an argumentation, which is a genre that has been explored extensively by linguists (Rose and Martin 2012).

"Systems"

Development of students' thinking in terms of "systems" can be promoted by setting a task that results in a product that includes graphic representations and text, for instance, about an electrical system in the house. The product will typically include a description of the function of the system, a description of its components, an explanation of the way the components work together to achieve the function (Norström 2014; Svensson and Ingerman 2010), and a reference to system boundaries (Klasander 2010). A part of the explanation could deal with maximum power load: "If more apparatus are switched on, the current adds up, because it is a parallel circuit." The word "because" is a "cohesive device" to mark cause-and-effect relations as part of the explanation (Rose and Martin 2012). It is also noteworthy that this student may have understood that the personal pronoun "I" would not be functional in this particular explanation. The explanation uses scientific theory, which is supposed to be objectified, universal, and therefore written in an authoritative rather than a personal tone (Rose and Martin 2012). Another feature of the explanation is the use of specialized vocabulary, such as "current" and "parallel circuit." Depending on the educational context, students need to understand and produce specialized technology vocabulary, even though the bandwidth for the correct use of concepts is sometimes larger in technology than in science as a result of technology's aim for usefulness rather than for universal truths (Norström 2014).

So far we have used core content in technology education, designing, and systems, to give examples of language demands. Similarly, language demands associated with other core concepts, modeling, resources, and values (Rossouw et al. 2011) could be distinguished. Such analyses contribute to formulating specific language objectives as part of a language and content integrated approach in technology education. The question now arises how technology teachers can plan and support student development of the language of technology.

Planning for Subject-Specific Language Development

Integration of language development in content areas has its roots in the education of second-language learners. Cummins (1979) related second-language learners' school success to their command of "Cognitive Academic Language Proficiency" (*CALP*) that is to be distinguished from "Basic Interpersonal Communication Skills" (*BICS*). This distinction is still used (Leung 2014), though it is characterized more as a continuum than as a dichotomy (Gibbons 2009). Table 1 lists and illustrates the differences between BICS and CALP.

The development of CALP would require a prolonged period of guidance and careful instruction. Different organizational models addressed the question where this guidance could best be located. The "content-based approach" of language learning (Brinton et al. 1989) regards content of school subjects as a starting point for program development for intermediate and advanced second-language learners. Language and content teachers play different roles in these models, from which "sheltered instruction" is of specific interest for this chapter. Here, content teachers prepare their lessons by explicitly formulating language objectives, using a range of specific instruction techniques to deliver content (Echevarria et al. 2013).

Table 1 BICS and CALP

	Characteristics (Cummins 1979; Leung 2014)	Example (Gibbons 2002)
BICS	Meaning is familiar within context	*We tried a pin . . . a pencil sharpener . . . some iron filings and a piece of plastic . . . the magnet didn't stick to the pin*
	Immediate situation at hand provides cues for meaning	
	Familiar forms of language, more oral-like	
	High-frequency words	
CALP	Nonroutine meaning expressed through language, without cues from immediate situation	*A magnet is an object that produces a magnetic field. This magnetic field is responsible for the force that pulls on other magnetic materials, such as iron, and attracts or repels other magnets*
	Unfamiliar forms of language	
	Low-frequency words	
	Complex syntax, more written-like	
	Abstract expressions that are not common in everyday conversation	
	Understanding and producing CALP is associated with academic progress	

Second-language acquisition theory accounts for the main headings of sheltered instruction teaching strategies: providing comprehensible input, opportunities for oral and written language production in classroom interaction, and provision of feedback. Examples of sheltered instruction, specifically for technology education, have been described by Van Dijk (2011). A considerable body of literature on science education argues for such an integration of language and content pedagogies (Wellington and Osborne 2001); some studies demonstrate their effectiveness (Hand and Prain 2012). Practical examples can also be found within the context of Content and Language Integrated Learning (*CLIL*) in foreign language programs. Students can be offered writing frames as prestructured outlines for their lab reports; they are offered explicit activities on science vocabulary or reading strategies to focus their attention while reading for meaning in science schoolbook texts (Vollmer 2006).

Gibbons' (2009) "high challenge-high support" approach can be placed in this family of content and language integrated approaches. Gibbons shows how teachers in subject areas can plan scaffolding language learners from oral, contextualized language through oral academic tasks into the written academic language along a mode continuum. Another approach is SFL-based genre pedagogy (Bawarshi and Reiff 2010; Rose and Martin 2012) in which teachers take a steering role in explicitly teaching the language of text types. In a teaching-learning cycle, introducing new subject knowledge to the group is followed by explicit deconstruction of texts and explication of language features. A phase of joint construction, led by the teacher, is followed by independent writing. Thematic content receives attention throughout the process, at times specifically focusing content representation in texts using SFL-based analytic tools.

These approaches have in common that subject teachers need knowledge about language (*KAL*) (Love 2009). Van Dijk et al. (2016) found that giving specific feedback on students' use of language in science and technology requires KAL to be relevant from the perspective of the content, viable, and complete enough to aid teaching in specific areas of the subject. KAL in this sense is seen as part of pedagogical content knowledge (Shulman 1986).

A Language-Sensitive Pedagogy of Technology

In this section, the potentials of content and language integrated teaching for technology are elaborated upon. This will lead to an outline for future research in this field. The paragraph structure follows Hajer and Meestringa's (2015) content and language integrated approach, which centers around "integration of content and language objectives," use of context, interaction, and high support in understanding and producing the language of a school subject.

Content and Language Learning Objectives

In order to plan for students' learning, teachers need to be able to distinguish language as part of their learning objectives. These explicit language objectives can be shared with students, at a level that is comprehensible and meaningful for them, in order to make them aware of what is expected in terms of language comprehension and use and integrate these objectives in the evaluation of students' learning.

The Role of Context

The meaning of words depends on context. Reference to contexts can aid understanding, successful use of technology concepts, and the transition from BICS to CALP. An additional and more sociocultural perspective on context takes account of the situation and the culture in which whole texts are used (Gilbert 2006; Rose and Martin 2012). Examples from authentic discourse practices can be used to illustrate how the context shapes a text. Information about solar panels is, for instance, presented differently in a folder aimed at consumers as compared to a textbook. Using authentic texts, both oral and written, from daily life and from vocations and elaborating on the way the context shapes the text make working with texts more meaningful (Allan 2013; Rose and Martin 2012).

Promoting Interaction and Language Production

Technology education is rich in opportunities for interaction that promote language development, both between the students and the teacher and between the students themselves. Interaction is inherent in design activities that are often collaborative in nature, both in authentic practice (Meijers and Kroes 2013) and in schools (Fox-Turnbull 2016). In her chapter in this volume, Fox-Turnbull highlights the role of intercognitive conversation plays in technology education. However, this does not automatically result in pedagogy that fosters language proficiency (Damhuis and De Blauw 2011). Planning for challenging and scaffolded interaction, in which students are stimulated to use disciplinary language, is a core feature in different content and language integrated approaches.

In paragraph "Language Demands in Technology Education," examples of writing tasks in technology education have been given. However, the learning environment is not always suitable for writing, and students may be apprehensive to write, because they perceive technology as a practical subject. For reasons we have outlined above, this perception is not entirely conducive to learning, even though we acknowledge the vital role of practical work. Students' awareness of the potential of writing for learning, aimed at conceptual understanding or at producing disciplinary genres, is required to broaden the focus on more than just superficial aspects of writing (Ellis et al. 2006). This calls for the teacher to share pedagogic motives behind writing (and drawing) tasks.

The Need for High Support

Gibbons (2009) offers a range of teaching strategies, which scaffold students' oral and written language use toward an academic, subject-specific language. "Writing frames" (Lewis and Wray 1998), for instance, provide a skeleton of a text and thereby scaffolding texts organization and sentence construction. Such support may, for instance, target the students' ability to produce specialized forms of reasoning in technology. If, for instance, learning objectives include the ability to justify a design decision (Barlex 2007; Kimbell and Stables 2008), a simple writing frame could take the shape: *I decided to use . . . against corrosion, because . . .*

Mastering specialized vocabulary can be supported by the use of diagrams and schemes, such as graphic organizers and concept maps, showing how concepts in technology are related. The provision of explicit feedback on language is another central form of support in content and language integrated approaches. In order to become proficient in the language of technology, students furthermore need to be exposed to high-quality examples of this language (Rose and Martin 2012). Textbooks and digital sources offer examples of multimodal technology language that can be deconstructed in class. Research in science education, however, warns us that textbooks do not necessarily model language as it is used in authentic practice. Textbooks in science need to explain content with students as an audience, which results in a genre that has limited resemblance with authentic genres. This problem might exist in technology education too. If so, textbooks need to be developed to include model texts. Alternatively, teachers can complement textbooks with (adapted) primary literature (Phillips and Norris 2009), such as a professional product description, or a justification for a design decision. Such texts can then be made accessible for students, by giving language support, and serve as model texts.

Challenges for Vocational Education

Vocational and engineering education has its own challenges with regard to a language-sensitive pedagogy of technology. Learning does not only take place in school but also at the workplace, which to some extent coincides with the theory-practice divide (Kilbrink 2013). Institutional boundaries create challenges for learning but also a learning potential (Akkerman and Bakker 2011). Collaboration between teachers and workplace coaches is needed in the area of the student's language development, aiming for a common understanding of the level of domain-specific language proficiency that is needed at the workplace. Collaboration is also useful for the construction and use of learning materials that can function as boundary objects (Akkerman and Bakker 2011) between these institutional contexts. An example of a boundary object is an internship report. Both teachers and coaches at the workplace can clarify what language is expected, in terms of general language characteristics as spelling and grammar but also in terms of specialized technology language. Again, in this collaborative effort, a focus can be used on text organization that is purposeful for sections of the text, multimodality, specialized vocabulary, and a functional tenor.

Further Research

In this chapter, a brief characterization has been given of the language of technology and a content and language integrated pedagogy of technology. Collaboration between researchers from applied linguistics, researchers in the pedagogy of technology, and teachers is required to uncover more systematically what is special and vital about oral and written language of technology. From such insights, curriculum design studies can show how students can learn to master both language and subject at different stages of education, with respect to different orientations such as vocational education, design education, and technological literacy. Such studies could also focus on the way the language of technology is modeled in curricula, by the teacher, or through multimodal teaching resources.

Multidisciplinary collaboration can also generate examples of interventions that are content specific and that help students to master the language of technology. Research should also address teacher development on this specific theme and study how teachers can learn to apply such pedagogy, both in initial teacher education programs and through professional development programs. Given the complexity of the matter, programs are only likely to be successful if they span a prolonged period of time and if the level of knowledge about language needed is relevant and viable for content teachers (Holmberg 2009).

This chapter aimed to contribute to the identification of a research agenda that takes the intricate relationship between technology and language into account and that aids the development of a language-sensitive pedagogy of technology. Increasingly diverse student populations, as well as calls for twenty-first century skills, that can be seen as a combination of literacies indicate the urgency of this research agenda in the foreseeable future.

References

Akkerman, S., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research, 81*(2), 132–169.

Allan, E. G. (2013). Multimodal rhetorics in the disciplines: Available means of persuasion in an undergraduate architecture studio. *Across the Disciplines*, *10*(2). Retrieved 21 Mar 2017, from http://wac.colostate.edu/atd/articles/allan2013.cfm.

Archer, A. (2008). 'The place is suffering': Enabling dialogue between students' discourses and academic literacy conventions in engineering. *English for Specific Purposes, 27*(3), 255–266.

Banks, F., & Barlex, D. (2014). *Teaching STEM in the secondary school: Helping teachers meet the challenge*. London: Routledge.

Barlex, D. (2007). Assessing capability in design & technology: The case for a minimally invasive approach. *Design and Technology Education: An International Journal, 12*(2), 49–56.

Bawarshi, A. S., & Reiff, M. J. (2010). *Genre: An introduction to history, theory, research and pedagogy*. Indiana: Parlor Press.

Brinton, D. M., Snow, M. A., & Wesche, M. B. (1989). *Content-based second language instruction*. Boston: Heinle & Heinle Publishers.

Christie, F. (1998). Science and apprenticeship, the pedagogic discourse. In J. Martin & R. Veel (Eds.), *Reading science: Critical and functional perspectives on discourses of science*. London: Routledge.

Cummins, J. (1979). Cognitive/academic language proficiency, linguistic interdependence, the optimum age question and some other matters. *Working Papers on Bilingualism, 19*, 121–129.

Damhuis, R., & De Blauw, A. (2011). High quality interaction in science and technology education. In M. De Vries, H. Van Keulen, S. Peters, & J. Walma van der Molen (Eds.), *Professional development for primary teachers in science and technology* (pp. 199–215). Rotterdam: Sense.

De Oliveira, L., & Schleppegrell, M. (2015). *Focus on grammar and meaning*. Oxford: Oxford University Press.

Derewianka, B. (1990). *Exploring how texts work*. Newtown: Primary English Teaching Association.

Dudley-Evans, T., & St-John, M. J. (1998). *Developments in English for specific purposes: A multi-disciplinary approach*. Cambridge, UK: Cambridge University Press.

Echevarria, J., Vogt, M. E., & Short, D. (2013). *Making content comprehensible for English learners: The SIOP model* (4th ed.). Boston: Allyn & Bacon.

Ellis, R., Taylor, C., & Drury, H. (2006). University student conceptions of learning science through writing. *Australian Journal of Education, 50*(1), 6–28.

Ferguson, E. S. (1994). *Engineering and the mind's eye*. Cambridge, MA: MIT Press.

Fox-Turnbull, W. (2016). The nature of primary students' conversation in technology education. *International Journal of Technology and Design Education, 26*(1), 21–41.

Gibbons, P. (2002). *Scaffolding language, scaffolding learning. Teaching second language learners in the mainstream classroom*. Portsmouth: Heinemann.

Gibbons, P. (2009). *English learners, academic literacy, and thinking: Learning in the challenge zone*. Portsmouth: Heinemann.

Gilbert, J. K. (2006). On the nature of 'context' in chemical education. *International Journal of Science Education, 28*(9), 957–976.

Hajer, M., & Meestringa, T. (2015). *Handboek taalgericht vakonderwijs*. Coutinho: Bussum.

Halliday, M. A. K. (Ed.). (2004). *The language of science*. London: Continuum.

Hand, B., & Prain, V. (2012). Writing as a learning tool in science: Lessons learnt and future agendas. In B. J. Fraser, K. G. Tobin, & M. R. CJ (Eds.), *Second international handbook of science education* (pp. 1375–1384). New York: Springer.

Holmberg, P. (2009). *Tid att lära genre. Utvärdering av "Språket i skolans ämnen och skolans ämnen i språket"*. Malmö: Resurscentrum för Mångfaldens Skola.

ITEA. (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed.). Reston: International Technology Education Association.

Kilbrink, N. (2013). Transfer of learning through integration of theory and practice in technical vocational education. In H. E. Middleton & L. K. J. Baartman (Eds.), *Transfer, transitions and transformations of learning* (pp. 69–84). Rotterdam: Sense.

Kimbell, R., & Stables, K. (2008). *Researching design learning: Issues and findings from two decades of research and development*. Dordrecht: Springer.

Klasander, C. (2010). *Talet om tekniska system: Förväntningar, traditioner och skolverkligheter*. Linköping: Linköpings Universität.

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: The rhetorics of the science classroom* (p. 223). London: Bloomsbury.

Lemke, J. (2006). Towards critical multimedia literacy: Technology, research, and politics. In M. McKenna, D. Reinking, L. Labbo, & R. Kieffer (Eds.), *International handbook of literacy & technology* (2nd ed., pp. 3–14). Mahwah: Erlbaum.

Leung, C. (2005). Convivial communication: Recontextualizing communicative competence. *International Journal of Applied Linguistics, 15*(2), 119–144.

Leung, C. (2014). Researching language and communication in schooling. *Linguistics and Education, 26*, 136–144.

Lewis, M., & Wray, D. (1998). *Writing across the curriculum: Frames to support learning*. Reading: Reading and Language Information Centre, University of Reading.

Love, K. (2009). Literacy pedagogical content knowledge in secondary teacher education: Reflecting on oral language and learning across the disciplines. *Language and Education, 23* (6), 541–560.
Meijers, A. W. M., & Kroes, P. A. (2013). Extending the scope of the theory of knowledge. In M. J. De Vries, S. O. Hansson, & M. AWM (Eds.), *Norms in technology* (pp. 15–34). Dordrecht: Springer.
Middleton, H. E. (2013). Representation in the transition from novice to expert architect. In H. E. Middleton & B. LKJ (Eds.), *Transfer, transitions and transformations of learning* (pp. 109–122). Rotterdam: Sense Publishers.
Norström, P. (2014). How technology teachers understand technological knowledge. *International Journal of Technology and Design Education, 24*(1), 19–38.
Phillips, L., & Norris, S. (2009). Bridging the gap between the language of science and the language of school science through the use of adapted primary literature. *Research in Science Education, 39*(3), 313–319.
Rose, D., & Martin, J. R. (2012). *Learning to write, reading to learn: Genre, knowledge and pedagogy in the Sydney school*. Bristol: Equinox.
Rossouw, A., Hacker, M., & De Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–424.
Ryle, G. (1949). *The concept of mind*. New York: Hutchinson's University Library.
Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.
Spence, P., & Liu, G. (2013). Engineering English and the high-tech industry: A case study of an English needs analysis of process integration engineers at a semiconductor manufacturing company in Taiwan. *English for Specific Purposes, 32*(2), 97–109.
Svensson, M., & Ingerman, A. (2010). Discerning technological systems related to everyday objects: Mapping the variation in pupils' experience. *International Journal of Technology and Design Education, 20*(3), 255–275.
Vaesen, K. (2013). Artefactual norms. In M. J. De Vries, S. O. Hansson, & A. W. M. Meijers (Eds.), *Norms in technology* (pp. 119–136). Dordrecht: Springer.
Van der Velde, D. (2010). Co-development of language and technological literacy. In M. J. de Vries (Ed.), *Positioning technology education in the curriculum* (pp. 180–188). Rotterdam: Sense Publishers.
Van Dijk, G. (2011). Learning language, learning technology. In M. J. de Vries (Ed.), *Positioning technology education in the curriculum* (pp. 165–178). Rotterdam: Sense Publishers.
Van Dijk, G., & Hajer, M. (2016). Specifying knowledge about genres for science teachers: An inventory for practical report writing developed in science teacher training, Orlando: American Association for Applied Linguistics (AAAL).
Vollmer, H.J. (2006). Language across the curriculum. Presented at an intergovernmental conference on languages of schooling: Towards a framework for Europe. Strasbourg: Council of Europe.
Wellington, J., & Osborne, J. (2001). *Language and literature in science education*. Buckingham: Open University Press.

Classroom Interaction in Technology Education

39

Classroom Talk in Technology Education

Wendy Fox-Turnbull

Abstract

This chapter explores classroom interaction in technology education, particularly interactions between students subsequently referred to as inter-student conversation. In authentic technological practice, working collaboratively in teams on the development of products or systems (technological outcome) is common practice, yet frequently in senior secondary schools, students work on individual projects, possibly with the help of a mentor. The summative assessment process is sometimes blamed for this; however, it is critical to encourage all our students to work collaboratively and cooperatively in technology. A vital part of working collaboratively is the ability to talk about and explore possibilities through conversation. This chapter explores the place and nature of conversation in learning technology and suggests the facilitation of inter-student intercognitive conversation as a powerful tool for advancing learning and collaborative practice in technology education.

Keywords

Intercognitive classroom talk • Twenty-first-century learning • Learning power • Funds of knowledge • Context-free learning intentions

Contents

W. Fox-Turnbull (✉)
School of Sciences and Physical Education, University of Canterbury, Christchurch, New Zealand
e-mail: wendy.fox-turnbull@canterbury.ac.nz

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_41

Introduction

This chapter presents a case for teaching students to talk about their thinking and understanding as an integral part of their learning in technology. Recent changes in education promote talk as an effective tool to assist students. This is particularly so in technology given the collaborative nature of technology practice and the inherently social nature of living in the information age, "Technology education offers rich contexts for study, social construction of outcomes, connections cooperation and collaboration" Snape and Fox-Turnbull (2011). Claxton et al. (2013) suggest "building learning power" through active learning which encourages student' ownership of and voice in their own learning. This approach is very much in-line with what has been referred to as "twenty-first-century learning" by Bellanca and Brandt (2010) and Brears et al. (2011) among others.

Alexander (2008) suggests that teachers need to "provide and promote the right kind of talk" (p. 10) in classrooms to ensure that students learn more effectively and efficiently. Mercer and Littleton (2007) discuss a pedagogical approach *Thinking Together* based on "interthinking" which teaches students to use language to think and learn together. Thinking collectively is activity in which knowledge and understanding are reached through conflict, debate, and cooperation. Oral conversation (talk) is a vital component of these processes.

In authentic technological practice, working collaboratively and cooperatively on the development of technological outcomes is common. A vital component of working collaboratively is the ability to explore possibilities through talk. Advancing students' skills, abilities, and understanding about the nature and role talk has on learning enables students to challenge, explain, and question their own and other's thinking, thus advancing their knowledge, understanding, and abilities. In short students can and do learn through talking; however, not all types of classroom talk advance learning.

This chapter focuses on why talk is important and how students can be assisted to develop skills associated with using talk to learn. Understanding the place and value of literally giving students a voice in learning through developing the ability to talk to other students about their own and others' learning, referred to in this chapter as inter-student talk as opposed to teacher-student talk, is vital for preparing students as potential developers, users, and consumers of technology in the decades to come.

Learning for the Current Century

Bellanca and Brandt (2010) suggest that teachers in the twenty-first century face a daunting challenge of equipping students with skills and knowledge necessary to survive in the information age. New knowledge and skills are needed to enable students' success in becoming lifelong learners in the twenty-first century (Gilbert 2005). Skills supporting innovation, creativity, critical thinking, and problem solving are needed to fulfill the expectations of the new economy (Bellanca and Brandt 2010). Current thinking suggests that it is essential for students to understand the nature of learning including skills, content, processes, values, and competencies to expand their learning capacity. Learning therefore needs to be made explicit. Identifying and sharing clear "learning intentions" to students will sharpen their learning focus and separate the importance of the learning from the context or activity undertaken (Clarke 2014).

Building Learning Power

Claxton et al. (2013) discuss the building of learning power within students through the development of dispositions and attitudes including the building of students' confidence and self-belief in their capabilities. Wagner (2008) and Claxton (2007, p. 117) advocate specific dispositions or capabilities necessary to be effective learners in the twenty-first century. These include engaging in or demonstrating:

- Critical thinking and problem solving, being skeptical and analytical
- Collaboration, learning by influence and also independently
- Agility, adaptability, open-mindedness, flexibility, and creativity
- Reflective, thoughtful, and self-evaluative thinking
- Methodical methods of working
- Resilience, determination, and focus
- Initiative and entrepreneurialism
- Effective oral and written communication
- Accessing and analyzing information
- Curiosity, creativity, and imagination, being adventurous and questioning
- Motivation to build on their products and performances

Claxton (2007) suggests it is essential that a classroom climate is established that will encourage and foster these dispositions or capabilities. He describes this climate as a culture where "students' questions are welcomed, discussed and refined, so the disposition to question becomes stronger, more and more robust; broader, more and more evident across different domains; and deeper, more and more flexible and sophisticated" (p. 120). Inter-student talk is a significant component of many of the above dispositions. For example, it is a vital component of effective oral communication in the transfer of thinking and collaboration. Demonstrating open-mindedness, flexibility, and creativity is also assisted through talk. Reflective and evaluative thinking can also be demonstrated orally and for some students much easier and more effective than when written.

To this end Claxton (2007) suggests that schools and classrooms need to change so that students' capacity for learning is more robust, broad, skilled, and flexible. Summarized below are the eight themes he advocates necessary for change:

1. Language – teachers need to encourage students to think and talk about their learning processes. Conversations require collaborative discussion and reflective thinking.
2. Potentiating activities – student engagement needs to develop a sense of challenge where thinking is hard and frustration or confusion may result.
3. Split-screen thinking – looking to extend students' grasp of content, teachers need to be considering how they challenge students' capacity to learn.
4. Wild topics – topics selected as contexts for learning need to be meaningful, real, relevant, and rich. Students will be challenged through taking greater responsibility and control over their learning and processes. These topics will raise high-quality questions and require substantive discussion and inquiry.
5. Transparency and involvement – students should be encouraged to be part of the change process, understand their role in the change process, and appreciate knowledge creating that is happening
6. Transfer thinking – students should be assisted to see how learning can be transferred to wider real-life contexts in order to better understand their world beyond the school.
7. Progression – learning must be scaffolded to develop understanding in a progressive way, building on previous learning and allowing for students to realize why rather than just be told how to complete a task.
8. Modeling – students need to see learning by seeing the capacity to learn modeled by those around them. Modeling enables students to experience and share learning in a cooperative way with a variety of others such as an expert, mentor, co-learner, or teacher.

Talking about learning is identified as a significant aspect of the themes above and in learning methods. It plays a significant role in the changes Claxton (2007) deems necessary for future learning. For example, talk is a significant and obvious aspect of the transfer thinking and modeling themes. Talk is also explicitly mentioned in the language theme and is an essential part of each of the remaining themes.

The Power of Talk

In ► Chap. 38, "Teaching the Language of Technology: Toward a Research Agenda," van Dijk and Hajer promote interaction as critical to the learning process. Oral interaction or talk is a vital component of interaction and a valuable tool for learning (Alexander 2008; Clarke 2014; Hiltunen et al. 2016; Mercer and Littleton 2007; Shields and Edwards 2005). "Language enters life through concrete utterances, and life enters language through concrete utterances as well" (Bakhtin 1981, cited in Gergen 2000, p. 167). Talk between people is a central aspect of cognitive, social, and cultural development (Burr 1995). When referring to talk in this chapter, we refer not to the managerial or social talk common in classrooms but rather talk that can be thought of as oral dialogue because it involves the relating to others. Oral dialogue or effective quality talk requires real engagement with people (Mercer and

Littleton 2007; Shields and Edwards 2005) and is “the discussion that takes place during the course of education activities” (Mercer and Littleton 2007, p. 1).

The place of talk in learning is considerably more important than has been demonstrated in schools in the past. “A sociocultural perspective raises the possibility that educational success and failure may be explained by the quality of educational dialogue, rather than simply by considering the capability of individual students or the skill of their teachers” (Mercer and Littleton 2007, p. 4). When people work together in problem-solving situations, they do much more than just talk together; they “inter-think” (Mercer and Littleton 2007, p. 57) by combining shared understanding, combining their intellects in creative ways often reaching outcomes that are well above the capability of each individual. Problem-solving situations involve a dynamic engagement of ideas with talk as the principle means used to establish a shared understanding, testing solutions and reaching agreement or compromise. Talk that involves thinking together is an important part of life and learning that has long been ignored or actively discouraged in schools (Mercer and Littleton 2007). Molinari and Mameli (2013) in their study of classroom discourse state that lessons that were “open” and “flexible” allowing students space to explore through talk by the sharing of relevant knowledge, challenging of ideas, evaluating evidence, and considering opinions of others while trying to reach agreement in an “equitable manner” (2013, p. 256) proved to be more effective than the more traditional closed lessons in which teachers engage students in a series of questions which they are required to answer with teacher’s predetermined responses. Furthermore talk is particularly relevant and valuable in technological practice as designers typically work collaboratively; therefore, “designerly talk” is a natural part of authentic technological practice.

Effective Classroom Talk

It is argued that teachers need to engage in quality classroom talk with students to help them make sense both cognitively and experientially of the world in which they live and work (Clarke 2014; Mercer and Littleton 2007; Shields and Edwards 2005). Engaging in this type of talk involves trust and some degree of relationship between the people involved. It cannot happen if one person treats the other person as an object, but requires people to be treated with “absolute regard” (Sharrat 1991, cited in Shields and Edwards 2005). Mercer and Dawes (2008) suggest that talk in education is either symmetrical or asymmetrical. Scott (2008) suggests classroom talk can be interactive or noninteractive.

Noninteractive or asymmetrical talk is described as the talk between teachers and students where one person takes the lead or has the power. Scott (2008) suggests this person is usually the teacher; however, it could also be a student as within groups when one student dominates conversation and decision making; thus, noninteractive talk is possible within groups of students as well as within teacher-student talk. Hiltunen et al. (2016) note that asymmetrical talk is common in classrooms and frequently typifies teacher – whole class interaction. Mercer and Dawes (2008) also suggest that most talk in the classroom is asymmetrical; teachers often have to act as arbiters of knowledge and therefore act with authority by leading their conversations through demonstrating and explaining to or correcting students.

Symmetrical or interactive talk occurs when participants are considered to have equal status and control within a conversation such as between students or between a groups of teachers. It is more likely to happen when students are working in pairs or small groups. The literature on symmetrical and interactive classroom talk suggests two subsections: cumulative (Mercer and Dawes 2008) and intercognitive (Fox-Turnbull 2016). Cumulative talk occurs when speakers build on and are supportive but uncritical of each other's contributions. In cumulative talk shared understandings are not developed, and individuals retain ownership of their own understandings. Intercognitive talk, on the other hand, describes talk where participants value and build on each other's contributions. This involves understanding, being supportive, and constructively critical of others' ideas. Intercognitive talk (Fox-Turnbull 2013, 2016) involves participants sharing ideas and understandings to develop new knowledge understandings that neither participant could have done alone.

Intercognitive Talk

Intercognitive talk (Fox-Turnbull 2016) challenges and extends participants' thinking, understanding, knowledge, and skills when working collaboratively, allowing participants to come to a position of new understandings. Intercognitive talk has two distinct categories (Fox-Turnbull 2013). The first, convergent growth conversation (CGC) describes talk when all participants' cognitive growth occurs in the same field or is shared, such as when students research together and co-construct new understandings about their object of research. The second type, divergent growth conversation (DGC), describes conversations when participants develop new understandings but in different fields, such as when teachers talk to their students to assist the students' learning in the context of learning but also learn themselves about how and why students are learning. In other words teachers develop pedagogical content knowledge as the students develop content knowledge. In this chapter intercognitive talk refers to that of CGC rather than DGC.

Alexander (2008), Clarke (2003, 2014), and Mercer and Littleton (2007) discuss the need for teachers to specifically teach intercognitive conversation skills which includes the use of specific ground rules such as accepting others' views, acknowledging others' views may be different to ones' own, being open to understanding how and why others think the way they do, and, most critical of all, be open to change. Teachers play an important role in developing skills and dispositions in students to enable them to be collective thinkers and talkers (Mercer and Littleton 2007). Techniques such as using the statements and questions outlined in the intercognitive talk framework in Table 1 can be taught to students to facilitate their engagement in intercognitive talk.

Undertaking or being involved in intercognitive talk will involve students coming up against ideas that are different to their own. It is part of human nature to consider

Table 1 Intercognitive talk framework – questions and statements to assist intercognitive talk

Questions
What makes you consider this? Why?
What changes would you make to . . .
Which do you think is the better/best? Why?
What if. . .?
If you were XXX (a different person, in a different place or time), how might you think differently?
How might this look in 50/100 years? Why?
What might have been a better choice? Why?
What is the next best alternative? Why?
Statements
I think. . . because. . .
I rate/rank my XXX as YYY because. . .
I hadn't thought of it that way. I could think of it through perspective XXX
My. . . is the same/different to yours because. . .
I would sequence these this way because. . .
I think differently because. . .
Your views would differ from mine because. . .
I came to this understanding because. . .

others' views and aims of any conversation. Doise and Mugny (1984) demonstrated that students working in pairs solved problems at a more advanced level than those working by themselves (regardless of the ability of the partner). Their studies revealed that coming up against an alternative point of view (not necessarily the correct one) during joint problem solving forces the student to coordinate his or her own viewpoint with that of other child. The conflict can only be resolved if cognitive restructuring takes place; therefore, mental change occurs as a result of social interaction and therefore stimulates cognitive development by permitting dyadic (people working in pairs) coordination to facilitate inner coordination (Lave and Wenger 1996). Mercer (2006) also identifies a range of definitions for the term "argument," from heated aggressive debate to rhetorical presentation of ideas. These two examples might be seen as extremes on an "argument continuum" with intercognitive talk situated midway between the two, which might be thought of as "reasoned debate."

Facilitating Intercognitive Talk

In order to get students engaged in intercognitive talk in meaningful ways, there are a number of specific teaching strategies that teachers can use and are particularly useful in technology. Below are three that are particularly useful in the facilitation of inter-student intercognitive talk. These are the identification of context-free learning intentions, facilitation of the deployment of funds of knowledge, and the use the Inquiry learning process to implement student-led technology.

Identification of Context-Free Learning Objectives

Context, the activity or "vehicle" through which learning occurs (Clarke 2005, 2008, 2014) is vitally important. Contexts should come from daily life, thus situating learning authentically (Turnbull 2002). The ways students talk within school differ from that of professionals, for example, an architect would talk about designing buildings in a different way to school students. To assisting students to grow into professional talk, this specificity in genre needs to be made explicit to them. van Dijk and Hajer refer to this as the induction perspective of genre pedagogy within a sociocultural approach.

Working cooperatively and collaboratively throughout all stages of learning including planning, deciding context of study, establishing the intended learning, developing or co-constructing success criteria, and critically engaging in analyzing learning is an excellent way to facilitate intercognitive and potentially professional talk (Clarke 2008, 2014; Fox-Turnbull 2016; Hiltunen et al. 2016). When preparing explicit learning objectives for students, the separation of the learning objective from its context ensures that students and teachers are clearly focused on learning. This facilitates not only teacher clarity when talking to students about their learning but also assists in focusing students when talking to each other about their learning. This can have a dramatic effect on teaching and learning.

Context-free learning objectives, shown in Table 2, assist teachers and students in the development of focused talk and the giving of relevant feedback. Also by making the learning objective and the context separate, students are better able to transfer skills and knowledge through to other contexts within and across curriculum areas (Clarke 2008). Table 2 shows two examples of technology learning intentions firstly muddled with the context and then separated from the context with clearly identified success criteria.

Clarke suggests that the receiving and giving of critical guidance and feedback enhance learning opportunities. Much of this can be performed orally (Black and Wiliam 1998) and can be given by peers when intended learning is explicit and clear success criteria are given as suggested above, to guide or even frame feedback conversations.

Funds of Knowledge

Students come to the classroom with a wealth of experiences and understanding derived from their cultural, home, and community experiences (González et al. 2005). People within any given community draw on a range of sources of knowledge to assist them to make sense of their world. Moje et al. (2004) suggest that utilizing knowledge from a range of sources such as home, church, community, and that learned at school contributes to students' knowledge and understanding, therefore allowing learning and intellectual growth to take place.

While working on the collaborative projects at school, students need to be encouraged to engage in and use home, cultural, and community experiences and

Table 2 Mixed and separated learning intentions

Mixed learning intention and context *The students are learning to...*	Context-free learning intention *The students are learning to...*	Separated context *(Vehicle for learning needs to be authentic to the students)*	Success criteria *(A description of successful learning)*
Draw a prop for the school production	Complete a detailed annotated drawing of their intended outcome	Props for the school production	The drawing will: Show annotations for measurements Identify suitable materials and joining methods to be used Show at least two different views Show an outcome that meets the needs of the client
Write a final brief and recipe for a healthy takeaway food	Write a final brief	Takeaway foods	The brief will: Include information gathered through research and testing Reflect client needs Contain a conceptual statement Contain a detailed list of specifications such as ingredients and measurements

knowledge to advance their own and their peers' understanding and capabilities ultimately advancing the cognitive development for all involved. "It is the responsibility of each teacher to attempt to learn something special about each child they teach" (Lopez 2010, p. 2). The above quote suggests that teachers can impact how, when, and why students share and deployed their funds of knowledge. Classroom climate needs to be conducive to risk taking and facilitate the sharing of such knowledge. Funds of knowledge also draws on sociocultural theory (Lantolf 2010; Wertsch 1998) that suggests that learning does not just take place "just between the ears" but is a social process bound within a wider social context. Students have knowledge given to them through their family and cultural life experiences. Engagement in intercognitive talk is more likely to occur when students are using personal funds of knowledge (González et al. 2005) to contribute to understanding because relevant knowledge and experiences brought to a specific situation from home and the community enable new connections to be made. It also has the added bonus of giving status to the student who contributed within that specific conversation or when solving a related problem.

The value of the contribution of students' funds of knowledge to technology was exemplified in a study recently undertaken. The 10- and 6-year-old students were required to design and build props for their school production. During the initial stages, the students needed to understand the character and function of props. One very quiet 6 year old was able to contribute significantly to her classmates' understanding as she had experienced going to the theater as a part of her family's recreational activities and seen props in action. Two 10-year-olds were able to contribute both knowledge and skills when working with wood collaboratively as one father worked in the construction industry and the other had built a tree house with his children. Finally another 6 year old assisted his group by sharing collaborative and cooperating strategies his father taught at home to improve harmony between three active brothers (Fox-Turnbull 2013).

Inquiry Learning

To ensure a high level on engagement from a full range of children in any class, each who have a range of funds of knowledge to draw from, teachers need to maximize the use of integration and authentic contexts for learning. Inquiry learning involves students in developing deep learning through the process of self-motivated inquiry that strives toward development of "big understandings" and "rich concepts" about the world (Murdoch 2004) and how it functions (Blythe 1998). It encompasses a wide range of skills and processes in active learning leading to a much broader understanding of the world the students are part of (Kuhlthau et al. 2007). When undertaking inquiry learning, students are encouraged to construct their knowledge and understandings within their own cultural settings. This is a process that enables students to take greater ownership of and responsibility for their learning. One type of inquiry learning focusing on the facilitation of independent learning is guided inquiry (Kuhlthau et al. 2007).

Guided inquiry reflects the belief that active involvement in construction of knowledge is essential for effective learning (Kuhlthau et al. 2007; Murdoch 2004). Guided inquiry proceeds through a number of teaching and learning phases. It is very different from "open" discovery learning in that the teachers have a major responsibility to structure a range of activities sequenced to maximize the development of skills and thinking processes of the learners in the early stages of each inquiry. Guided inquiry uses a wide range of teaching approaches from teachers' exposition to independent student research (Murdoch 2004). All inquiry learning facilitates integration of knowledge construction within the "third space" (Moje et al. 2004). The third space can be thought of as merged knowledges from peoples' homes, peer networks and communities, and funds of knowledge – the "first space" with discourses encountered at school and other more formalized institutions such as work – the "second space." Figure 1 illustrates this in the context of students designing and developing props for their school production. Some students brought from home knowledge of theater and the role of props play in the stage production. At school in technology, they learned the design process and how and why to model their design ideas, and in maths they learned to measure. By intersecting these two spaces, students were enabled to create the quality props needed.

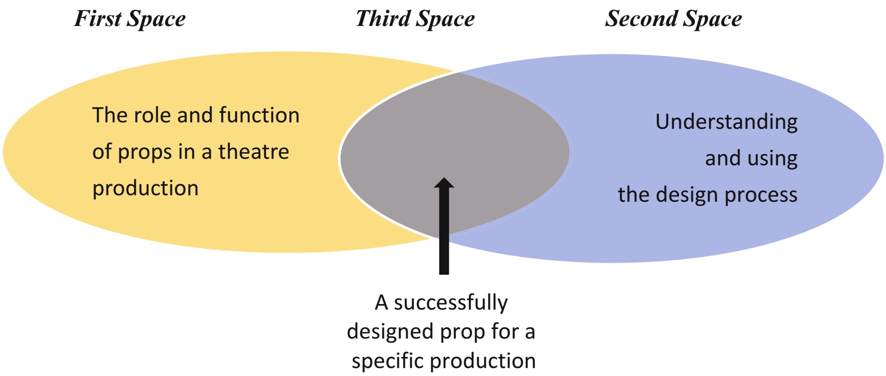


Fig. 1 The three “spaces” illustrated through technology

Context-free learning intentions, funds of knowledge, and inquiry learning are described and illustrated above. Each is a useful way to facilitate inter-student talk in technology. Classroom talk is perhaps more important in technology than some other curriculum areas because of its practical and frequently collaborative nature and the fact that when undertaken using authentic contexts interaction with clients and other stakeholders is an integral part of the process.

A Case for Talking Technology

When participating in technology education, students require a range of academic, social, and physical skills in order for them to collaboratively develop technological solutions to meet identified needs or opportunities (Ministry of Education 1995). It is the physical, hands-on nature of technology education that makes developing “third space” understanding explicit to students by emphasizing the merger of the school and community or social spaces in which they and others interact (Moje et al. 2004). Much sharing of knowledge in collaborative projects occurs through inter-student talk. However talk does not only enhance students’ learning in technology. The case for “talking technology” is twofold. The first is that technology practice is enhanced by talk as suggested above. The second is that technology practice is an excellent tool for assisting students in developing skills in talking and understanding of the value intercognitive talk particularly plays in learning. Table 3 gives an overview of learning in both categories across the three strategies mentioned above. Each is explained in more detail in the following two sections.

Talk to Enhance Technology

When undertaking technological practice, students share, discuss, debate, and draw from their funds of knowledge to engage with their peers to design technological

Table 3 Overview of the three strategies outlining technology talk

Intercognitive talk		
Strategies	Talk to enhance learning in technology (teacher strategies)	Technology education enhancing talk (student talk)
Context-free learning intentions with specific success criteria	Asking questions and making statements to describe learning within each lesson	Learning intentions and success criteria assist students to focus talk on learning achieved or the degree of which learning is achieved
Funds of knowledge	Culturally based skills and knowledge contribute to students' technology practice and outcomes	Understanding how culturally based skills and knowledge assist their own and others' learning which positively influences students' self-esteem
Guided inquiry approach	Working collaboratively and cooperatively on authentic technological inquiry-based projects. Compromise and being open to others' view are essential skills for success	Developing awareness of the intense satisfaction and sense of achievement of using talk to solve problems in a group when individuals are unable to progress alone

outcomes. Knowledge and skills learned by students come from two aspects. The first is that of the context within which the project is situated, such as school production props in the example mentioned above, and is known as specific content knowledge. The second is knowledge of technology and technology practice, known as generic technology knowledge. Generic technology knowledge holds the key to ensuring learning from one project is transferrable to other projects. Table 4 outlines how context-free learning intentions (Table 2) can be overlaid in the intercognitive framework (Table 1). It can be seen that the context-free learning intentions and questions are applicable to any number of technology projects. Within the potential statements, the context, although present, could easily be changed.

Students' funds of knowledge are a valuable source of practical and theoretical knowledge in technology as students assist their own and others' practice by volunteering culturally based skills and knowledge only they may have experienced. Talking is central to this process as it is immediate and less onerous than other forms of sharing for many students especially those who find writing and/or drawing challenging. It is particularly useful as students frequently work in small groups and with a range of people including peers and potential stakeholders; thus, in any one project, a number of "funds of knowledge" may contribute, and with the smaller groups, everyone's voice is likely to be heard.

During technology practice students are highly likely to experience points of view both similar and different to their own, ultimately leading to new and varied understandings especially as they come to grips with the reality of collaboratively developing a single technological outcome. This is a typical scenario in guided inquiry when students are researching and investigating technologies to develop design ideas for a single "group-produced" outcome. Reasoned debate is a normal part of this process. It is the experience of the author that the quality of group

Table 4 Using context-free learning intentions and success criteria to evaluate outcomes

We are learning to draw our intended outcome *Context – props for the school production*		
Success criteria	Questions to be asked	Potential sample statements
1. Show annotations for measurements	What made you consider these measurements when the real ones are smaller?	The measurements we have selected are slightly bigger than an original because I think on the stage, the prop needs to be clearly visible and recognizable to the audience
2. Identify suitable materials and joining methods to be used	How do you justify the materials you have selected?	The materials I have selected are wood and corflute plastic because both are durable, readily available, and cheap and I can work with them
3. Show at least two different views	What if the views you drew were from other aspects than the ones you have selected? How might this add value to your plan?	I came to the understanding that I needed two views on my plan because if I was making this prop I would need to know what all the sides look like and the shape it is from above
4. Meets the needs of the client	Which design best meets the needs of the client? Why is this?	I think this plan of my prop is better than the one done by X group because my designs clearly state how I have meet the needs of our stakeholders

collaboration and communication also impacts on the quality of the technological outcome; however, there is acknowledgment that this is an area that needs further investigation.

Technology Enhancing Talk

Technology education has an emphasis on design, innovation, creativity, entrepreneurialism, cooperation, and societal integration, often through practical involvement. It therefore seems well placed to facilitate learning for the future across all walks of life both in and out of formal schooling. The multidisciplinary nature and holistic approach of technology allows students to make meaningful connections. Current learning theory tells us learning must be made explicit to students (Bellanca and Brandt 2010; Clarke 2008; Claxton et al. 2013). Shared context-free learning intentions do this. In technology students design and develop technological outcomes to meet authentic needs and opportunities. They know what they are designing and why. Having an authentic context engages and motivates students as it enables them to see reason behind what they are learning. Context-free learning intentions assist students' ability to transfer skills and knowledge across disciplines. With assistance from their teachers, students can be shown the role talk plays in developing their thinking and learning process not only in technology but in all areas of life.

Technology will also assist students, especially for those in minority groups, in understanding the role and value of their funds of knowledge and how they contribute to their own and peers' learning. When contributing in this manner, students receive status within the conversation and most importantly assist in the development of new joint understandings which enable their group to move forward in their practices in technology. Being able to make valuable contributions to others' learning assists in the building of self-esteem. Increased self-esteem has the potential to improve achievement (Clarke et al. 2003). Technology offers real and varied opportunities for all students to contribute regardless of culture, ethnicity, gender, or ability by having input from a range of practical, academic, and social skills and knowledge into their collaborative technology practice.

When working on an inquiry-based project collaboratively with peers to develop a single technological outcome, a single solution has to be found for all problems that arise during the process. Students need to reach agreement about the nature of their intended final outcome. During this process just sharing ideas and listening to each other are not enough. When differences occur students need to move and/or merge their understandings and knowledge with that of others. Technology therefore offers a perfect opportunity to advance understanding in the role of talk in learning. Through intercognitive talk students will be challenged, grow, and develop together with their peers. The advantage of using intercognitive talk is clearly illustrated. Students can then be taught that these strategies may apply to other learning situations within which they find themselves. By being challenged and open to change, students learn that they can and do advance their thinking and understanding through talk.

Conclusion and Future Directions

This chapter has focused on the place and value of oral interaction (talk) in the classroom. It has also presented a number of strategies that are well situated to enhance students' learning through intercognitive talk in technology. It offers a framework that teachers and researchers alike can use with students to increase the quality of talk in technology and suggests ways in which talking in technology can assist learning in other areas. To conclude the chapter opens a number of opportunities for potential research in the field of technology education.

Today many students do much of their informal interaction with peers in the form of online chat (texts, tweets, etc.). This chapter does not consider online "talk-like" interaction, but it does raise the question as to whether this type of online chat is just as effective as the face-to-face interaction suggested in the chapter. What are students' attitudes toward a more formal conversation framework being suggested for this less formal medium of communication with peers? Would talk lose its effectiveness and would students resist communicating in this way if it suddenly becomes part of their "school work?"

Mentioned earlier in the chapter is the anecdotal evidence from the author that suggests, that there is a relationship between the quality of the conversations and the quality of the technology outcomes small groups of students produce. This is another area in the field of interaction in technology that needs investigation. Just how valuable is quality talk in technology? What impact does intercognitive talk have on the quality of technology outcomes? Why is this so?

Finally understanding the place and value of talk in the classroom and the role plays on students' learning is changing thinking and practice in teaching. Research into inquiry learning and the role of talk plays in learning technology has challenged prior beliefs about effective learning and has turned many teaching practices upside down. Rather than being quiet places of learning, classrooms should now be full of learning-focused talk. Students should be taught how to talk and challenge others' ideas while accepting and understanding that all ideas have a place in the learning process. Independent inquiry learning plays a significant part in teaching technology education and will continue to do so in the future.

References

Alexander, R. (2008). *Towards dialogic teaching: Rethinking classroom talk* (4th ed.). Cambridge: Dialogos.

Bellanca, J., & Brandt, R. (Eds.). (2010). *21st century skills: Rethinking how students learn*. Bloomington: Solution Tree Press.

Black, P., & Wiliam, D. (1998). *Inside the black box- raising standards through classroom assessment* (1st ed.). London: King's College.

Blythe, T. (1998). *The teaching for understanding guide*. San Francisco: Jossy-Bass.

Brears, L., MacIntyre, B., & O'Sullivan, G. (2011). Preparing teachers for the 21st century using PBL as an integrating strategy in science and technology. *Design and Technology Education: An International Journal, 16*(1), 36–41.

Burr, V. (1995). *An introduction to social constructionism*. London: Routledge.

Clarke, S. (2003). *Enriching feedback in the primary classroom*. Oxon: Hodder Murray.

Clarke, S. (2005). *Formative assessment in action: Weaving the elements together*. Oxon: Hodder Murray.

Clarke, S. (2008). *Active learning through formative assessment*. London: Hodder Education.

Clarke, S. (2014). *Outstanding formative assessment: Culture and practice*. London: Hodder Education.

Clarke, S., Hattie, J., & Timperley, H. (2003). *Unlocking formative assessment- practical strategies for enhancing learning in the primary and intermediate classroom* (New Zealand edition). Auckland: Hodder Moa Beckett.

Claxton, G. (2007). Expanding young people's capacity to learn. *British Journal of Educational Studies, 55*(2), 115–134.

Claxton, G., Chambers, M., Powell, G., & Lucas, B. (2013). *The learning powered school: Pioneering 21st century education*. Bristol: TLO Limited.

Doise, W., & Mugny, G. (1984). *The social development of intellect*. Oxford: Pergamon Press.

Fox-Turnbull, W. (2013). *The nature of conversation of primary students in technology education: Implications for teaching and learning*. PhD, University of Waikato, Waikato.

Fox-Turnbull, W. (2016). The nature of primary students' conversation in technology education. *International Journal of Technology and Design Education, 26*(1), 21–41.

Gergen, K. J. (2000). *An invitation to social construction*. London: Sage.

Gilbert, J. (2005). *Catching the knowledge wave? The knowledge society and the future of education*. Wellington: NZCER Press.
González, N., Moll, L. C., & Amanti, C. (Eds.) (2005). *Funds of knowledge* (1st ed., Vol. 2009, Reprint). New York: Routledge.
Hiltunen, M., Kärkkäinen, S., Keinonen, T., Hähkiöniemi, M., Lehesvuori, S., & Tikkanen, P. (2016). Primary school student teachers' classroom talk during inquiry-based biology lessons. *Problems of Education in the 21st Century, 69*, 37–56.
Kuhlthau, C., Maniotes, K., & Caspari, A. (2007). *Guided inquiry: Learning in the 21St century*. Westport: Libraries Unlimited Inc.
Lantolf, J. P. (2010). Introducing socio cultural theory, 26. Retrieved from http://fds.oup.com/www.oup.com/pdf/elt/catalogue/0-19-442160-0-a.pdf
Lave, J., & Wenger, E. (1996). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.
Lopez, J. K. (2010). Funds of knowledge. *Learn NC*. Retrieved from www.learnnc.org
Mercer, N. (2006). *Words & minds: How we use language to think together*. Abingdon: Routledge.
Mercer, N., & Dawes, L. (2008). The value of exploratory talk. In N. Mercer & S. Hodgkinson (Eds.), *Exploring talk in school* (pp. 55–71). London: Sage.
Mercer, N., & Littleton, K. (2007). *Dialogue and the development of children's thinking- a sociocultural approach*. Oxon: Routledge.
Ministry of Education. (1995). *Technology in the New Zealand curriculum*. Wellington: Learning Media.
Moje, B., Ciechanowski, M., Kramer, K., Ellis, L., Carrillo, R., & Collazo, T. (2004). Working toward third space in content area literacy: An examination of everyday funds of knowledge and discourse. *Reading Research Quarterly, 39*(1), 38–70.
Molinari, L., & Mameli, C. (2013). Process quality of classroom discourse: Pupil participation and learning opportunities. *International Journal of Educational Research, 62*, 249–258.
Murdoch, K. (2004). *Classroom connections- strategies for integrated learning*. South Yarra: Eleanor Curtain Publishing.
Scott, P. (2008). Talking a way to understanding in science classrooms. In N. Mercer & S. Hodgkinson (Eds.), *Exploring talk in school* (pp. 17–36). London: Sage.
Shields, C., & Edwards, M. (2005). *Dialogue is not just talk- a new ground for educational leadership*. New York: Peter Lang Publishing Inc.
Snape, P., Fox-Turnbull, W. (2011). Perspectives on authenticity: implementation of technology education. International journal of technology and design education
Turnbull, W. (2002). The place of authenticity in technological in the New Zealand curriculum. *International Journal of Technology and Design Education, 12*(1), 23–40.
Wagner, T. (2008). *The global achievement gap: Why even our best schools don't teach the new survival skills our children need- and what we can do about it*. New York: Basic Books.
Wertsch, J. (1998). *Mind as action: The task of sociocultural analysis*. New York: Oxford University Press.

Linking Knowledge and Activities: How can Classroom Activities in Technology Reflect Professional Technological Knowledge and Practices?

40

Bjørn-Tore Esjeholm and Berit Bungum

Abstract

This chapter investigates in what ways school technology may reflect professional technological practices. Using the historical development within the aeronautical industry as an example, characteristics of technological practice and knowledge are presented. In particular, it is referred how manufacturing, testing, and operating a technological device produce knowledge that affects the design process and the fundamental design concepts of the artefact. By means of a literature review and a multi-case study, it is found that D&T classrooms may have similarities with how design and engineering takes place in a professional community. The role of heuristics and repetitive testing is important for both cases. Examples from both professional engineering and classroom activity show that utilizing science and mathematics in a fruitful way in developing technology is challenging. However, there are some distinct differences as well. The students' lack of expertise is an imperative for D&T teachers to provide students with basic understanding of the fundamental design concepts involved in the activity.

Keywords

Technological practices • Classroom activity • Authenticity • Design concepts • Knowledge content

---

B.-T. Esjeholm (✉)
The University of Tromsø – The Arctic University of Norway, Alta, Norway
e-mail: bjarn-tore.esjeholm@uit.no

B. Bungum
Faculty of Social and Educational Sciences, Department of Teacher Education, NTNU-The Norwegian University of Science and Technology, Trondheim, Norway
e-mail: berit.bungum@ntnu.no

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_42

Contents

Introduction

Technology as part of general education may give students opportunities to experience aspects of how professional technologists work and acquire knowledge that is typical for professional knowledge in the field. Even if school technology also has other purposes (such as educating students as responsible citizens), it is therefore important to consider how the school subject can reflect how professionals work and the knowledge they possess.

Technology as a form of knowledge is intimately connected to technological practices, as the knowledge itself is developed and acquired though activity. Mitcham (1994) emphasizes that the essence of technological development through inventing is the process of making ideas and conceptions physically real. Technology as activity is associated with a variety of human behaviors: crafting, inventing, designing, manufacturing, working, operating and maintaining.

Correspondingly, the teaching of technology in schools is associated with practical activities for students: they design, draw, investigate and create objects, build constructions, use a wide range of tools and materials, and test and evaluate solutions. It is often the activities themselves that define the subject for teachers and students, and the knowledge content it represents may be less articulated (Björkholm et al. 2012).

How do these activities reflect professional practices and knowledge held and developed by professionals? This chapter investigates the issue in light of conceptualizations of technology as knowledge and how it develops. We start with a "case story" from airplane design based on Vincenti (1990), in order to connect the discussion of technology in education to concrete examples of professional knowledge and practices. This is followed by a discussion of how these are reflected in student activities in technology teaching, exemplified by a multi-case study in schools in order to anchor the discussion also in the school context.

Airplane Design: A Case Story of Invention and Development

Technology has undergone an unprecedented development over the last hundred years. The aeronautical industry is one of many examples of technology that was little developed or even nonexistent at the beginning of the twentieth century while playing a pivotal role in the globalized modern societies of today.

Vincenti (1990) has analyzed in detail how design knowledge within aeronautical industry developed from the beginning of the twentieth century where merely all problems concerning manned flight were ill-defined to a mass production of hi-tech aircrafts for a variety of purposes less than 50 years later. His analysis shows the complex and interwoven interaction between theoretical knowledge and practical experiences in the development of the modern aircraft.

In the early phases of developing the airplane, the awareness of stability versus maneuverability grew as a consequence of feedback from pilots and their experiences. High stability comes at the price of reduced ability to control the aircraft. Engineers testing unpiloted models discovered that they "had to have an inherently stable system for success" (p. 57). This was in contrast to experiences from the early pilots who emphasized the importance of controlling the airplane, at the expense of reduced stability. This knowledge gained by the pilots was crucial for recognizing the matter of stability versus control as a problem. Later in the process, it was concluded that "the knowledge [of the desirable degree of stability] can only be obtained from the experience of pilots in flight" (p. 63). This example shows that the pilots' experiences were important in terms of defining and recognizing basic issues of airplanes as such. However, practical experiences and direct trial play an important role throughout the knowledge development in the design process. These experiences may come as a result of lab testing by professionals at any stage of the process as well as everyday operation by customers and users. In particular, experiences and trial that reveal errors and malfunction will make a strong impact on changing design elements of the product. As an example, frequently manufacturers of cars have to recall and repair a series of their products as the everyday use by their customers has uncovered actual or possible malfunction in the product.

Vincenti also shows examples of how production and manufacturing serve as a source of knowledge that makes impact on the development of a technological artefact. In the early 1930s, airplanes were held together by dome-shaped rivets that protruded beyond the surface of the aircraft. Ten years later the rivets had changed to a conical shape and were flush with the surface. This development was motivated by aerodynamic considerations based on both theoretical and experimental knowledge gained in the period. However, the implementation of this knowledge would have been impossible without developing the methods of production. As an example, it turned out that the original standard of conical shaped rivets with 78-degree head angles, a heritage from the army and the navy, was at the Douglas factory left in favor of rivets with a 100-degree head angle. This change came about as a result of the fact that the 78-degree heads led to cracking and deformation of the fragile and lightweight materials in the dimpling and upsetting operations in the production process. The problems were identified upon production and solved by changing the angle to 100 degrees.

What Characterizes Professional Technological Knowledge and Practices?

As the examples from the airplane development described above display, the anatomy of technological knowledge is fairly complex even when it is delineated to its relation to activity. Based on a more general analysis, Vincenti (1990) identifies seven knowledge-generating activities in technology: transfer from science, invention, theoretical engineering research, experimental engineering research, design practice, production, and direct trial (including operation). These activities in turn generate knowledge of various kinds. Vincenti makes a distinction between knowledge used by engineers and knowledge generated by engineers and makes a point that though engineers extensively utilize knowledge from science, the majority of growth of technological knowledge stems from prior engineering knowledge and engineering activities. Vincenti presents several other examples showing that practical experiences in terms of experimental research, design practice, production, or operation produce knowledge into all of his knowledge categories that represents engineering design knowledge. Although Vincenti has used the airplane and its history in his approach, the analysis is transferable to engineering in general. Several other authors have given attention to the role of activity in the knowledge-generating process, e.g., Mitcham (1994), Vèrillon (2009), De Vries (2016), Parkinson and Hope (2009), and Koehler and Mishra (2005).

One characteristic of technological knowledge that is particularly relevant to technology education is the intimate and insoluble relation between knowledge and practical activity in any specific context (e.g., McCormick (2004)). Activity is more than an efficient way of learning. There is a two-way iterative process between thinking and doing where both are affected by the other. As McCormick (2004) points out, “This is crucial for technology education, because that is in a sense what technology educators are trying to get children to be able to do to think through their doing, and for the feedback from this doing to affect their thinking.” The role of practical activity is supported by Tiles and Oberdiek (1995) who claim that “knowledge of the variable conditions of application is as important as knowledge of fundamental theory; practical skill is as important as the theoretical understanding” (p. 104). Tiles and Oberdiek also point out how different kinds of knowledge are used opportunistically and heuristically within technology. In the process of developing technology, a designer will draw upon any available knowledge suitable for solving the problem at hand. Others like Carlson and Goreman (1992), Lewis (2009), and Christiaans and Venselaar (2005) argue in a similar vein.

The complexity of the nature of technological knowledge is also recognized by Arthur (2009) who emphasizes that all technologies are combinations of components, assemblies, or subsystems put together in a specific way to fulfil a human purpose. A successful solution requires knowledge of the specific parts and their interaction in making the system as a whole as well as the systems interaction with the surrounding environment. A significant part of the required knowledge can only be acquired through practical activity.

Though the knowledge in technology is always related to a practical context, it may be both practical and theoretical in nature. Ropohl (1997) has described technological knowledge as five components: technical know-how, functional rules, structural rules, technological laws, and socio-technological understanding. The technical know-how and technological laws create a span from the mainly practical knowledge and skills to the conceptual knowledge that professionals possess in technology. This knowledge, which corresponds to Staudenmaier's conception of "engineering theory" (Staudenmaier 1985), may be based on general scientific knowledge, but is in a different form – the knowledge is generic but contains concepts more applicable in specific practical contexts. This corresponds with how among others Layton (1991), Knorr-Cetina (2013), and Boon (2006) have described how scientific knowledge on a theoretical level has to be reconstructed for becoming useful in a practical situation. The reconstruction involves lowering the level of abstraction and adjusting the knowledge to the practical contexts.

Another hallmark of technological knowledge is the element of tacit knowledge. This forms part of the technical know-how in Ropohl's conceptualization of technological knowledge. In developing, using, or maintaining technology, a part of the knowledge involved will be beyond explicit description, written or orally. Polanyi (2002 [1958]) describes two forms of tacit knowledge: connoisseurship and skill. The first is associated with the ability to troubleshoot or assess a device or process just by sensing sound or visual impressions. The latter comprises the ability to actively make impact on the technological device or process such as adjusting the bolts and nuts of a machine to make it perform better. Polanyi emphasizes that tacit knowledge is embedded in all kinds of knowledge, also the explicit.

Based on his studies of the evolution of aeronautical knowledge described in the foregoing, Vincenti (1990) categorized design knowledge used and developed by engineers in the process of making airplanes in the first part of the twentieth century. The most basic of his categories is the *fundamental design concepts*. Any artefact or its subparts relies on a basic operational principle that defines the artefact or subpart as such. This operational principle serves also as a success criterion; if the device works according to the operational principle, it is by definition a success. The operational principle can be manifested in a variety of configurations. By this is understood how the parts and assemblies are arranged and how they are working together to fulfil the operational principle. Vincenti refers to typical engineering activity as "normal design." Within normal design, the engineering community will often agree upon and take the operational principle and configuration for granted. This is in contrast to "radical design" where the configuration is new though the fundamental design concept may be known or slightly altered from earlier known technology. If the fundamental design concept is completely new, and consequently introducing a new configuration, the design may be regarded as "revolutionary." Vincenti emphasizes that the vast majority of engineering enterprise in the world is within normal design. Inventing in terms of producing completely new ideas based on novel and hitherto unknown fundamental design concepts is a rare thing in the world of engineering.

Mitcham (1994) uses the terms invention and design respectively to separate these two forms of evolution processes: “As opposed to designing, inventing appears as an action that proceeds by nonrational, unconscious, intuitive, or even accidental means. Designing implies intentionally planning” (p. 217). Similar demarcation between invention and design is presented by Arthur (2009) who uses the term “standard engineering” as a denotation for design.

What role does creativity have in the inventive process? Invention is characterized by rapid, ad hoc, and unstructured changes of previous ideas. This is in contrast to refining already existing ideas where changes are small and incremental and typically takes place over period of time in an iterative process. It is worth emphasizing that creativity is not restricted to the process of inventing. Even within normal design or standard engineering, the designer has to combine and develop knowledge in a creative and not prescribed manner to solve the problem at hand.

Arthur (2009) shares much of Vincenti’s views and points out that “technology is always organized around a central concept or principle” [p. 33]. These principles and concepts rest on natural phenomena and effects existing independently of humans and of technology. He further claims that a principle is “the idea of use of a phenomenon for some purpose” [p. 49]. Arthur sees engineering as the application of known concepts and methods in making a new version of already known technology. Schön (1982) argues in a similar vein using the term “seeing as” when describing how new solutions occur as a consequence of identifying a novel problem as somewhat similar to an older and known one. Experience is thus a key factor in terms of being creative.

The approach to technological knowledge by Vincenti and Arthur is characteristic for engineering enterprise and may be seen as a technocratic view of this knowledge. Their frameworks comprise conceptual and procedural aspects of how to develop an idea into a fulfilled technological artefact and deal mainly with the internal knowledge required in this process. Others like Feenberg (1999) and Tiles and Oberdiek (1995) have emphasized more of the ethic and social aspects of technology where normative questions associated with technology are given a more prominent role.

In What Ways Are Technological Knowledge and Practices Represented in School Technology?

From Vincenti’s story about the evolution of aeronautical knowledge and the perspectives presented in the foregoing, technological development can be described as a dynamic process where knowledge developed is deeply situated in existing practices. What does this mean for students’ development of technological knowledge in a school context?

In a process of learning in technology, the outcome will be directly influenced by the specific context and how the practical activity is guided and restricted by the teacher and contextual factors. This view of developing knowledge is often referred to as “situated learning” (e.g., Brown et al. 1989; Lave and Wenger 1991; McCormick 2004) and implies that knowledge is included in the context and not in the abstractions made from it. As a consequence, altering the context will affect and change the knowledge involved. This means that transfer between contexts cannot be taken for granted, as pointed to by Layton (1991), and that, for example, the use of tools and specific procedures should be regarded as important knowledge content in itself. Still, technological knowledge is not only purely practical in nature; it spans from generic theoretical knowledge represented in systematic forms to purely practical skills and tacit knowledge, as described by, for example, Ropohl (1997).

The situated nature of technological knowledge may suggest that specific knowledge and practices from a broad range of specific technological areas should be represented in the school curriculum. On the other hand, there might also be common features that students could learn across technology fields. In a major Delphi study, Rossouw et al. (2011) identified specific as well as generic aspects of technological knowledge by investigating how professionals formulate knowledge in their fields. Experts in various fields of technology were consulted in order to identify key components of knowledge that professional technologists possess and use. The study resulted in a list of contexts and concepts that can be used to develop curricula for education about engineering and technology as a contribution to technological literacy goals in education. The list includes concepts and sub-concepts from a range of contexts such as shelter, health, mobility, energy, and safety. It also includes general concepts such as systems and structure and generic technological practices such as designing, innovation, and invention.

With regard to designing as a general skill, many attempts have been made in order to conceptualize a generic design process that students would use across contexts. This was in particular prominent in the formulation of design and technology and the subject's assessment criteria in the national curriculum in England and Wales back in the late 1980s. The anticipation of the existence and transferability of a design process was questioned by many (e.g., Chidgey (1994), Johnsey (1995), Murphy and McCormick (1997), Mawson (2003)). It has also been argued that the focus on the design process fails to take into account the high degree of specialization in the world of work and hence creates an artificial image of technology as a professional activity (Medway 1992). This is in line with how Bucciarelli (1996) stated that there is no single design process in engineering and that experienced problem-solvers draw on an extensive knowledge of problem types and a broad repertoire of solution procedures.

A more recent process approach in technology is found in the curriculum program Next Generation Science Standards (see www.nextgenscience.org/) in the USA. It defines "engineering practices" in parallel to science practices within science as a subject. The engineering practices students should participate in include defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, designing solutions, engaging in argument from evidence, and finally obtaining, evaluating, and communicating information. With the lessons learned from the formation of Design and Technology in England and Wales two decades ago, this approach is likely to succeed only with a good balance between specific content components and the generalized process skills.

Comprehensive case studies undertaken by Hill and Anning (2001) revealed a complexity of various approaches employed by professional designers. They found that designers in different technology fields need different skills and knowledge in research, materials, tools, and processes. Designers described the work as an iterative process between generating ideas and developing prototypes rather than steps through ideas, design, and making. This mirrors the case story in the foregoing, where aspects of airplane design history were summarized based on Vincenti (1990). In school settings, in contrast, Hill and Anning found that students were supposed to develop and perform isolated drawing skills, modeling skills, and design process skills that are generic in nature. The study illustrates that attempts to include "designerly thinking" in school technology may create an artificial picture of how designers work.

Authenticity in technology education may have two distinct different meanings; technological problems may be authentic to the life world of students or to professional technological communities (Turnbull 2002). With regard to the latter interpretation, one way of enhancing authenticity in school technology may be to involve professionals in teaching for school children. It may support students' learning by including aspects of apprenticeship in the activities. In a study from Finnish schools, Kangas et al. (2013) investigated how authentic processes based on professional design practices might form part of school technology. In a project where elementary school children were designing lamps in collaboration with expert designers, the experts introduced the learners to domain-specific knowledge and problem-solving strategies in an apprenticeship manner. Collaboration that offers expert knowledge that individual school teachers cannot be expected to possess may contribute to introduce students to the world of expert designing.

In their study, Kangas et al. identify four prerequisites for activities to be successful in this regard: They should be (1) feasible in that learners can design and perform inquiries to solve the task, (2) worthwhile in that they have rich content and relate to what professionals really do, (3) contextualized in that they represent important real-world phenomena, and (4) meaningful in that they are interesting and exciting to learners.

These prerequisites are of more general relevance to technology teaching in order to make it authentic for technological practices, also without direct contact with professionals. With regard to knowledge content, the first two points are essential: tasks for students should have an openness that allows for students' creativity and individual solutions, but on the other hand be possible to solve in competent ways with a repertoire that students have acquired in advance. Amabile (1996) offers a definition of creativity that is relevant for technology education: "a product or a response will be judged as creative to the extent that (a) it is both a novel and appropriate, useful, correct or valuable response to the task at hand, and (b) the task is heuristic rather than algorithmic" (p.35). In terms of Vincenti's concepts, this could mean that students are familiar with operational principles and at least to some extent possible configurations for constructions before they are challenged to create their own solutions.

It should also be noted that "authenticity" could apply to technology as a field of professional activity as a whole, not necessarily the practice of individual professionals. Innovations and development are mainly undertaken within collective practices where individuals work on very specific problems. The development of the airplane serves as an adequate example of this. Through the twentieth century, progress was made in every aspect of design and performance of the airplane. The design of propellers was in the period 1916–1926 dominated by the work of only two professors in mechanical engineering producing data that were used by the airplane designers in the whole industry during that period. This may be reflected in school technology by letting students work on specific parts of a larger joint project. However, authenticity may also be provided for by letting students experience the variety of activities involved in a technological project.

Knowledge Content in Student Projects: A Multi-Case Study

In order to illustrate more concrete how projects in technology classrooms may – or may not – contain aspects of authentic technological knowledge and practices, a multi-case study undertaken in six Norwegian schools is here presented. The study involved collaboration between researchers and local teachers in developing teaching projects for grades 3–10 (students aged 8–16 years) in line with the specification in the Norwegian curriculum. The curriculum, implemented in 2006 (UDIR 2010), has placed technology and design as a cross-curricular topic where students are supposed to apply knowledge from science, mathematics, and arts and crafts in practical contexts. The idea in the curriculum was that technology provides motivating contexts for pupils' learning of science and mathematics.

Each of the teaching projects was designed to be authentic in one or both of the meanings described by Turnbull (2002), in terms of relevance to students' life world, or authentic to problems encountered in professional practices. The research part of the multi-case study investigated the knowledge content of the teaching projects in terms of the kind of knowledge represented in dialogues within groups of students and between students and teaching during the entire project time. Results show that knowledge content from science and mathematics were hardly represented even if the projects were supposed to support students' learning in these subjects. Instead, knowledge content in the student dialogues and activities were technological in nature (Bungum et al. 2014). For example, students in grade 10 at one of the schools were creating a large model of their home town with landscapes and buildings supposed to be in correct scales. The task of calculating scales became rather challenging since the landscape had irregular shapes and the students had to go between three sets of representations: the landscape itself, the map available, and the model they were creating. In addition, the model had constraints in the size of the base available. The students were struggling with this challenge when one of the students, without any incentives from the teacher, came up with the idea of using an overhead projector available in the classroom to scale up the map projected on the wall until it fitted the base in the most optimal way.

The student's solution reflects technological ways of working in that it is flexible and pragmatic in use of tools and procedures. As there was no need for exact calculations of scales, the students picked the most effective way of achieving the desired result. The idea of utilizing the overhead projector clearly also involved a mathematical understanding of what scales means and what an overhead projector does. However, students did not perform the calculations required to fulfill the curriculum in the mathematics part of the project. This outcome of the student project illustrates that technological knowledge is in different form than conceptual knowledge from science and mathematics and that theoretical knowledge needs to be reconstructed to be useful in practical contexts as described by Layton (1991).

In one of the other student projects investigated, students in grade 8 (age 13–14) were to construct a drilling mechanism for a model of an oilrig. This formed part of a larger teaching program about oil resources and exploitation and a current political discussion of new oil fields in the local region. Students worked with a combination of technical Lego and wood materials. The key challenge the students encountered was to construct a mechanism that simultaneously rotated and moved vertically, to model the oil drill. The activity was intended to call upon students' creativity. However, the analysis of video data shows that the project turned out very teacher led and with little creativity for students (Esjeholm and Bungum 2013). In Vincenti's terms, the students lacked knowledge of the relevant domain-specific operational principles, and they were hence not able to establish a fundamental design concept for their construction. This represents "engineering theory" (Staudenmaier 1985) or "technological laws" (Ropohl 1997), and the science-based principles from physics would be far less applicable. In a pedagogical perspective, the activity missed out on the first prerequisite for authentic technology teaching described by Kangas et al. (2013) and referred in the foregoing, namely, that activities should be feasible in that learners can design and perform inquiries to solve the task.

This influenced students' opportunities for using their creativity. When introduced to a possible solution by the teacher, students learned to use this design concept, but do not experience how designers work creatively with developing solutions based on a variety of possibilities. They lacked the repertoire of potential solutions necessary for developing their own solutions in creative and informed ways.

The case illustrates the main message of a comprehensive meta-study undertaken by Scott et al. (2004). They investigated 70 empirical studies of the outcomes of creativity training programs. It was found that open-ended, ill-defined problems were superior to expression of unexplored ideas in terms of fostering creativity. Further, analysis of the relative effectiveness of training programs indicated that programs focusing on the development of cognitive skills and involving realistic exercises appropriate for the domain at hand were most successful in developing students' creativity. The researchers hence recommended that students should be introduced to basic concepts and principles and explore these through extensive training with various discrete cognitive skills and relevant heuristics before they turn to working with more complex and open-ended challenges. Middleton (2005) has emphasized how higher-order thinking is facilitated by the manipulation of concrete materials. Results from the multi-case study illustrate that familiarity with the concrete materials and insights in their principles are prerequisites for creativity as a higher-order thinking skill. This means that teaching that aspire to provide students with authentic experiences of technology as a creative practice should start with basic training of fundamental principles and procedures.

Conclusion

Based on the foregoing, activities in a D&T classroom may have similarities with how designing and engineering takes place in a professional community. Typical classroom activities reflect the practical approach within engineering and display how heuristics play an important role even within normal design. The need for feedback into the iterative design process from actual testing of the device is essential in both cases. Just like professionals, students' ability to succeed in their designing process relies on their level of knowledge and skills in the actual domain of technology they are engaged in.

Compared to professionals, however, students will typically have a low level of expertise and have a limited repertoire of experience and knowledge concerning the fundamental design concepts involved. As a consequence, the D&T classroom must facilitate this basic knowledge in a way that fosters students' creativity and opportunities to apply and combine knowledge in a variety of ways. As noted by Fox-Turnbull (2006), a prerequisite for authenticity in technology education is that teachers have thorough knowledge of technological practice. This must involve domain-specific knowledge and skills in a variety of technological areas. In order to create opportunities for authentic technological work, it is also important that students are given enough time in projects to acquire the required skills and knowledge and to allow for trial and error – and retrial – as part of a development process.

The examples from classroom activity described in this chapter also show that combining D&T with mathematics and science in a fruitful way is far from straightforward. This is a parallel to the history of how the airplane developed. As Vincenti lines out, mathematical models and methods for calculating drag and performance of different wing profiles in general were established in the mid-thirties. Still, it took a great deal of effort and time before actual wing profiles could be developed based on this knowledge as this process required knowledge from other areas as well, in particular from practical testing in wind tunnels, from pilots' experiences, and from manufacturing and production. Knowledge is thus gained throughout the process of creating a technological artefact. In order to familiarize young people with how professionals work in technology, such activities should form part of their general education.

However, technology teaching should not only aspire to mirror the work of professionals. As part of their general education, students also need insights for addressing questions of social and ethical nature, such as how the climate and the environment is affected by our lifestyle and how technology can be utilized to make a better life for third-world citizens. Technology teaching should combine these concerns with activities that provide students with the joy and the practical knowledge involved in developing technology.

References

Amabile, T. (1996). *Creativity in context: Update to the socilal psycology of creativity*. Colorado: West View Press.

Arthur, B. (2009). *The nature of technology: What it is and how it evolves*. New York: Free Press.

Björkholm, E., Andrée, M., & Carlgren, I. (2012). Exploring technical knowledge in the primary technology classroom. *Australasian Journal of Technology Education, 3*, 2–16.

Boon, M. (2006). How science is applied in technology. *International Studies in the Philosophy of Science, 20*(1), 27–47. doi:10.1080/02698590600640992.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32.

Bucciarelli, L. (1996). *Designing engineers*. Cambridge, MA: MIT Press.

Bungum, B., Esjeholm, B.-T., & Lysne, D. A. (2014). Science and mathematics as part of practical projects in technology and design: An analysis of challenges in realising the curriculum in Norwegian school. *NorDiNa, 10*(1), 3–15.

Carlson, W. B., & Gorman, M. E. (1992). A cognitive framework to understand technological creativity: Bell, Edison, and the telephone. In R. J. Weber & D. N. Perkins (Eds.), *Inventive minds*. New York: Oxford University Press.

Chidgey, J. (1994). A critique of the design process. In F. Burns (Ed.), *Teaching technology* (pp. 89–93). London: Routledge.

Christiaans, H., & Venselaar, K. (2005). Creativity in design engineering and the role of knowledge: Modelling the expert. *International Journal of Technology and Design Education, 15*(3), 217–236. doi:10.1007/s10798-004-1904-4.

De Vries, M. (2016). *Teaching about technology*. Cham: Springer international publishing.

Esjeholm, B. T., & Bungum, B. (2013). Design knowledge and teacher-student interactions in an inventive construction task. *International Journal of Technology and Design Education, 23*(3), 675–689. doi:10.1007/s10798-012-9209-5.

Feenberg, A. (1999). *Questioning technology*. London: Routledge.

Fox-Turnbull, W. (2006). The influence of teacher knowledge and authentic formative assessment on students learning in technology education. *International Journal of Technology and Design Education, 16*, 53–77.

Hill, A. M., & Anning, A. (2001). Comparisons and contrasts between elementary/primary 'school situated design' and 'workplace design' in Canada and England. *International Journal of Technology and Design Education, 11*(2), 111–136. doi:10.1023/a:1011245632705.

Johnsey, R. (1995). The design process – Does it exist? A critical review of published models for the design process in England and Wales. *International Journal of Technology and Design Education, 5*(3), 199–217.

Kangas, K., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2013). Design expert's participation in elementary students' collaborative design process. *International Journal of Technology and Design Education, 23*(2), 161–178. doi:10.1007/s10798-011-9172-6.

Knorr-Cetina, K.-D. (2013). *The manufacture of knowledge*. Elsevier.

Koehler, M. J., & Mishra, P. (2005). Teachers learning technology by design. *Journal of Computing in Teacher Education, 21*(3), 94–102. doi:10.1080/10402454.2005.10784518.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Layton, D. (1991). Science education and praxis: The relationship of school science to practical action. *Studies in Science Education, 19*, 43–78.

Lewis, T. (2009). Creativity in technology education: Providing children with glimpses of their inventive potential. *International Journal of Technology and Design Education, 19*(3), 255–268. doi:10.1007/s10798-008-9051-y.
Mawson, B. (2003). Beyond 'the design process': An alternative pedagogy for technology education. *International Journal of Technology and Design Education, 13*(2), 117–128. doi:10.1023/a:1024186814591.
McCormick, R. (2004). Issues of learning and knowledge in technology education. *International Journal of Technology and Design Education, 14*(1), 21–44. doi:10.1023/B:ITDE.0000007359.81781.7c.
Medway, P. (1992). Constructions of technology: Refelctions on a new subject. In J. Beynon & H. Macay (Eds.), *Technological literacy and the curriculum*. London: The Falmer Press.
Middleton, H. (2005). Creative thinking, values and design and technology education. *International Journal of Technology and Design Education, 15*(1), 61–71. doi:10.1007/s10798-004-6199-y.
Mitcham, C. (1994). *Thinking through technology: The path between engineering and philosophy*. Chicago: University of Chicago Press.
Murphy, P., & McCormick, R. (1997). Problem solving in science and technology education. *Research in Science Education, 27*(3), 461–481.
Parkinson, E., & Hope, G. (2009). Conceptual learning in and through technology. In A. Jones & M. De Vries (Eds.), *International handbook of research and development in technology education*. Rotterdam: Sense Publishers.
Polanyi, M. (2002 [1958]). *Personal knowledge: Towards a post-critical philosophy*. London: Routledge.
Ropohl, G. (1997). Knowledge types in technology. *International Journal of Technology and Design Education, 7*(1), 65–72.
Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–424. doi:10.1007/s10798-010-9129-1.
Schön, D. A. (1982). *The reflective practitioner. How professionals think in action*. New York: Basic Books.
Scott, G., Leritz, L. E., & Mumford, M. D. (2004). The effectiveness of creativity training: A quantitative review. *Creativity Research Journal, 16*, 361–388.
Staudenmaier, J. M. (1985). *Technology's storytellers. Reweaving the human fabric*. Cambridge, MA/London: Society for the History of Technology/The M.I.T. Press.
Tiles, M., & Oberdiek, H. (1995). *Living in a technological culture: Human tools and human values*. London: Routledge.
Turnbull, W. (2002). The place of authenticity in technology in the New Zealand Curriculum. *International Journal of Technology and Design Education, 12*(1), 23–40.
UDIR. (2010). *Curriculum for science*. Retrieved from http://www.udir.no/Lareplaner/
Vèrillon, P. (2009). Tools and concepts in technological development. In A. Jones & M. De Vries (Eds.), *International handbook of research and development in technology education*. (pp. 175–197). Rotterdam: Sense Publishers.
Vincenti, W. G. (1990). *What engineers know and how they know it: Analytical studies from aeronautical history*. Baltimore: Johns Hopkins University Press.

Perceptions and Attitudes of Pupils Toward Technology

41

Piet Ankiewicz

Abstract

Students' technological concepts and attitudes have been researched for just over three decades. The chapter addresses several viewpoints concerning the construct of attitudes toward technology, such as definitions of attitude, and fundamental reasons for measuring students' attitudes. The main part of the chapter presents the Pupils' Attitudes Toward Technology-Netherlands (PATT-NL) instrument and the PATT-USA instrument associated with the classical PATT studies, as well as the PATT Short Questionnaire (PATT-SQ) as a recent adaptation of PATT-USA. It also focuses on new instruments, such as the Attitudinal Technology Profile (ATP) questionnaire that were developed based on regional and contextual factors. The latter part of the chapter provides general research findings from the PATT studies on students' attitudes toward technology, as well as examples of recent multidimensional versus unidimensional studies.

Keywords

Technology education • Attitudes • Concepts • Behavior • Attitude measurement

Contents

P. Ankiewicz (✉)
Department of Science and Technology Education, University of Johannesburg, Auckland Park, South Africa
e-mail: pieta@uj.ac.za

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_43

Introduction

The chapter addresses several viewpoints concerning the construct of attitudes toward technology, such as definitions of attitude, and fundamental reasons for measuring students' attitudes. The main part of the chapter presents the Pupils' Attitudes Toward Technology-Netherlands (PATT-NL) instrument and the PATT-USA instrument associated with the classical PATT studies, as well as the PATT Short Questionnaire (PATT-SQ) as a recent adaptation of PATT-USA. It also focuses on new instruments, such as the Attitudinal Technology Profile (ATP) questionnaire that were developed based on regional and contextual factors. The latter part of the chapter provides general research findings from just over three decades of PATT studies on students' attitudes toward technology, as well as examples of recent multidimensional versus unidimensional studies.

In the next section, reasons why researchers are interested in measuring students' attitudes toward technology will be considered.

Rationale for Ascertaining Pupils' Attitudes Toward Technology

Researchers regard studying students' attitudes toward technology as important for the following reasons:

- The development of attitudes is part of pragmatic education where the student as an individual is the focal point, within a social context. The role of the teacher is one of facilitator or group leader (De Klerk Wolters 1989a; Hill 1997).
- The development of students' technological concepts and attitudes is part of the aims of technology education (De Vries 2000, 2005).
- Students' attitudes have a major impact on career choices, courses of study, and subject fields in school (Ardies et al. 2013; De Klerk Wolters 1989a; Gaotlhobogwe 2015; Mammes 2004; Rohaan et al. 2010; Volk and Yip 1999).
- Students' attitudes toward technology play a significant role in alleviating anticipated shortages for technology within the labor market (Ardies et al. 2015b).
- Students' attitudes toward technology may be used to predict their achievement (Volk et al. 2003).

- Knowledge of students' attitudes toward technology enables curriculum developers, course designers, and teachers to better assist students in learning technology (De Klerk Wolters 1989a; Dunlap and Dugger 1991; Prime 1991; Yu et al. 2012).
- An understanding of students' technological literacy and attitudes toward technology is a prerequisite for effective technology teaching (Ardies et al. 2013; Bame 1991; Bame et al. 1993; De Klerk Wolters 1989a; Jeffrey 1995).
- Students' attitudes toward technology could inform teacher education (De Klerk Wolters 1989a).

In order to measure attitudes, a clear understanding of the concept is necessary; therefore, definitions of the concept will be discussed in the next section.

Definitions of Attitude

Attitude is a broad concept with different definitions and interpretations. A controversy has long existed in literature regarding the dimensionality of attitudes, with various models comprising one to three dimensions (Ankiewicz et al. 2001; Ardies et al. 2013). The traditional approach is that attitudes have an integrated three-dimensional nature, consisting of cognitive, affective, and behavioral components (Breckler 1984; Fishbein and Ajzen 1973; Ostrom 1969). This approach forms part of the consistent theories as one category of three attitude theories, namely, functional, formational, and consistent theories. Attitude theories and their components are not exclusive but complement one another (Metsärinne and Kallio 2015).

The cognitive component of attitudes includes a person's ideas or opinions that express the relationship between situational and attitudinal objects (Gagné 1977). Statements that reflect a person's perception and knowledge of the attitudinal object are part of the cognitive component (Corsini and Ozaki 1984). The affective component refers to a person's "feeling" or emotion concerning an attitudinal object (Heaven 1982). The behavioral component includes a person's predisposition or readiness for action, as well as his or her actions concerning the "behavioral object" (Ankiewicz et al. 2001; Gagné 1977). For Bagozzi and Burnkrant (1979), attitude is primarily the interplay of affect and cognition, with the behavioral tendency as a secondary consequence (Ankiewicz et al. 2001; Van Rensburg et al. 1999).

According to the traditional approach, an attitude toward a concept such as technology thus is the person's collection of beliefs about it (cognitive component) and associated episodes linked with emotional reactions (affective component). The stimulation of these reactions results in decisions to engage in behavior (behavioral component), such as choosing to take a technology course, to read about technological matters, or to adopt a technology-related hobby (Ankiewicz et al. 2001; White 1988). Researchers in technology education often acknowledge, either implicitly or explicitly, the traditional approach to attitudes (De Klerk Wolters 1988, 1989a; Metsärinne and Kallio 2015; Rohaan et al. 2010; Tseng et al. 2013; Volk and Yip 1999).

Measuring Attitudes

The construct of attitude toward technology is multidimensional and may include enthusiasm/enjoyment or its antagonist, boredom, interest in the subject, students' career aspirations and future intentions, the perceived difficulty of technology, and one's beliefs regarding the consequences of technology (Ardies et al. 2015b). Attitude consists of a large number of sub-constructs, all contributing in varying proportions toward an individual's attitude. Hence, producing a unitary score on attitude is of no use. Care needs to be taken when separate constructs are combined to form one scale, with justification that these constructs are closely related (Ardies et al. 2013).

Attitudes have commonly been measured in PATT studies using questionnaires consisting of Likert scale items, which are ordinal scales used to determine students' levels of agreement or disagreement. Concepts have been measured using three-point scales, usually treated as dichotomous scales (Jeffrey 1993, 1995). Items were derived from an underlying theoretical framework, views of experts, and/or free-response answers generated by students, which is the major justification for their validity. Such open responses were then reduced to a set of usable and reliable items, piloted, and further refined by statistical analyses to eliminate those that fail to discriminate (Ardies et al. 2013; Rennie and Jarvis 1995a).

Based on the aforementioned sections, various instruments have been developed to measure attitudes. These will subsequently be discussed.

Pupils' Attitudes Toward Technology (PATT) Instruments for Ascertaining Students' Attitudes Toward Technology

The Contribution of the Pupils' Attitudes Toward Technology (PATT) Foundation and Its Studies to Instruments for Ascertaining Students' Attitudes

Before the 1980s, research related to students' attitudes toward technology was unusual (Yu et al. 2012). In the 1980s, several countries introduced technology education as a successor to some form of craft or technical education, and it began to develop its own distinct research area. Studies into students' attitudes toward and concepts of technology mostly contained information on students' ideas when entering technology education (Kőycű and De Vries 2016).

The most noted study of students' attitudes toward technology has probably been the work pioneered by Prof Jan Raat and Marc de Vries as part of "Project Physics and Technology" in the Department of Physics Education at Eindhoven University of Technology in the Netherlands in 1984 (De Vries 1988; Volk and Yip 1999). The first part of the research was done among students of ages 13–14 in secondary general education regarding their attitudes as well as how they conceptualized technology.

The PATT instrument used in the Netherlands, referred to as PATT-NL, was the first instrument specifically designed for this purpose. Results in the Netherlands were so significant that an international extension of the research was the logical next step (Ardies et al. 2013). In 1986, ten countries participated in pilot studies with the aim to increase the reliability and validity of the PATT-NL instrument. In 1987, 12 countries from across the world (e.g., Australia, India, Kenya, Mexico, Nigeria, and also European countries like Belgium, France, Italy, Poland, and the UK) started using the PATT-NL in survey studies with the aim to ascertain and describe the attitudes of students toward technology (De Klerk Wolters 1989a, c; Dugger 1988).

Initially PATT studies aimed to investigate secondary school students' attitudes and the concepts they had of technology (De Klerk Wolters 1988). PATT was a means of generating theoretical knowledge with practical implications for the development and assessment of technology education and was not aimed primarily at curriculum content (De Klerk Wolters 1989a), although it valued the link between research and curriculum development (Raat 1988).

The subsequent development of related international surveys led to workshops and the annual PATT conference, which has brought scholars involved in technology education together for over 25 years to provide a discussion platform for PATT-related issues (Jones et al. 2013; Kőycű and De Vries 2016; Volk and Yip 1999).

PATT studies as well as the PATT Foundation have played an international leadership role in the field of technology education. It has been instrumental in determining the research agenda and establishing an international research fraternity in technology education. It has also become an international discussion forum for all aspects of technology education, like curriculum development, research, teacher education, assessment, and pedagogical issues in primary and secondary schools. It brings scholars together to offer opportunities for an exchange of ideas and information to contribute toward the development of technology education (Jones et al. 2013; Mottier et al. 1991).

PATT conferences, because of their frequency, are the most productive source of research papers in the field of technology education (Williams 2016). The number of classical PATT studies focusing on students' views of technology at these conferences has declined over time in favor of technological literacy, which is still the most common category of papers presented (Volk and Yip 1999; Williams 2013, 2016).

Classical PATT studies generally made use of the following five instruments:

- An attitude questionnaire
- A concept questionnaire
- Qualitative methods like essays with the topic "*What do you think technology is*?" (age group 13–15), drawings (age group 10–12), and open-ended questions (age group 16–18) to get more information on students' attitudes and concepts
- The Technology Attitude Scale (TAS)
- The Teacher Attitude Questionnaire (De Klerk Wolters 1988, 1989a)

The PATT-Netherlands Instrument (PATT-NL)

PATT-NL was the result of an extensive development process that involved rigorous theoretical frameworks, student interviews, and expert opinions to draft the Likert-type items, as well as written responses to validate the results of early pilot studies. Large-scale survey studies in the Netherlands and international pilot studies in more than a dozen other countries resulted in two questionnaires to measure high school students' affective and cognitive perceptions about technology (De Klerk Wolters 1988, 1989a; Luckay and Collier-Reed 2014; Raat and De Vries 1986, 1987; Rennie and Jarvis 1995a).

PATT-NL consisted of the **attitude questionnaire** (De Klerk Wolters 1988; Rennie and Jarvis 1995a; Rohaan et al. 2010; Van Rensburg et al. 1999) and the **concept questionnaire** (Bame and Dugger 1989; Becker and Maunsaiyat 2002; De Klerk Wolters 1989a, b; De Vries 1992; Jeffrey 1993; Rennie and Jarvis 1995a; Rohaan et al. 2010; Van Rensburg et al. 1999) measuring the affective and the cognitive components of attitudes, respectively.

One of the aims of technology education is the formation of a positive concept of technology; therefore, students' concepts have always been an important element in PATT studies (De Vries 2005). Most of the work on students' concepts has been in relation to student perceptions of technology, using the PATT concept questionnaire (De Klerk Wolters 1988, 1989a; Raat and De Vries 1986) which was undertaken in 22 countries spread over Europe, Asia, America, Australia, and Africa (Bame et al. 1993; Jones 1997; Mawson 2010; Rennie and Jarvis 1995b; Solomonidou and Tassios 2007). In its early form, PATT-NL also included an **essay (qualitative) section.** This read *Technology can mean different things to different people. When you read the word 'technology' what comes into your mind?* to ascertain students' cognitive views of technology (Luckay and Collier-Reed 2014).

PATT-NL was subsequently adapted for use in other parts of the world, for example, the USA and South Africa. These adaptations will be briefly discussed in the next section.

The PATT-USA Instrument (PATT-USA)

The original PATT-NL was translated and modified by Bame et al. (1993) for use in the USA (Bame and Dugger 1989; Boser et al. 1998; De Klerk Wolters 1988, 1989a; Householder and Bolin 1993; Volk and Yip 1999; Zuga 1997).

PATT-USA was a one-page instrument consisting of four parts. The first was a short written description of technology, then 11 questions to gather demographic data and information about the technological climate of students' homes, 58 statements (items 12–69) with a five-point Likert-type scale to assess students' attitudes toward technology, and 31 statements (items 70–100) with a three-point Likert-type scale to assess students' concept of technology. The PATT-NL essay question was replaced with a brief statement of what the students thought technology was (Bame and Dugger 1989; Boser et al. 1998; De Klerk Wolters 1988, 1989a).

After adjusting the instrument to the specific regional context, the PATT-USA has been used in countries around the world including Botswana, Kenya, India, South Africa, Nigeria, and Mexico (Ankiewicz et al. 2001; Ardies et al. 2013; Becker and Maunsaiyat 2002; Chikasanda et al. 2013; De Klerk Wolters 1989a; Kapiyo and Otieno 1986; Meide 1997; Rajput 1988; Van Rensburg et al. 1999; Volk and Yip 1999). The language of the instrument often had to be changed, and context-specific items had to be adapted, for example, the technological toys children were exposed to (Ardies et al. 2013; Bame et al. 1993; Volk and Yip 1999). As noted by Bame et al. (1993), the international PATT studies used similar instruments, but the scales used and conditions under which the instrument was administered were different (Volk and Yip 1999).

The PATT-USA was applied in South Africa with less success than in the USA and in some other developing countries in Africa (Gaotlhobogwe 2012; Gaotlhobogwe et al. 2011; Van Rensburg et al. 1999). In Asia, Volk and Yip (1999) revised PATT-USA to develop the PATT-Hong Kong (PATT-HK). Drawing on the PATT series of instruments, Yu et al. developed an instrument suitable for junior high school students in Taiwan (in Ardies et al. 2015b). This is important as the Asian region had been neglected – the PATT studies of over 20 countries, on which the instrument was based, largely focused on countries from Europe, North America, and Africa, the sole exception being India (Bame et al. 1993; Volk and Yip 1999).

The application of PATT-USA in South Africa, as an example of a developing context, as well as the development of new instruments based on regional and contextual factors, such as the Attitudinal Technology Profile (ATP) questionnaire, will be discussed in the next section.

The Application of PATT-USA in South Africa

Van Rensburg et al. (1999) analyzed the data collected with the PATT-USA attitude questionnaire (affective component) among 1,010 students in South Africa. Contrary to the PATT-USA findings, it was found that South African girls had more positive attitudes toward technology than boys did. Girls also viewed boys as more competent at or knowledgeable in technology than boys viewed themselves. Based on the low explained variance (24.4%) and the Cronbach alpha (0.66), Van Rensburg et al. (1999) concluded however, that the PATT-USA attitude questionnaire in this instance had not yielded valid and reliable results. The researchers attributed these differences to problems concerning the questionnaire design and its application in developing countries. They pointed out that the understanding of concepts and terminology due to language barriers, frame of reference, culture, and how items were formulated influenced the empirical research (Solomonidou and Tassios 2007; Van Rensburg et al. 1999).

The affective-related items (12–69) in PATT-USA were formulated using prescriptive or evaluative propositions (Van Rensburg et al. 1999). Its revisions departed from the original PATT-NL, and in the overwhelming majority of attitude measures, the items were formulated as prescriptive or evaluative propositions.

In resolving the contextual and formulation problems experienced with the PATT-USA, Van Rensburg et al. (1999) designed the **Attitudinal Technology Profile (ATP) questionnaire** to be used in the lower secondary school (ages 13–14). In Part A of this instrument, students were familiarized with the construct of technological product, in order to avoid misconceptions. In Part B, 24 items were included on a five-point Likert-type scale to assess students' attitudinal technology profile (Ankiewicz et al. 2001).

The ATP questionnaire avoided demanding any high-level language proficiency. The items were designed and formulated as descriptive propositions linked to the affective components of the content of technology and attitude. By using descriptive propositions, it was also possible to integrate the affective component of attitude to some extent with the behavioral component (only students' readiness for action). PATT-USA did not address the behavioral component of attitude. In the ATP questionnaire, students had to respond to gender-neutral descriptive items. The responses of the boys on all items were then compared with the responses of the girls on all items in order to determine whether any gender-related differences existed (Ankiewicz et al. 2001; Van Rensburg et al. 1999).

The ATP questionnaire was piloted in two so-called township schools among 481 students. Only four factors or subscales were identified, in contrast to the six factors identified with PATT-USA. The 24 affective-related items, based on descriptive propositions, yielded more valid and reliable results than the 58 affective-related items of PATT-USA, which were based on evaluative/prescriptive propositions, had done. The explained variance (35.5%) and the Cronbach alpha (0.78) were higher, compared to 24.4% and 0.66 for PATT-USA previously used in South Africa (Ankiewicz et al. 2001).

Several researchers stated that PATT-NL and PATT-USA were useful, but often too long to administer in a study combining instruments. If measuring attitude and technological literacy in the same students, time limitation became an issue (Ardies et al. 2013; Volk and Yip 1999). The problem of length was partly addressed, at least for the attitude questionnaire, by the shorter PATT-SQ version.

The Reconstruction of PATT-USA into the PATT Short Questionnaire (PATT-SQ)

The attitude questionnaire (affective component) of the PATT-USA instrument as developed in the 1990s was recently reconstructed and revalidated by Ardies et al. (2013). This resulted in the shorter PATT-SQ instrument with six sub-factors (career aspirations, interest in technology, tediousness, positive perception of effects of technology, perception of difficulty, and perception of technology as a subject for boys or for boys and girls) and 24 items of attitude toward technology (Ardies et al. 2013).

PATT studies of students' attitudes toward technology often focus on the effects of a single determinant or predictive characteristic (e.g., gender) on one aspect of attitude (e.g., interest in technology) as a unidimensional concept. The total effect can then not be ascertained adequately as attitude is a multidimensional concept. In contrast to most earlier research, Yu et al. (2012) and Ardies et al. (2013, 2015b) embarked on multidimensional (multivariate, multilevel) studies, which will be discussed next.

Multidimensional (Multivariate, Multilevel) Versus Unidimensional Studies

By drawing on the PATT series of instruments, Yu et al. (2005, in Yu et al. 2012) developed the Attitudes Toward Technology Scale for junior high school students in Taiwan to enable Taiwanese scholars of technology education to design and implement research consistent with international norms. By comparing the five attitude factors based on dimensions of the affective domain to the six PATT-NL factors, they proposed five factors, namely, technology interest, identification, perplexity, curriculum, and career (Yu et al. 2012). The technology acceptance model (TAM) explains relationships among users' attitudes, motivations, and use by focusing on the usefulness and ease of use of technology. The correlations among the five factors, namely, technology interest, identification, perplexity, curriculum, and career (Yu et al. 2012) themselves, the effect of the factors on the attitudes of junior high school students in Taiwan, and the identification of the factor with the strongest influence on their attitudes were studied through path analyses of effects via multiple regression analyses. Contrary to the expectation of significant other correlations, this study confirmed only the correlation of intention to pursue a career in technology with identification with technology and with experience of technology curricula (Yu et al. 2012).

Ardies et al. (2015b) developed a matrix in which the five different dimensions of attitude as described by De Vries (1988) were set up as rows. The predictive characteristics found in literature (i.e., gender, age, toys, and parents) were set up as columns. The studies, presented in the cells of the matrix, drew on technology (T), science (S), or the broader domain of STEM. The PATT-SQ instrument was used in a large-scale multivariate (i.e., a statistical model that allows analyses of multiple dependent variables in one analysis), multilevel (i.e., the first level is the student level and the second level is the teacher level) investigation of 12–14-year-old students in Flanders (grade 1 and 2 of secondary education). The aim was to determine the effect of all predictive characteristics or determinants (Ardies et al. 2015a) on all aspects of students' attitudes. The results confirmed previous fragmented studies in related disciplines like science education (Ardies et al. 2015b).

Ardies et al. (2015a) also performed a longitudinal investigation with PATT-SQ of 12–14-year-old students in Flanders, exploring the evolution of their interest in technology and the determining characteristics for differences in the attitudes of boys and girls, respectively, over time. The results indicated that boys' and girls' interest in technology evolved differently and that the initial differences between them diminished over time.

A summary of the general research findings regarding students' attitudes toward and concepts of technology, in particular in the PATT studies, is given in the next section.

Summary of General Research Findings on Students' Attitudes Toward and Concepts of Technology

The general findings of research studies, in particular the international PATT, indicated that while students had positive attitudes toward technology, they generally had a limited concept of technology. Students often perceived technology as a recent phenomenon and as artifacts or products (e.g., domestic appliances and computers) and did not recognize it as a process (Bame et al. 1993; Cajas 2002; De Klerk Wolters 1989b; De Vries 1988; De Vries and Tamir 1997; Jones 1997; Rennie and Jarvis 1995b; Rohaan et al. 2010; Solomonidou and Tassios 2007).

Students' attitudes toward technology may be attributed to various determinants or predictive characteristics (Ankiewicz et al. 2001; Becker and Maunsaiyat 2002; Van Rensburg et al. 1999) such as context, gender, students' age, the technological nature of the family's professions, and the technological toys and facilities at home (Ardies et al. 2015a).

Context is an important determinant or predictive characteristic that influences students' attitudes. Educational research is far from easy because of the importance of context (Ardies et al. 2015b). The contextual problems experienced with PATT-USA in a developing country have already been alluded to. Gaotlhobogwe (2012) also found that in a developing context, a lack of resources (i.e., the availability of materials, tools, and other equipment) in schools may influence secondary school students' attitudes and perceptions toward technology to such an extent that they did not choose the subject technology.

The age of students as a determinant has an influence on how students perceive technology and their attitudes toward it (Bame 1991; De Vries 1988). De Klerk Wolters (1989b) found that a student aged 10 already had a clear perception or concept of technology as a base for developing attitudes toward technology.

Another important determinant is gender. Findings from studies examining gender issues generally indicated that boys had more positive attitudes toward technology than girls did (Ardies et al. 2015a; Bame et al. 1993; De Klerk Wolters 1989b; De Vries 1988; Mawson 2010; Rennie 1988; Rohaan et al. 2010). Exceptions to these findings were noted by Balogun (1988) in Nigeria and Prime (1991) in Trinidad and Tobago, where no significant gender differences with regard to attitudes and concepts were found. However, on the African continent, attitudes seemed less clear-cut (Meide 1997). Gaotlhobogwe et al. (2011) reported that girls' attitudes toward technology were generally less positive than boys'. In South Africa as another example of a developing context, Van Rensburg et al. (1999) found, on the contrary, that boys were less interested in technology than girls. Furthermore, girls were found to possess more positive attitudes toward technology than boys

(Ankiewicz et al. 2001). In Asia, the PATT-HK results paralleled many of the broad characteristics found in the PATT-USA data on other developed countries (Volk and Yip 1999).

Gender differences are also related to age (Ardies et al. 2015a; Lou et al. 2011; Mawson 2010; Rasinen et al. 2009; Salminen-Karlsson 2007). Gender differences have been found to exist at the age of 10 already and do not disappear on the attitude scales over time (De Klerk Wolters 1989b, c). Recently Ardies et al. (2015a) found the contrary regarding the interest scale, where the gender differences diminished over time. There was an increase in the perceived utility of technology for boys between the ages of 10 and 14 years old, resulting in differences between boys and girls from the age of 14 (Ardies et al. 2015b).

The presence of technological toys has a stimulating effect on students' attitudes, and gender differences may correlate with the presence of and actually playing with technological toys (Ardies et al. 2015b; Bame et al. 1993; Volk and Yip 1999). Rasinen et al. (2009) and Salminen-Karlsson (2007) point out that stereotypical ideas, for example, that technology is a male profession, are stimulated from primary school age by giving students gender-specific toys (Ardies et al. 2015b; Volk and Yip 1999).

Factors such as parents' level of training and/or occupation, their interest in technology, and technology education at primary school level have a positive effect on the attitudes of both boys and girls (Doornekamp 1991). Parents in a profession related to technology have a positive influence on several aspects of attitude toward technology (Ardies et al. 2015b; Bame et al. 1993; Becker and Maunsaiyat 2002).

Students' perceptions of technology and technology education influence what knowledge and skills they operationalize in a technological task and hence affect their technological capability. Students with a broad concept of technology are more likely to undertake technological activities in a holistic fashion, i.e., displaying links between the various stages in the process. A narrow concept of technology constrains students' technological practice and limits their potential for learning technological concepts and processes (Jones 1997). Students associating technology only with computers and modern appliances have less positive attitudes toward technology. Unfortunately, but not fully accidentally, these tend to be mostly girls (Jarvis and Rennie 1996; Rohaan et al. 2010). It has also been found that students' understanding of the concepts of technology increases with age (Bame et al. 1993; Becker and Maunsaiyat 2002; Mawson 2010).

From the PATT studies, it can be concluded that students' concepts of technology are strongly related to their attitudes toward technology. Concept appears to influence affect and not the other way around. This result indicates that a correct and comprehensive concept corresponds with a positive attitude toward technology (De Klerk Wolters 1989b; Rohaan et al. 2010).

Studies of students' attitudes toward technology often focus on the effects of a single determinant or predictive characteristic (e.g., gender) on one aspect of attitude (e.g., interest in technology) as a unidimensional concept. The total effect can then not be ascertained adequately as attitude is a multidimensional concept.

Conclusion

PATT studies were a pioneering initiative in ascertaining students' attitudes toward and perceptions or concepts of technology in the mid-1980s. These were pivotal in setting the broader research agenda for the field of technology education and played a major role in establishing and unifying the international research fraternity in technology education by providing frequent opportunities to share broader research findings.

Based on contextual factors such as language and age, the PATT-NL was adapted for several countries like the USA, Hong Kong, and Taiwan. Subsequently new instruments, such as the ATP, were also developed.

It has been found that students generally have a positive attitude toward technology but a limited concept of technology. Students often perceive technology as a recent phenomenon and as artifacts or products and do not recognize it as a process. Their attitudes toward technology may be attributed to various determinants or predictive characteristics such as gender, technological nature of family's professions, existence of technological toys, and facilities at home.

Research has evolved to a stage now where researchers are interested in small- to medium-scale multidimensional (multivariate, multilevel) studies to determine the effect of all characteristics or determinants on all aspects of students' attitudes as opposed to the effects of a characteristic on a specific aspect of attitude only. More such effect studies will be crucial for deepening our understanding of students' perceptions of and attitudes toward technology.

Acknowledgment I would like to express my sincere gratitude toward my former colleague and Master's student, Dr. Susan van Rensburg, and colleague, Prof Chris Myburgh all working together enthusiastically and committedly on this theme toward the end of the previous century. Also to my research assistant, Ben Low who assisted me in collating and meticulously organizing the applicable sources over a short period.

References

Ankiewicz, P., Van Rensburg, S., & Myburgh, C. (2001). Assessing the attitudinal profile of South African learners: A pilot study. *International Journal of Technology and Design Education, 11* (2), 93–109. doi:10.1023/A:1011210013642.

Ardies, J., De Maeyer, S., & Gijbels, D. (2013). Reconstructing the pupils attitude towards technology-survey. *Design and Technology Education: An International Journal, 18*(1), 8–19.

Ardies, J., De Maeyer, S., & Gijbels, D. (2015a). How do male and female secondary students' attitudes towards technology evolve? In *PATT 29 conference proceedings* (pp. 26–34). Marseille: Presses Universitaires de Provence.

Ardies, J., De Maeyer, S., Gijbels, D., & van Keulen, H. (2015b). Students' attitudes towards technology. *International Journal of Technology and Design Education, 25*(1), 43–65.

Bagozzi, R. P., & Burnkrant, R. E. (1979). Attitude organization and the attitude-behaviour relationship. *Journal of Personality and Social Psychology, 37*, 913–929.

Balogun, T. A. (1988). Nigerian pupils' attitudes and conceptions of technology. In *PATT 3 conference proceedings* (pp. 294–302). Eindhoven.

Bame, A. E. (1991). PATT – Research: Perspective and prospect. In *PATT 5 conference proceedings* (Vol. 2, pp. 129–140). Eindhoven.
Bame, E. A., & Dugger, W. E. (1989). Pupils' attitude towards technology: PATT-USA. In *PATT 4 conference proceedings* (pp. 309–319). Eindhoven.
Bame, E., Dugger, W., de Vries, M., & McBee, J. (1993). Pupils' attitudes toward technology – PATT-USA. *Journal of Technology Studies, 19*(1), 40–48.
Becker, K. H., & Maunsaiyat, S. (2002). Thai students' attitudes and concepts of technology. *Journal of Technology Education, 13*(2), 6–19.
Boser, R. A., Palmer, J. D., & Daugherty, M. K. (1998). Students attitudes toward technology in selected technology education programmes. *Journal of Technology Education, 10*(1), 4–19.
Breckler, S. J. (1984). Empirical validation of affect, behaviour, and cognition as distinct components of attitude. *Journal of Personality and Social Psychology, 47*(6), 1191–1205.
Cajas, F. (2002). The role of research in improving learning technological concepts and skills: The context of technological literacy. *International Journal of Technology and Design Education, 12*(3), 175–188.
Chikasanda, V. K. M., Otrel-Cass, K., Williams, J., & Jones, A. (2013). Enhancing teachers' technological pedagogical knowledge and practices: A professional development model for technology teachers in Malawi. *International Journal of Technology and Design Education, 23*(3), 597–622.
Corsini, R. J., & Ozaki, B. D. (Eds.). (1984). *Encyclopedia of psychology* (Vol. 1). New York: Wiley.
De Klerk Wolters, F. (1988). PATT research in 1987/88. In *PATT 3 conference proceedings* (pp. 39–46). Eindhoven.
De Klerk Wolters, F. (1989a). The PATT-project, an overview of an international project in technology education. In *PATT 4 conference proceedings* (pp. 290–308). Eindhoven.
De Klerk Wolters, F. (1989b). A PATT study among 10 to 12-year-olds. In *PATT 4 conference proceedings* (pp. 324–330). Eindhoven.
De Klerk Wolters, F. (1989c). Summary of theme 2. In *PATT 4 conference proceedings* (pp. 331–334). Eindhoven.
De Vries, M. (1988). Technology in physics education. In *PATT 3 conference proceedings* (pp. 182–188). Eindhoven.
De Vries, M. J. (1992). Dutch technology education developments: A comment. *International Journal of Technology and Design Education, 2*(3), 58–60.
De Vries, M. J. (2000). Concepts in technology: Seeing the order in the chaos. In G. E. Martin (Ed.), *Technology education for the 21st century* (pp. 207–212). Peoria: Glencoe/McGraw-Hill.
De Vries, M. J. (2005). The nature of technological knowledge: Philosophical reflections and educational consequences. *International Journal of Technology and Design Education, 15*(2), 149–154.
De Vries, M. J., & Tamir, A. (1997). Shaping concepts of technology: What concepts and how to shape them. *International Journal of Technology and Design Education, 7*, 3–10.
Doornekamp, B. G. (1991). Gender differences in the acquisition of technical knowledge, skills and attitudes in Dutch primary education: The need for technology education. *International Journal of Technology and Design Education, 2*(1), 37–47.
Dugger, W. E. (1988). Technology – The discipline. In *PATT 3 conference proceedings* (pp. 255–271). Eindhoven.
Dunlap, D. D., & Dugger, W. E. (1991). Comparing attitudes towards technology of third and forth grade students in Virginia relative to their exposure to technology. In *PATT 5 conference proceedings* (Vol. 2, pp. 194–201). Eindhoven.
Fishbein, M., & Ajzen, I. (1973). Attitudes and opinions. *Annual Review of Psychology, 24*, 487–544.
Gagné, R. M. (1977). *The conditions of learning*. New York: Holt, Rinehart & Wilson.
Gaotlhobogwe, M. (2012). The impact of lack of resources on declining students' enrolments in design and technology in Botswana junior secondary schools. *Design and Technology Education: An International Journal, 17*(1), 10–17.

Gaotlhobogwe, M. (2015). A comparative analysis of patterns of girls' attitudes towards D&T: The case of Botswana and Swaziland. In *PATT 29 conference proceedings* (pp. 146–153). Marseille: Presses Universitaires de Provence.

Gaotlhobogwe, M., Laugharne, J., & Durance, I. (2011). The potential of multivariate analysis in assessing students' attitude to curriculum subjects. *Educational Research, 53*(1), 65–83. doi:10.1080/00131881.2011.552241.

Heaven, P. C. C. (1982). *Houdings*. Pretoria: Academia. (in Afrikaans).

Hill, A. M. (1997). Reconstructionism in technology education. *International Journal of Technology and Design Education, 7*, 121–139.

Householder, D. L., & Bolin, B. (1993). Technology: Its influence in the secondary school upon achievement in academic subjects and upon students' attitude toward technology. *International Journal of Technology and Design Education, 3*(2), 5–18.

Jarvis, T., & Rennie, L. (1996). Perceptions about technology held by primary teachers in England. *Research in Science and Technology Education, 14*(1), 43–54.

Jeffrey, T. J. (1993). Validation of a technology attitude scale for use by American teachers at the middle school level. In *PATT 6 conference proceedings* (pp. 357–364). Breukelen.

Jeffrey, T. J. (1995). Adaption and validation of a technology attitude scale for use by American teachers at the middle school level. In *PATT 7 conference proceedings* (pp. 53–58). Breukelen.

Jones, A. (1997). Recent research in learning technological concepts and processes. *International Journal of Technology and Design Education, 7*(1–2), 83–96.

Jones, A., Bunting, C., & De Vries, M. J. (2013). The developing field of technology education: A review to look forward. *International Journal of Technology and Design Education, 23*, 191–212.

Kapiyo, R., & Otieno, F. (1986). Some aspects in the measurement of pupils' attitude to technology in a third world context: Highlights from Kenya. In J. H. Raat & M. J. De Vries (Eds.), *What do girls and boys think of technology? PATT workshop report* (pp.82–89). Eindhoven.

Kőycű, Ü., & De Vries, M. J. (2016). What preconceptions and attitudes about engineering are prevalent amongst upper secondary school pupils? An international study. *International Journal of Technology and Design Education, 26*(2), 243–258.

Lou, S. J., Shih, R. C., Diez, C. R., & Tseng, K. H. (2011). The impact of problem-based learning strategies on STEM knowledge integration and attitudes: An exploratory study among female Taiwanese senior high school students. *International Journal of Technology and Design Education, 21*(2), 195–215.

Luckay, M. B., & Collier-Reed, B. I. (2014). An instrument to determine the technological literacy levels of upper secondary school students. *International Journal of Technology and Design Education, 24*(3), 261–273.

Mammes, I. (2004). Promoting girls' interest in technology through technology education: A research study. *International Journal of Technology and Design Education, 14*(2), 89–100.

Mawson, B. (2010). Children's developing understanding of technology. *International Journal of Technology and Design Education, 20*(1), 1–13.

Meide, J. B. (1997). Pupils' attitudes towards technology: Botswana. In *PATT 8 conference proceedings* (pp. 208–213). Scheveningen.

Metsärinne, M., & Kallio, M. (2015). How are students' attitudes related to learning outcomes? *International Journal of Technology and Design Education*, 1–19. doi:10.1007/s10798-015-9317-0.

Mottier, I., Raat, J. H., & De Vries, M. J. (Eds.). (1991). Report on the PATT 5 conference. In *PATT 5 conference proceedings* (Vol. 1, pp. 9–13). Eindhoven.

Ostrom, T. M. (1969). The relationship between the affective, behavioral, and cognitive components of attitude. *Journal of Experimental Social Psychology, 5*, 12–13.

Prime, G. (1991). The attitudes and concepts of Trinidad and Tobago secondary school students toward technology. In *PATT 5 conference proceedings* (Vol. 2, pp. 172–181). Eindhoven.

Raat, J. H. (1988). Introduction to the theme of the conference. In *PATT 3 conference proceedings* (pp. 30–38). Eindhoven.

Raat, J. H., & De Vries, M. J. (1986). What do girls and boys think of technology? In *PATT workshop report* (pp. 13–25). Eindhoven.

Raat, J. H., & De Vries, M. (Eds.). (1987). Technology in education: Research and development in the project 'Physics and Technology'. *International Journal of Science Education, 9*, 159–168.

Rajput, R. S. (1988). Projection of different gender and social setting over attitudinal difference to technology. In *PATT 3 conference proceedings* (pp. 337–356). Eindhoven.

Rasinen, A., Virtanen, S., Endepohls-Ulpe, M., Ikonen, P., Ebach, J., & Stahl-von Zabern, J. (2009). Technology education for children in primary schools in Finland and Germany: Different schools systems, similar problems and how to overcome them. *International Journal of Technology and Design Education, 19*(4), 367–379.

Rennie, L. J. (1988). How can we make technology interesting for girls? In *PATT 3 conference proceedings* (pp. 397–414). Eindhoven.

Rennie, L., & Jarvis, T. (1995a). Three approaches to measuring children's perceptions of technology'. *International Journal of Science Education, 17*(6), 755–774.

Rennie, L., & Jarvis, T. (1995b). English and Australian children's perceptions about technology. *Research in Science & Technological Education, 13*(1), 37–52.

Rohaan, E. J., Taconis, R., & Jochems, W. M. (2010). Reviewing the relations between teachers' knowledge and pupils' attitude in the field of primary technology education. *International Journal of Technology and Design Education, 20*(1), 15–26.

Salminen-Karlsson, M. (2007). Girls' groups and boys' groups at a municipal technology centre. *International Journal of Science Education, 29*(8), 1019–1033.

Solomonidou, C., & Tassios, A. (2007). A phenomenographic study of Greek primary school students' representations concerning technology in daily life. *International Journal of Technology and Design Education, 17*(2), 113–133.

Tseng, K. H., Chang, C. C., Lou, S. J., & Chen, W. P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education, 23*(1), 87–102.

Van Rensburg, S., Ankiewicz, P., & Myburgh, C. (1999). Assessing South Africa learners' attitudes towards technology by using the PATT (pupils' attitudes towards technology) questionnaire. *International Journal of Technology and Design Education, 9*, 137–151.

Volk, K. S., & Yip, W. M. (1999). Gender and technology in Hong Kong: A study of pupils' attitudes toward technology. *International Journal of Technology and Design Education, 9*, 57–71.

Volk, K., Yip, W. M., & Lo, T. K. (2003). Hong Kong pupils' attitudes toward technology: The impact of design and technology programs. *Journal of Technology Education, 15*(1), 48–63.

White, R. T. (1988). *Learning science*. New York: Basil Blackwell.

Williams, P. J. (2013). Research in technology education: Looking back to move forward. *International Journal of Technology and Design Education, 23*(1), 1–9.

Williams, P. J. (2016). Research in technology education: Looking back to move forward... again. *International Journal of Technology and Design Education, 26*(2), 149–157.

Yu, K.-C., Lin, K.-Y., Han, F.-N., & Hsu, I. Y. (2012). A model of junior high school students' attitudes toward technology. *International Journal of Technology and Design Education, 22*(4), 423–436.

Zuga, K. F. (1997). An analysis of technology education in the United States based upon an historical overview and review of contemporary curriculum research. *International Journal of Technology and Design Education, 7*(3), 203–217.

Collaborative Design Work in Technology Education

42

Kaiju Kangas and Pirita Seitamaa-Hakkarainen

Abstract

This chapter examines how designing, particularly collaborative designing, could be promoted in technology education classrooms. A few pedagogical models, where the design process is approached through collaborative inquiry, are presented. One approach, *Learning by Collaborative Design* (LCD), is described in greater detail, because of its unique applicability to technology education. The approach focuses on object-oriented learning, i.e., learning activities organized around the systematic and deliberate pursuit of knowledge creation by constructing design artifacts. The chapter introduces focal elements of the LCD model, such as authentic design tasks that balance openness and constraints, as well as promotion of mediated and embodied design practices, and discusses their implications for technology education. In conclusion, the linkage between design learning and the maker movement is examined, and directions for future research are proposed.

Keywords

Design learning • Collaborative designing • Design problems • Design constraints • Design practices

Contents

K. Kangas (✉) • P. Seitamaa-Hakkarainen
Faculty of Educational Sciences, University of Helsinki, Helsinki, Finland
e-mail: kaiju.kangas@helsinki.fi

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_44

Introduction

In the contemporary world, design is all-pervasive, with the social, cultural, and environmental effects of design apparent either directly or through various media. Designed artifacts and solutions affect our lives and values, both from a personal and societal perspective. In a broad sense, design concerns the ways in which human beings modify their environments to better satisfy their needs and wants (e.g., de Vries 2009; ITEA 2007). In many cases, the design process is realized through working with various materials and technologies. Furthermore, the visual and technical knowledge of designing is essential; students learn how to generate design ideas, develop their ability to advance the ideas by drawing and using CAD tools (e.g., Kelley and Sung 2016), and learn to materialize their ideas with different tools, techniques, and materials (e.g., Welch 1998). Consequently, the overall aim of design learning in general education (i.e., elementary and secondary school) can be seen as generating a basic understanding of how design and technology affect the world and how we exist around design and technology (de Vries 2009; ITEA 2007). Thus it can be argued that design is at the core of technology education, and neither design nor technology can be fully appreciated without an understanding of the other.

Both design and technology are still newcomers in education; in most Western countries design and technology education has been developed only in the past two or three decades (de Vries 2009). There is considerable variation between countries in how design is included in the curriculum and used in the classroom (e.g., Kelley and Sung 2016). In some countries (such as the UK), design is included in technology education; in others, it is a cross-curricular subject or integrated with other school subjects, such as science, art, home economics, or craft. Design can be a subject of investigation, a means of investigation, or both. It can be either compulsory or optional. Thus, design education lacks the identity and long tradition of a well-established subject, such as mathematics or science, and still needs a framework and a basic concept as a subject in education (Dahlin et al. 2013).

This chapter examines how collaborative designing could be promoted within technology education. As with any other form of intelligence, design competence is not a given "talent" or "gift," but can be learned and developed. Learning through design (Harel 1991) is based on a constructionist theory that regards learners as builders of their own knowledge (Kafai 2006; Papert 1991) and sees learning not only as the development of knowledge but also as the cultivation of ways of thinking and acting. Collaborative designing refers to a process in which students actively communicate and work together in identifying design constraints, creating and sharing design ideas, deliberately making joint decisions and producing shared design objects, constructing and modifying their design solutions, as well as evaluating their outcomes through discourse (Hennessy and Murphy 1999).As the design process closely resembles inquiry process, this chapter, first, presents a few pedagogical models where the design process is approached with collaborative inquiry. Then, one model, the *Learning by Collaborative Design* model, is described more thoroughly, as it is considered especially applicable to technology education. Focal elements of the model, design problems, and constraints, as well as mediated and embodied design practices, are presented and implications for technology education discussed. Finally, conclusions and future directions of designing within technology education will be considered.

Approaching Design and Technology Through Collaborative Inquiry

Inquiry-based approaches to design and technology education have originally been developed in countries (such as the USA), where mainly technology, but also design, has been considered as part of STEM education. These approaches purposefully use design and technology as a vehicle for constructing new science knowledge. Integrating design and technology with science is seen as a valuable process, allowing students to construct a deep understanding of scientific principles. An inquiry approach to the scientific process as mentioned by Fox-Turnbull, in ▶ Chap. 39, "Classroom Interaction in Technology Education" of this volume, and Krajick and Merritt (2012) emphasizes, for example, asking questions, planning investigations, using resources to find information, analyzing data, communicating results, and recognizing and analyzing alternative explanations and predictions. Learning through design encourages students to engage in many of these practices.

Learning by Design™ (LBD) (Kolodner et al. 2003) and *Design-Based Science* (DBS) (Fortus et al. 2004) are programs in which a design challenge provides students a reason for learning science content; engaging in the challenge provides an authentic and meaningful context for using both science and design skills. In both LBD and DBS classrooms, the work is built on multiple iterative cycles of constructing, evaluating, and revising models, along with discussion of issues that arise while solving the design challenge. The main distinction between the programs is that in LBD, all iterations focus on the same science concepts, but at increasing levels of complexity, whereas in DBS each iteration focuses on a different science concept. However, each cycle also returns to the concepts presented in former cycles in order to facilitate the development of a deep understanding of each of the studied concepts. LBD and DBS have much in common with other inquiry-based programs, which all share certain features: they (a) focus on authentic tasks for lengthy periods of time, (b) lead to the creation of artifacts, (c) encourage the use of alternative assessment methods, (d) make use of computer-based technology, (e) build upon collaboration, and (f) view the teacher as a facilitator and a learner along with the students.

The inquiry activities common to science classrooms can be used as a part of design and technology education (Krajick and Merritt 2012). However, designing also includes many features that cannot be reached through logical reasoning or other methods used in science. In order to support students and teachers in engaging in an inquiry-based approach to design within technology, two pedagogical models have been developed: *Design-Oriented Pedagogy* (DOP) (Liljeström et al. 2014; Vartiainen et al. 2012) and *Learning by Collaborative Design* (LCD) (Seitamaa-Hakkarainen et al. 2001, 2010). Both approaches share several similarities with other inquiry-based pedagogies, but in particular they focus on object-oriented learning, i.e., learning activities organized around the systematic and deliberate pursuit of knowledge creation through shared "objects" (see Hakkarainen et al. 2004; Paavola et al. 2004). The main distinction between the approaches is that within LCD, students create knowledge through constructing design artifacts, whereas in the DOP the emphasis is more on working with knowledge that is embedded in or bound to cultural artifacts or natural objects.

The DOP (Liljeström et al. 2014; Vartiainen et al. 2012) emphasizes participatory perspectives on learning and situates learning in out-of-school environments. The DOP framework consists of four main phases: articulation of the phenomenon, designing of the learning object, data collection of the learning object, and construction of the learning object. Typically the process begins at school and then extends to a natural or cultural environment (such as a forest or museum) and to network communities. The learning process is anchored on students' ideas, thoughts, conceptions, and interpretations about the shared design task, and participation in an expert community is driven by the students' own interests and research questions. Students work together in teams in pursuit of advancing their own understanding to be shared with the extended community. Moreover, the DOP employs the notion of self-organizing systems of participatory cultures by underlining that the process is not scripted in detail in advance, but has to be negotiated and actively designed by the learners themselves.

Similarly, the LCD approach (Seitamaa-Hakkarainen et al. 2001, 2010) emphasizes the open-endedness of the design learning process, as well as distributed expertise and collaboration in all the phases of the process. Design problems are complex and multidisciplinary in nature, and competence in design results largely from interaction and collaboration with other individuals. Drawing on over 20 years of educational research, the learning sciences have consistently proved that successful collaboration supports learning in many ways, for example, by fostering deep understanding (see, e.g., Sawyer 2006). The experiences of collaborative designing in educational settings appear to promote both participants' creativity and their practices of collective elaboration of design ideas (Fischer et al. 2005) and the implementation of these ideas in the actual design of artifacts. Furthermore, the LCD underlines the use of expert tools and practices already in elementary school, since expert knowledge is adapted to its purpose, and facilitates flexible problem-solving (Kangas et al. 2013a).

The DOP framework focuses particularly on knowledge creation through natural or cultural artifacts in extended learning environments; the LCD is a more general approach to design learning especially applicable to technology education. In the next section, the background and elements of the LCD approach are described.

Learning by Collaborative Design

The Learning by Collaborative Design model (LCD) has its theoretical foundations in the pedagogical approaches of knowledge building (e.g., Bereiter and Scardamalia 2003; Scardamalia and Bereiter 2003) and progressive inquiry (e.g., Hakkarainen 2009). In addition to discussing and sharing their opinions of the issues and themes under study, students engage in crystallizing, externalizing, sharing, and developing knowledge artifacts, such as sketches or prototypes, which embody their ideas (Scardamalia and Bereiter 2003). Creating new knowledge is seen to be a process embedded in the practices enacted, and knowledge is treated as something that can be shared and jointly developed (Hakkarainen 2009). Knowledge is dealt through the *design mode* where the focal concern is the usefulness, adequacy, improvability, and developmental potential of all ideas (Bereiter and Scardamalia 2003). The LCD approach has been developed for over 10 years, both in the higher education context (e.g., Lahti et al. 2004) and in elementary schools (e.g., Kangas et al. 2013b; Seitamaa-Hakkarainen et al. 2010; Viilo et al. 2011).

The visual LCD model depicts designing as a spiral and cyclical process that is approached iteratively through successive sequences (Fig. 1). The model consists of the following phases: (1) creating the design context; (2) defining the design task and related design constraints; (3) creating conceptual and visual (physical) design ideas; (4) evaluating design ideas and constraints; (5) connecting to expert communities and collecting data; (6) experimenting and testing design ideas by sketching, modeling, and prototyping; (7) evaluating functions of prototypes; and (8) elaborating design ideas and redesigning. However, the phases of the LCD model are not a prescription of rigidly specified design stages; rather, they describe the intertwined facets of the complex and iterative design process. The participants (students, teachers, and domain experts) share their expertise in creating a meaningful and authentic design context and task for analyzing design constraints and collecting knowledge, as well as providing feedback, in order to develop a shared design object.

While the knowledge building pedagogy highlights conceptual aspects of inquiry (e.g., students' own theories), the LCD approach additionally underlines the role of tools, instruments, prototypes, and other physically embodied aspects of inquiry as essential parts of the process (see Hakkarainen 2009); the interaction through and around these design elements is primary. Designing involves the creation and use of various forms of 2D and 3D representations, such as sketches, drawings, mind maps, material collages, mock-ups, and prototypes. Through visualization and materialization, design ideas become visible for joint evaluation and development; therefore, externalization of ideas plays a crucial role in collaborative designing. From the beginning to the end, the design process is mediated by the shared artifacts being designed. Thus, constant cycles of idea generation, and testing of design ideas by visual

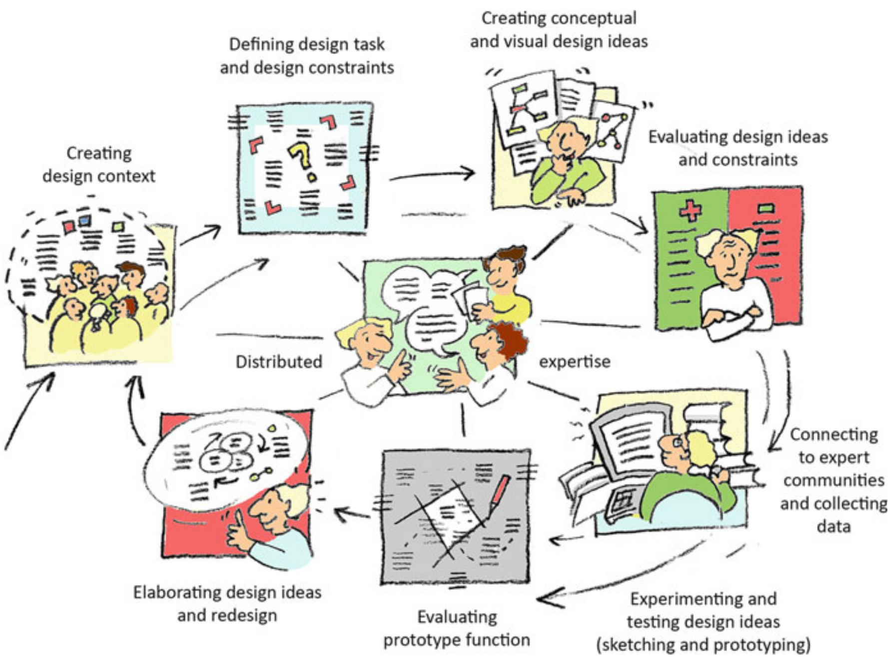


Fig. 1 The model of learning by collaborative design (adapted from Seitamaa-Hakkarainen et al. 2010)

modeling or prototyping, characterize the process. The participants transform conceptual ideas into material forms in a way that, in turn, elicit further elaboration of ideas.

The following two sections of this chapter concentrate on the focal elements of the LCD approach. First, the role of design tasks and constraints within technology education is examined, and second, the mediated and embodied nature of design practices is studied.

The Role of Design Tasks and Design Constraints

The LCD approach emphasizes an authentic design task situated in a meaningful context as the foundation of the whole design learning process. Furthermore, the model highlights design constraints as essential characteristics of the process. Setting up a design task for the students is a constant quest for balance between the openness and constraints of the task. According to Sawyer (2012) too much openness or a lack of constraints may lead to traditional ways of making, whereas tasks that have constraints in balance prevent students from following familiar patterns and lead them to more advanced conceptions.

An authentic task refers to a problem that is both coherent and personally meaningful, as well as purposeful within a social framework (Hennessy and Murphy 1999).

Within the framework of designing, problems have a special nature and a particular structure. Design problems are ill-defined and ill-structured (Goel and Pirolli 1992), that is, they are complex, open-ended, and dynamic; the process of solving the problem is parallel with the understanding of its nature (Dorst and Cross 2001; Lawson 2006). Creative designing simultaneously develops and refines both the design problem at hand and ideas for its solution, with constant iteration of analysis, synthesis, and evaluation processes (Dorst 2006; Dorst and Cross 2001).

In principle, the number of possible solutions to design problems is unlimited, which can be overwhelming for young students' learning design. However, design constraints determine and limit the amount of solutions (Lawson 2006). Such constraints have a central role in the design process; through them a designer is able to construct a rationale for design decisions (Goel and Pirolli 1992; Goel 1995; Seitamaa-Hakkarainen and Hakkarainen 2000). Lawson (2006) divides the design constraints into two main types, those that are linked with some external factor not under the designer's control (e.g., user needs) or those that are internal to the system or object being designed (e.g., safety regulations). External constraints are generated through the needs of participants in the design process, the requirements of the physical environment of the product being designed, or in terms of available resources, among other factors. They are more rigid than internal constraints and can sometimes determine the whole form of the process. On the other hand, external constraints can be inspirational and compose the very essence of the special, possibly unique, context for designing. Internal constraints form the basis of the problem-solving process, are flexible, and have only an abstract connection to the designed object.

As described above, the LCD model underlines collaboration and distributed expertise in all the phases of the design learning process, including the definition of the design task and the constraints. In schools generally, and in technology education particularly, design projects can address several themes from cultural phenomena to interdisciplinary topics. The meaning of the process is constructed by the teacher, on one hand, who embeds different goals to the design tasks and anchors it to students' previous knowledge. On the other hand, the reason for designing is formulated by the students themselves through the process of framing the design task, generating design ideas, and constructing the problem and solution simultaneously (Laamanen and Seitamaa-Hakkarainen 2014). When students are actively involved in formulating the design task and the related constraints, they are better able to deal with the ambiguity of the design process, and they become more capable of seeing structure in the complex and open-ended design task. Further, they are better able to focus their attention on the relevant aspects of the design problem space, to move beyond their familiar patterns, and to carry out multidimensional reflections of design ideas (Kangas et al. 2013a, b).

Mediated and Embodied Design Practices

The design context, task, and constraints described above form the basis of the design process, but they are also further defined through design practices implemented – in the course of design ideation as well as iterative experimentation, evaluation, and elaboration of ideas (see Fig. 1). In designing, and in technology education, the practices enacted are socially and materially mediated, as well as embodied in nature. Learning in design and technology takes place through several levels of interaction: verbal and nonverbal communication with others; interaction with tools and machines; thinking and communicating through sketches, pictures, drawings, and instructions; and through materials, products, and aesthetic and emotional experiences (Illum and Johansson 2012; Johansson 2006).

In design ideation the emphasis is on seeing beyond the obvious and developing personal constraints on the design task; it is the start of the generating-transforming process in which a designer uses knowledge, skills, materials, and tools in order to create something new or change a situation. Designers usually employ sketches as the first step of the process, for externalizing and visualizing ideas at an individual level (Goel 1995). Sketching has a crucial role in generating, developing, and communicating ideas; it is both a powerful form of thinking and the fundamental language of designing (Hope 2000; MacDonald et al. 2007; Welch et al. 2000). Designing is also material-centric and object-oriented; engagement with and manipulation of physical materials is often an intrinsic part of the design process (Ramduny-Ellis et al. 2010). Designers build various kinds of models to explore their ideas in 3D form, from sketch models to appearance models and functional prototypes (Pei et al. 2010). Material properties affect both the process and the outcomes of design activity, constraining and inspiring the work of a designer (Ramduny-Ellis et al. 2010).

The various design representations are focal in the work of professional designers; however, the function and significance of these representations are not apparent for schoolchildren learning design (Hope 2000; MacDonald et al. 2007; Welch 1998; Welch et al. 2000). The formal design representations can become prioritized at the expense of participation and learning when the purpose and advantages of using them as design tools are not understood (Murphy and Hennessy 2001). Therefore, students should be more explicitly taught how to use varied tools and techniques to facilitate the generation, not just the execution, of ideas (MacDonald et al. 2007). In order to achieve this, students should be involved in several projects in which they can practice externalizing with different types of media. Drawing is often considered the most common tool that expert designers use; however, students usually experience drawing as very challenging. If possible, young students tend to move immediately to three-dimensional modeling (Welch 1998), and these material, as well as verbal, methods may similarly support ideation.

Usually cheap and easy-to-manipulate materials (e.g., cardboard, masking tape, wire) are used for modeling; however, rapid prototyping tools, such as 3D printers, laser cutters, virtual modeling tools, and sue of CAD programs, provide new possibilities for design and technology education. These so-called maker technologies allow elements of a design to be easily changed and manipulated, enabling multiple iterations of testing and making models and encouraging students to take risks in exploring novel solutions. Mistakes and failures are seen as natural parts of the process, providing opportunities for reflection and further advancement of learning (Blikstein 2013). According to Campbell and Jane (2012), understanding various representation methods, recognizing how they are used to construct explanations, and negotiating the meaning of different representations are crucial to learning in technology education.

Besides the social and material aspects of designing, recent research has emphasized the embodied dimensions of design work, i.e., how the body is actively involved in designers' thinking and communication processes (e.g., Keller and Keller 1996; Poulsen and Thøgersen 2011). Competence in design develops through several connected levels – social, material, and embodied – of thinking, interacting, and meaning making. Authentic design tasks are challenging and require distribution of expertise in various ways: between humans; between humans, tools, materials, and the surrounding space; and between mind and body. Further, designing requires the generation and use of various kinds of knowledge in order to know, on one hand, how to do design and, on the other hand, how to generate the new knowledge that such doing requires (see Vincenti 1990). In technology education, the coevolution of conceptual, material, practice-related, and physically embodied artifacts and activities is essential for the advancement of students' design ideas (Kangas et al. 2013a, b). This, however, requires careful facilitation; students need support at all levels of interaction and in moving between levels. They need to learn, for example, how to collaborate constructively, how to use tools and materials, or how to produce and use design representations for generating, developing, storing, and communicating ideas.

Conclusions and Future Directions

Design learning aims to develop one's ability to see beyond the obvious, to experiment with new ideas by sketching and prototyping, to make leaps of imagination, as well as to systematically analyze, generalize, and synthesize observations. Open-ended design projects challenge traditional ways of learning by, for example, disrupting the notion of "right" answers and the ideal of measurable achievement (Kafai et al. 2014). They provide novel possibilities for learning and knowledge creation; as from their very premise, they aim to create something new. Further, since the objects and effects of design are daily apparent all around us, engaging in and comprehending design processes provide a means of developing a deep understanding of the less tangible issues affecting us humans and the world we inhabit. Through designing, students can be socialized to creative practices of working with knowledge, which is seen as a fundamental future competence.

However, teaching designing to young students requires a great deal from the teacher: accepting uncertainty, maintaining motivation and engagement, and fitting the whole project into restricted time, space, and material resources. Creative processes have an inherent power of motivation, but the process needs to be encouraged by, for example, enabling choice and self-direction (Campbell and Jane 2012). As a starting point, the design learning process requires an open-ended design task that is both authentic and meaningful and that has constraints in balance. The task should also provide ways of generating meaning for the process in order to pursue ideation toward wider contexts of learning (Laamanen and Seitamaa-Hakkarainen 2014). In addition, the design process should include various tools and techniques for generating ideas, so that students can learn to understand the dynamics of design ideation. Students should be guided to constantly move between thinking and doing activities, in order for knowledge creation to take place on social, material, and embodied levels of interaction.

In order to answer these challenges and to find new pathways for learning, educators and researchers in the field of design and technology education have started to examine the ideas and implementation of the maker movement (e.g., Blikstein 2013; Kafai et al. 2014). Applied to educational contexts, the maker movement represents a form of learning by doing, which might appear to echo the earlier formal apprenticeship model of learning, but instead emphasizes informal, networked, peer-led, and shared learning activities in a community of practice. It underlines experimentation, innovation, and the testing of theory through practical, self-directed tasks and production of tangible artifacts and is seen as having the potential to contribute to a more participatory approach to learning. From the perspective of knowledge creation, maker activities contribute to the development of students' sense of identity and agency, which enables them to see themselves as capable of improving ideas and creating knowledge. The maker movement includes not only the process of creating artifacts but also the social and learning cultures surrounding their construction. These communities are both physical and virtual, and according to Thomas and Brown (2011), particularly online collectives represent a new culture of learning, where learning emerges from the environment and grows along with it. This kind of learning is suited for our world of constant change, because it comprises two important elements: a massive information network providing almost unlimited access and resources to learn about anything and a constrained and structured environment that allows for unlimited agency to build and experiment with anything within the boundaries of that environment.

There is some research available on designing in the field of technology education, providing insights into, for example, various aspects of teaching and learning design (for review, see Williams 2016). The research suggests, for example, that designing supports students' engagement in authentic practice and provides a route to deep learning. However, to a much lesser extent, research has systemically addressed the question of what is actually learned through designing, what kind of knowledge the students generate, and how this is related to a given curriculum. This challenge is partly connected to the desired learning gains; how is it possible to define what counts as success or evidence of the development of complex cultural practices that may take several years to become fully articulated? Nevertheless, more research is needed that provides evidence that design activities will lead to measurable advancement in depth of understanding of the design inquiry process, mastery of associated methods and practices, intellectual engagement, as well as an enhanced sense of being able to contribute to collective knowledge creation efforts.

Cross-References

- ▶ Authentic Learning and Technology Education
- ▶ Classroom Interaction in Technology Education
- ▶ Linking Knowledge and Activities: How Can Classroom Activities in Technology Reflect Professional Technological Knowledge and Practices?
- ▶ Middle Childhood Education: Engineering Concepts, Practices, and Trajectories
- ▶ Teaching Science and Technology
- ▶ Technology Education: An International History
- ▶ Technology Education: History of Research
- ▶ Maker Movement in Education: History and Prospects

References

Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. In E. de Corte, L. Verschaffel, N. Entwistle, & J. van Merriënboer (Eds.), *Powerful learning environments. Unravelling basic components and dimensions* (pp. 55–68). Oxford: Pergamon/Elsevier Science.

Blikstein, P. (2013). Digital fabrication and making in education: The democratization of invention. In J. Walter-Herrmann & C. Büching (Eds.), *FabLab. Of machines, makers, and inventors* (pp. 203–222). Transcript: Bielefeld.

Campbell, C., & Jane, B. (2012). Motivating children to learn: The role of technology education. *International Journal of Technology and Design Education, 22*(1), 1–11.

Dahlin, L. K., Voll, L. O., & Svorkmo, A. (2013). Technology and design as part of a public school from 1st to 10th grade. In J. B. Reitan, P. Lloyd, E. Bohemia, L. M. Nielsen, I. Digranes, & E. Lutnaes (Eds.), *Design learning for tomorrow. Design education from kindergarten to PhD. proceedings from the 2nd international conference for design education researchers* (Vol. 4, pp. 1938–1950). ABM-media: Oslo.

de Vries, M. (2009). The developing field of technology education: An introduction. In M. de Vries & A. Jones (Eds.), *International handbook of research and development in technology education* (pp. 1–9). Rotterdam: Sense.

Dorst, K. (2006). Design problems and design paradoxes. *Design Issues, 22*(3), 4–17.

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies, 22*(5), 425–437.

Fischer, G., Giaccardi, E., Eden, H., Sugimoto, M., & Ye, Y. (2005). Beyond binary choices: Integrating individual and social creativity. *International Journal of Human-Computer Studies, 63*(4), 482–512.

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching, 41*(10), 1081–1110.

Goel, V. (1995). *Sketches of thought*. Cambridge, MA: MIT Press.

Goel, V., & Pirolli, P. (1992). The structure of design problem spaces. *Cognitive Science, 16*(3), 395–429.

Hakkarainen, K. (2009). Three generations of technology-enhanced learning. *British Journal of Educational Technology, 40*(5), 879–888.

Hakkarainen, K., Palonen, T., Paavola, S., & Lehtinen, E. (2004). *Communities of networked expertise: Professional and educational perspectives*. Amsterdam: Elsevier.

Harel, I. (1991). *Children designers*. New York: Ablex.

Hennessy, S., & Murphy, P. (1999). The potential for collaborative problem solving in design and technology. *International Journal of Technology and Design Education, 9*(1), 1–36.

Hope, G. (2000). Beyond draw one and make it. *The Journal of Technology and Design Education, 6*(3), 197–201.
Illum, B., & Johansson, M. (2012). Transforming physical materials into artefacts – learning in the school's practice of sloyd. *Techne Series A, 19*(1), 2–16.
International Technology Education Association (ITEA). (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed). Retrieved from http://www.iteaconnect.org/TAA/PDFs/xstnd.pdf. Accessed 22 Apr 2013.
Johansson, M. (2006). The work in the classroom of sloyd. *Journal of Research in Teacher Education, 13*(2–3), 152–171.
Kafai, Y. B. (2006). Constructionism. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 35–46). New York: Cambridge University Press.
Kafai, Y. B., Fields, D. A., & Searle, K. A. (2014). Electronic textiles as disruptive designs: Supporting and challenging maker activities in schools. *Harvard Educational Review, 84*(4), 532–556.
Kangas, K., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2013a). Figuring the world of designing: Expert participation in elementary classroom. *International Journal of Technology and Design Education, 23*(2), 425–442.
Kangas, K., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2013b). Design thinking in elementary students' collaborative lamp designing process. *Design and Technology Education: An International Journal, 18*(1), 30–43.
Keller, C., & Keller, J. D. (1996). *Cognition and tool use. The blacksmith at work*. New York: Cambridge University Press.
Kelley, T. R., & Sung, E. (2016). Sketching by design: Teaching sketching to young learners. *International Journal of Technology and Design Education*. doi:10.1007/s10798-016-9354-3.
Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., et al. (2003). Problem-based learning meets case-based reasoning in the middleschool science classroom: Putting Learning by Design™ into practice. *Journal of the Learning Sciences, 12*(4), 495–547.
Krajick, J., & Merritt, J. (2012). Engaging students in scientific practices: What does constructing and revising models look like in the science classroom*? Science and Children, 49*(7), 10–13.
Laamanen, T. K., & Seitamaa-Hakkarainen, P. (2014). Constraining the open-ended design task by interpreting sources of inspiration. *Art, Design and Communication in Higher Education, 13*(2), 135–156.
Lahti, H., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2004). Collaboration patterns in computer-supported collaborative designing. *Design Studies, 25*(4), 351–371.
Lawson, B. (2006). *How designers think: The design process demystified* (4th ed.). Oxford: Architectural Press.
Liljeström, A., Enkenberg, J., & Pöllänen, S. (2014). The case of design-oriented pedagogy: What students' digital video stories say about emerging learning ecosystems. *Education and Information Technologies, 19*(3), 583–601.
MacDonald, D., Gustafson, B. J., & Gentilini, S. (2007). Enhancing children's drawing in design technology planning and making. *Research in Science & Technological Education, 25*(1), 59–75.
Murphy, P., & Hennessy, S. (2001). Realising the potential – and lost opportunities – for peer collaboration in a D&T setting. *International Journal of Technology and Design Education, 11*(3), 203–237.
Paavola, S., Lipponen, L., & Hakkarainen, K. (2004). Modeling innovative knowledge communities: A knowledge-creation approach to learning. *Review of Educational Research, 74*, 557–576.
Papert, S. (1991). Situating constructionism. In S. Papert & I. Harel (Eds.), *Constructionism*. Cambridge, MA: MIT Press.
Pei, E., Campbell, I. R., & Evans, M. A. (2010). Development of a tool for building shared representations among industrial designers and engineering designers. *CoDesign, 6*(3), 139–166.

Poulsen, S. B., & Thøgersen, U. (2011). Embodied design thinking: A phenomenological perspective. *CoDesign, 7*(1), 29–44.
Ramduny-Ellis, D., Dix, A., Evans, M., Hare, J., & Gill, S. (2010). Physicality in design: An exploration. *Design Journal, 13*(1), 48–76.
Sawyer, K. R. (2006). Introduction: The new science of learning. In K. R. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 1–16). New York: Cambridge University Press.
Sawyer, K. (2012). Learning how to create: Toward a learning sciences of art and design. In J. van Aalst, K. Thompson, M.J. Jacobson, & P. Reimann (Eds.), *The future of learning: Proceedings of the 10th International conference of the learning sciences (ICLS 2012)* (Vol. 1, full papers, pp. 33–36). Sydney/NSW: International Society of the Learning Sciences.
Scardamalia, M., & Bereiter, C. (2003). Knowledge building. In *Encyclopedia of education* (2nd ed., pp. 1370–1373). New York: Macmillan Reference.
Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2000). Visualization and sketching in the design process. *The Design Journal, 3*(1), 3–14.
Seitamaa-Hakkarainen, P., Raunio, A.-M., Muukkonen, H., & Hakkarainen, K. (2001). Computer support for collaborative designing. *International Journal of Technology and Design Education, 11*(2), 181–202.
Seitamaa-Hakkarainen, P., Viilo, M., & Hakkarainen, K. (2010). Learning by collaborative designing: Technology-enhanced knowledge practices. *International Journal of Technology and Design Education, 20*(2), 109–136.
Thomas, D., & Brown, J. S. (2011). *A new culture of learning: Cultivating the imagination for a world of constant change*. Lexington: CreateSpace.
Vartiainen, H., Liljeström, A., & Enkenberg, J. (2012). Design-oriented pedagogy for technology-enhanced learning to cross over the borders between formal and informal environments. *Journal of Universal Computer Science, 18*(15), 2097–2119.
Viilo, M., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2011). Supporting the technology-enhanced collaborative inquiry and design project: A teacher's reflections on practices. *Teachers and Teaching: Theory and Practice, 17*(1), 51–72.
Vincenti, W. G. (1990). *What engineers know and how they know it. Analytical studies from aeronautical history*. Baltimore: The Johns Hopkins University Press.
Welch, M. (1998). Students' use of three-dimensional modelling while designing and making a solution to a technological problem. *International Journal of Technology and Design Education, 8*(3), 241–260.
Welch, M., Barlex, D., & Lim, H. S. (2000). Sketching: Friend or foe to the novice designer? *International Journal of Technology and Design Education, 10*(2), 125–148.
Williams, P. J. (2016). Research in technology education: Looking back to move forward... again. *International Journal of Technology and Design Education, 26*(2), 149–157.

Modeling in Technology Education: A Route to Technological Literacy

43

Bev France

Abstract

Modeling is a central part of the technological enterprise, and its scope and purpose are important to examine when developing technological literacy. An understanding of the role of models provides an epistemological foundation to the concept of functionality. This chapter will explore these issues.

Keywords

Technological modelling • Technoscience artifacts

Contents

Introduction

It was during the 2014 New Zealand elections that the "Ban 1080" party became part of the political news of New Zealand. Such headlines as "Ban 1080 party in push for election" (Hubbard 2015) and "1080 battle gets political" (Charman 2014) were

B. France
School of Curriculum and Pedagogy, Faculty of Education and Social Work, The University of Auckland, Auckland, New Zealand
e-mail: b.france@auckland.ac.nz

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_45

examples of this political party's national impact. This party contested the 2014 election with 14 candidates, and, even though it was unsuccessful, it provoked debate about an issue that was a solution to the problem of possum control. Possums are introduced marsupials (*Trichosurus vulpecula*) that carry *bovine tuberculosis* (bTB) that infects cattle. In addition to this economic effect, they also have a dramatic impact on native forest and bird populations. The solution to this problem was a program of aerial dispersal of poison pellets containing 1080 (sodium fluoroacetate). This technological solution has garnered considerable opposition both on the streets, through the media and in protest action. As a result of this public response, 1080 is instantly recognized as a poison and is inextricably linked with the perception of an action by the government and big business (Fonterra) that has not taken into account the views of the public and especially not their safety.

This chapter will argue that this technological outcome, that is, a process for delivering 1080 impregnated poison bait, demonstrates the complexity of releasing such a technological artifact into a complex ecosystem that includes the natural world, humans, and their social interactions. In fact this technological artifact was not "fit for purpose." It is argued that this epistemic shortfall was the result of insufficient attention to technological modeling as identified in the *New Zealand Curriculum* document (NZC 2007), Ministry of Education (2007, 2010a, b). In order to develop this argument, the following components will be discussed from an epistemic perspective. These are:

- The relationship between technology and science
- The role of models in technology
- Models as techno-scientific artifacts
- Critiquing the 1080 solution through the lens of techno-scientific modeling
- Using models to explore and develop an understanding of technological literacy

The Relationship Between Technology and Science

There is the perception in New Zealand that the aerial dispersal of 1080 was a scientific problem that was solved by scientists using technology (Parliamentary Commissioner for the Environment 2013). This view of the relationship between the problem and solution reflects a view of technology being the handmaiden of science. The following section will explore this relationship as well as others. Furthermore it will suggest that solutions to scientifically based problems that may involve aspects of technology may need to embody a truly technological perspective that sets as its evaluative outcome from a technological epistemic perspective. This premise is that technological knowledge is validated by a relevant community of technologists by its ability to support successful function (Ministry of Education 2010a, b).

As Haglund and Strömdahl (2012) comment, "knowing" and "doing" reflect the fundamentally different goals of the communities of science to describe the world and technology to change the world. However the delineation between science's epistemic aims, that is, the acquisition of knowledge that is based on empirical data obtained through observation, experimentation, and inference that provides theoretical explanations that are generalizable and the practical focus of technology being the "construction of things or processes with socially useful function" (Radder 2009, p. 66), does not reflect the complexity of knowledge creation in both disciplines.

Instead of separating science with its explanatory aims from technology with its functionality focus, I argue that both disciplines have an epistemic foundation that is concerned with knowledge development. However in many instances the historical supremacy of science is reflected in the naming of this relationship, for example, applied science where there is the perception that the findings of science are used to solve problems. In this instance even though the label technology as applied science (TAS) positions technology first, there is an assumption of a linear relationship in which science is used to develop a technology. Another view of this relationship – technoscience – provides an expression of the relationship where technology is seen as an enabler for science to occur, for example, the use of technology to reveal the microscopic world via electron microscopes. Another example from this decade is the use of a DNA sequencer to automate the DNA sequencing process. Another expression of this relationship is when technology is viewed as finalized science, for example, the process of producing fertilizers in agricultural science and drugs in biomedical science. Here Radder (2009) describes this view of the relationship that had been developed in the 1970s by a group of German scholars (Starnberg group), where "finalized science demotes a particular stage of scientific development that is, more or less consciously, oriented towards external social goals and interests" (p. 74).

Whatever the relationship is called, knowledge creation cannot be confined to science, for these days it is transdisciplinary, complex, and hybridized (Yawson 2012), with real-life practices in science and technology often indistinguishable as communities develop and use knowledge (Franssen 2015).This complex view acknowledges that both technology and science can claim this epistemic role of knowledge building. Rather than technology using knowledge from other domains, Mitcham (1994) conceptualizes technology as objects, knowledge, activities, and volition. For example, technological knowledge is carried and validated by the materiality of the outcome itself. As described by Baird, "the things we make bear our knowledge of the world, on a par with the words we speak" (2002, p. 13). Whereas the activity of science is to pose questions about the phenomena in the world and provide explanations that are "the most plausible, most parsimonious, most generalizable and most fruitful that can be devised"(Gilbert and Boulter 1998, p. 89). In contrast to the epistemic aims of science, much of technological knowledge development is about the particular, and there is the view that industrial experimentation can also provide knowledge that informs the development of a particular artifact or process (Yawson 2012).

Furthermore this indistinct relationship is recognized by Jerome Ravetz (1999) when he reviews the sorts of questions that should be asked when investigating science. He suggests the questions "what if?" rather than "what/how?" or "how/why?" should also be asked so that one is made aware of the scientific uncertainties not only when science is practiced but even more when scientific applications are released into the environment. Such a broader focus of questions that need to be asked by all that are involved in the scientific enterprise indicate that in many cases when scientific knowledge is used to inform a problem, a technological knowledge focus is implied even though at that time knowledge development could be considered to be in the science domain. This broader focus of knowledge building was implicit in the explanation of the model for postnormal science (Funtowicz and Ravetz 1993) where these philosophers took scientific knowledge building out of the laboratory when they considered the level of system uncertainties that needed to be taken into account when "scientific problems" were solved and applied. They deduced that the level of epistemological/ethical system uncertainties was reflected in the increasing impact of decisions that would occur when "scientific" solutions were realized and used within environment and/or by society (p. 750). It is more than 20 years since this way of explaining the relationship between traditional science and its application in the world was proposed, and postnormal science still provides pertinent justification for increasing the input of relevant stakeholders when "scientific" solutions are evaluated. Certainly the response of nongovernment organizations and interest groups to the 1080 solution shows that the decision stakes were high when this solution to possum control was realized (Hubbard 2015; Moore 2014).

In fact the criteria and the dimensions of the process of quality assurance that are indicated in their model of postnormal science have parallels when evaluating an artifact/process during functional modeling (Ministry of Education 2010a, b). This view of modeling in technology will be explored in the next section.

The Role of Models in Technology

Models can be seen as bridges between theory and the world as experienced (Haglund and Strömdahl 2012). Gilbert's explanation of a model being a representation of an idea, object, event process, or system (Gilbert et al. 2000) accommodates both of these domains, and there appears to be some differences in their use that could provide more clarity about the epistemic differences between them.

If the purpose of science is to explain phenomena, then Giere's (1988) assertion that models "are the means by which scientists represent the world both to themselves and for others" (p. 80) puts model building center stage. Scientists use models in a pragmatic fashion seeing them as tools that they utilize to understand the world. They are often in use at the frontiers of science as scientists build and test models that enable predictions to be made. Scientific modeling is underpinned by both inductive and deductive reasoning.

In summary, models in science are central to knowledge building which rests on the epistemological criterion of scientific knowledge, that is, truth. They provide explanations of phenomena or allow for predictions to be tested. Furthermore the presence of more than one consensus model, the variety of roles that models can fulfill and the realization that models can evolve, provides support for the tentative nature of science (van Der Valk et al. 2007).

This small review of the literature has demonstrated that theoretical knowledge building appears to be the focus of model use in science while in technology the focus is much broader. Nia and de Vries (2016) have reviewed a range of perspectives about the nature and use of models in technology, and these authors have focused on their discussion of the multifunctionality of models as it provides information about the diversity of roles for models and especially locates The New Zealand Curriculum's (NZC) (Ministry of Education 2007) view of modeling as described in the curriculum support documents allied to this curriculum (Ministry of Education 2010).

As well as a theory-building role, Nia and de Vries (2016) draw attention to the diversity of epistemic functions of models in technology. They observe that technological knowledge can be developed by building, manipulating, and using models. As well as using models to understand and optimize the behavior of technological artifacts – which the NZC would call prototyping – Nia and de Vries have identified that models can be built to explain the workings of something that is already functional as well as testing the design concepts before the artifact is realized (France et al. 2011). They comment that, in a similar fashion to science, technological models are able to support communication (Nia and de Vries 2016).

The technology component of NZC presents modeling as central to the technological enterprise, and its epistemic function is to achieve an outcome that is fit for purpose. The following description of technological modeling that was developed to supplement and explain the technology component of the NZC describes the epistemic role of functional modeling during the development of the design concept and the role of prototyping during the practical testing of the realized outcome (Compton and France 2007). Here the authors emphasize that before a technological artifact and/or system is realized, there is an opportunity to test all aspects of the design concept in order to identify and minimize the unknown or unintended consequences of this release. Consequently during this process of exploration and evaluation – which we label as functional modeling – there is an opportunity for decisions to be made about its future development in order to enhance risk mitigation. This process is essentially part of the design phase, and, because the focus is epistemic, (establishing whether the design is "fit for purpose"), it must occur before the prototype is realized. Prior to implementation, prototyping occurs which is more likely to result in tweaking rather than a go/no decision that can occur during the functional modeling stage. These authors assert that prototyping provides evidence for its acceptance as well as allowing space for further development. Consequently they assert that both components of technological modeling, that is, functional modeling and prototyping provide epistemic strategies to ensure the technological outcome is "fit for purpose" (Compton and France 2007).

In contrast to the processes of inductive and deductive reasoning that occurs in science model building, technological modeling is underpinned by both functional and practical reasoning. These two cognitive activities reflect the considerations that are needed in order to assess whether a technological outcome is fit for purpose, not just from a technical perspective but also by examining the normative aspects that are difficult to identify but essential for the acceptability of any technological solution. Consequently functional reasoning occurs throughout the modeling process, for example, when technical feasibility is explored during the functional modeling phase – "how to make it happen" – and during the prototyping phase as the technologist reexamines "how it is happening." Whereas practical reasoning explores the normative aspects of a proposed technological design, for example, the sociocultural acceptability of outcomes, for example, the moral and ethical factors, and supplies the crucial normative element of technology (Ministry of Education 2010). For example, "should it happen" during the functional modeling stage and "should it be happening" during the prototyping phase of technological modeling?

The next section of the chapter considers a new way of examining the role and function of models. Nia and de Vries (2016) have made the educational case for considering models as techno-scientific artifacts.

Models as Techno-scientific Artifacts

Rather than attempting to classify models according to their composition, form, and function, Nia and de Vries (2016) have provided a broader perspective when describing and characterizing models as techno-scientific artifacts. They suggest that they have an intrinsic nature (where their materiality is expressed in different forms) and an intentional nature that can be realized as epistemic techno-scientific. Furthermore they argue that this intentional nature has an epistemic function during communication between people for education, by providing procedural information and by using models to make managerial decisions in order to mitigate risk.

However the separation of these two essential features of models does not deflect from a technological view that an artifact is a complex relationship between materiality and function. Instead they argue that this duality of nature holds for models as well in that when seen from an "intrinsic-nature" angle, their materiality and form can be explored, while the "intentional nature" provides the link to their epistemic function as epistemic tools "to either support development of or communicate about knowledge and artifacts" (Nia and de Vries 2016, p. 20).

In the following section this view of models as a techno-scientific artifact will be explored by examining the context of the aerial dispersal of poison pellets containing 1080 (sodium fluoroacetate) to control possum populations in New Zealand. This author suggests that critiquing this scientific/technological solution from a technological modeling perspective may first provide some insight into the intrinsic and intentional nature of these techno-scientific artifacts as well as their dual nature. Secondly this critique may reveal the potential that this depiction of models could provide as a route to the enhancement of scientific and technological literacy – particularly when the solutions cannot be arbitrarily separated into scientific or technological solutions.

Critiquing the 1080 Solution Through the Lens of Techno-scientific Modeling

First some background about the 1080 issue.

In New Zealand bovine tuberculosis (bTB) infects cows and deer and has the potential to adversely affect export and the reputation of New Zealand as a high-quality producer of beef, dairy, and venison products. bTB is an infectious disease caused by the bacterium (Mycobacterium bovis), and the infected animals have pus-oozing sores that is spread to grass and other animals through contact. In NZ the main vectors of bTB are possums and ferrets. Infected possums live in bush, and, because many farms are adjacent, they can wander into paddocks where inquisitive animals nuzzle and lick them. The brush tail possum (Tricosurus vulpecula) was introduced from Australia in the 1870s to establish a fur trade. Because possums have no natural predators in NZ, they are widely established. A recent study estimates that there are about 30 million in total. As well as spreading bTB, they attack New Zealand native bush and animals – particularly endemic birds.

Tbfree New Zealand is a government-funded nationwide program of livestock testing and pest control that aims to eradicate bTB from wild animals in 25% of NZ's at-risk areas by 2026. Effective bTB control requires possum numbers to be kept very low for several years. Hand-laid traps and poison are strategies used in about 80% of the possum control programs, and in the remaining 20%, the control is done by an aerial dispersal of 1080. Normally this happens when the terrain is inaccessible and the possum population is very high. 1080 (sodium monofluoroacetate) is a naturally occurring poison that is biodegradable, does not persist in soil or water, does not persist in animals that consume a nonlethal dose, and does not accumulate in the food chain. It is the only poison licensed for aerial dispersal, and it is the preferred choice because possums will eat the bait directly.

So what is the problem? Although 1080 kills possums and stoats, it is also deadly to birds, livestock, deer, dogs, and people. While the majority of New Zealanders believe that possums need to be killed, there is disagreement about how this is done (Russell 2014).

As Nia and de Vries (2016) suggest that if one embraces the proposition that models are a techno-scientific artifact and they have a dual nature, then their proposed framework has some merit in this analysis and critique of the 1080 solution. Because this chapter has a focus on the epistemic nature of modeling, this critique will endeavor to demonstrate how aspects of Nia and de Vries' view of models as techno-scientific artifacts strongly provide clues to their epistemic role.

This author argues that the "1080 solution" is an example of science knowledge being used to solve this problem, i.e., an applied science solution. The following critique will show that in many instances science was perceived to be leading the way and the solution had not been exposed to the rigors of a technological modeling process that would occur before this technological artifact (aerial system of 1080 dispersal) was released into world.

A scientific view of this solution was apparent in the way the solution was arrived at. Rather than considering that the solution was a technological, the scientific route did not acknowledge that there were two components of this solution, that is, the pellet containing poison and a delivery system. Because of this scientific focus, the solution was the pellet rather than the pellet and its delivery. The interaction between these two components would have been recognized during the technological modeling phase. For example, during the functional modeling phase the ecological implications would have been identified and discussed – such as color of the pellet. Originally it was colored red, and its size and shape made it attractive to birds that caused ecological damage. Furthermore there were issues about the indiscriminate aerial delivery of pellets that was responsible for widespread killing of mammalian populations such as deer and dogs. Early in the aerial dispersal phase there were a few examples of these catastrophic outcomes that contributed to the perception that this solution caused widespread ecological damage (Green and Rohan 2012).

Nia and de Vries (2016) have proposed that the use of models can involve three types of epistemic intentions. First of all the design concept needs to be identified and tested during this prerelease phase of functional modeling. In this situation such things as toxicity, biodegradation rate, attractiveness to nontarget animals, as well as the normative components – people's views of spraying a "poison" from the sky (Parliamentary Commissioner for the Envrionment 2011) would have been identified during the functional modeling phase. At this early stage practical reasoning would have been employed to assess the normative aspects of this proposed solution, for example the views of Maori indigenous people about the pollution of Waiora, the reactions of hunters seeing their trophies (deer and possums) being killed in an unnecessarily cruel way. At this early stage of the development, input into the development of this solution would have provided scientific data, technological input, and given voice to the people who were impacted by the decision to aerially deliver this poisonous pellet onto large areas of bush (Eason et al. 2011).

Another epistemic function that Nia and de Vries have identified is the communicative role of models. Communication needed to occur during the production of the artifact, for example, planners, farmers, and people potentially involved in the outcome of this aerial dispersal of poisoned pellets who could have provided normative information that could increase its epistemic value. Nia and de Vries (2016) note that aspect occurs during functional modeling where decisions are made, not just about its technical feasibility but whether it should happen at all (Ministry of Education 2010). As an aside it appears that these days the aerial dispersal of these pellets has been restricted to certain times of the year and there is ample warning when such aerial drops take place (Parliamentary Commissioner for the Envrionment 2011). Consequently the epistemic value of this solution has been improved when the intentional aspects of this modeling phase has provided space for decision about the way these pellets can be delivered.

In conclusion Nia and de Vries' proposition that modeling of many scientific technological solutions cannot be separated has resonance when such science/technology solutions are critiqued in terms of postnormal science (Ravetz 1999). I suggest that "what if?" questions should have been asked when assessing the impact of such a technological solution. Certainly this view of modeling makes it possible to examine more factors when one is determining whether a technological artifact that bears technological knowledge is truly “fit for purpose.”

This author would assert that initially the technological solution of a 1080 aerial poison drop was not epistemically sound. She would suggest that technological modeling, especially when one incorporates aspects of scientific modeling as acknowledged in Nia and de Vries’ view of a model being a techno-scientific artifact, could be a better epistemic tool for establishing whether such a technological system should have gone ahead.

Using Models to Explore and Develop an Understanding of Technological Literacy

Finally Nia and de Vries (2016) have suggested that an examination of the intrinsic and intentional interactions of modeling would provide a gateway into a deeper understanding of technological literacy.

Although 1080 has been evaluated as “effective and safe” and still considered the most effective tool for controlling possums over large areas, there are still groups of people who hold differing views about its efficacy. In fact for many people it is not accepted as being “fit for purpose” (Parliamentary Commissioner for the Environment 2011).

What is apparent in this examination of the 1080 solution for possum control was that in the early stages of its use, there needed to be wider consultation of the stakeholder group. If this had occurred, attention could have given to normative assessment during the functional modeling phase. For example, in the early stages of using 1080, members of the Forest and Bird Society were convinced that the science was settled and the benefits of 1080 were indisputable, whereas other groups, for example, hunters and dog owners, were less than convinced (Hubbard 2015). At an early stage Maori had mixed feelings about the use of 1080 but recent Hui have persuaded that this poison could prevent the dying off of bush in the north (McLean 2016).

Yawson (2012) has presented a framework that expands the view of technological literacy in order for the public to meaningfully participate in nanotechnology discussions. He opines that such discussion is important as this modern technology has the potential to raise moral and ethical considerations. He suggests that an enhanced epistemological framework is needed for people to be aware of and involved in knowledge development where science, technology, risk issues, and governance intersect. He argues that a broader knowledgeable stakeholder group is required so that the epistemic foundation of a technological outcome is based on an awareness that disciplinarity is not the overriding scheme for knowledge creation. I suggest that such an expression can occur when considering the role of models within a techno-scientific function.

When reviewing the history of 1080 in New Zealand, it is apparent that at the early stage of this implementation the 1080 pest control solution was seen from an applied science perspective. In the 1950s there was less attention given to the “what if" questions – especially when normative issues were raised. Certainly more attention are given to these components, and there is less opposition to this program since the 2007 reforms (Parliamentary Commissioner for the Envrionment 2011).

What this story has illustrated is the power of a model when used as a techno-scientific artifact. It demonstrates that literacies cannot be seen in isolation but are a composite of understandings of the environment, science, and technology and citizens need to be aware of the power of this epistemic tool.

Conclusion and Future Directions

This illustration of the importance of understanding the role of models as techno-scientific artifacts will allow students to use their knowledge about the intentional nature of the model in question to enhance communication when a techno-scientific solution is employed as a solution. It is hoped that students could develop an enhanced criticality about techno-scientific artifacts when examining controversial issues such as pest control.

Glossary

Waiora Clean and healthy water
Hui Gathering for discussion

References

Baird, D. (2002). Thing knowledge-function and truth. *Techne: Journal of the Society of Philosophy and Technology, 6*(2), 13–27.

Charman P. 1080 battle gets political. New Zealand Herald News. 2014 Jun 20 [cited 2014 Jun 19]:14. Available from: NZ Herald. http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11277899

Compton VJ, France B. (2007). *Redefining technological literacy in New Zealand: From concepts to curriculum constructs*. In: Proceedings of the pupils' attitudes towards technology (PATT) International Design & Technology Education Conference: Teaching and learning technological literacy in the classroom. Glasgow.

Eason, C., Miller, A., Ogilvie, S., & Fairweather, A. (2011). An updated review of the toxicology and ecotoxicology of sodium fluoroacetate (1080) in relation to its use as a pest control tool in New Zealand. *New Zealand Journal of Ecology, 35*(1), 1–20.

France, B., Compton, V. J., & Gilbert, J. K. (2011). Understanding modeling in technology and science: The potential of stories from the field. *International Journal of Technology and Design Education, 21*, 381–394. doi:10.1007/s10798-010798-9126-4,381-304.

Franssen, M. (2015). Philosophy of science and philosophy of technology: One or two philosophies of one or two objects? In S. O. Hansson (Ed.), *Philosophy of engineering and technology 18 the role of technology in science: Philosophical perspectives*. Dordrecht: Springer. [cited 2016 Jun 11]: 235–258. Available from: Springer.

Functowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures, 25*(7), 735–755.

Giere, R. N. (1988). *Explaining science: A cognitive approach*. Chicago: University of Chicago Press.

Gilbert, J. K., & Boulter, C. (1998). Models in explanations, Part 1: Horses for courses? *International Journal of Science Education, 20*(1), 83–97.

Gilbert, J. K., Boulter, C., & Elmer, R. (2000). Positioning models in science education and in design and technology education. In J. K. Gilbert & C. J. Boulter (Eds.), *Developing models in science education*. Dordrecht: Kluwer.

Green, W., & Rohan, M. (2012). Opposition to aerial 1080 poisoning for control of invasive mammals in New Zealand: Risk perceptions and agency responses. *Journal of the Royal Society of New Zealand, 42*(3), 185–213.

Haglund, J., & Strömdahl, H. (2012). Perspective on models in theoretical and practical traditions of knowledge: The example of Otto engine animations. *International Journal of Technology and Design Education, 22*, 311–327. doi:10.1007/s10798-010-9146-0.

Hubbard A. (2015, March 15). A toxic history of 1080 in New Zealand. Available from http://www.stuff.co.nz/business/farming/67386321/a-toxic-history-of-1080-in-new-zealand

McLean, M. (2016, March 6). Mixed feelings on use of 1080. Available from http://www.maoritelevision.com/news/regional/mixed-feelings-on-use-1080

Ministry of Education. (2010a). Technology online. Technology in NZC. Technological modeling. [Internet] n.d. [updated n.d; cited 2016 June 11]. Available from: http://technology.tki.org.nz/Technology-in-the-NZC/Technological-knowledge/Technological-modelling. N.d

Ministry of Education. (2010b). Technology curriculum support. [Internet] 2010. [updated n.d; cited 2016 June 11]. Available from https://www.google.co.nz/#q=Ministry+of+education+NZ+technology+curriculum+support&gws_rd=cr

Ministry of Education of New Zealand. (2007). The New Zealand Curriculum. Wellington.

Mitcham, K. (1994). *Thinking through technology: The path between engineering and philosophy.* Chicago: The University of Chicago Press.

Moore B. (2014, June 18). Ban 1080 party in push for election. Available from: http://www.stuff.co.nz/national/politics/10172333/Ban-1080-party-in-push-for-election

Nia, M. G., & de Vries, M. J. (2016). Models as artifacts of a dual nature: A philosophical contribution to teaching about models designed and used in engineering practice. *International Journal of Technology and Design Education*. doi:10.1007/s10798-016-9364-1.

Parliamentary Commissioner for the Environment (PCE). Evaluating the use of 1080: Predators, poisons and silent forests. 2011. [cited 2016 Jun 16]. Available from http://www.pce.parliament.nz/media/1294/evaluating-the-use-of-1080.pdf

Parliamentary Commissioner for the Environment (PCE). Update report – Evaluating the use of 1080 2013. [cited 2016 Jun 16]. Available from http://www.pce.parliament.nz/publications/update-report-evaluating-the-use-of-1080-predators-poisons-and-silent-forests

Radder, H. (2009). Science, technology and the science-technology relationship. In A. Meijers (Ed.), *Handbook of the philosophy of science, Volume 9: Philosophy of technology and engineering sciences*. Oxford: Elsevier.

Ravetz, J. (1999). What is post-normal science? *Futures, 31*, 647–653.

Russell, J. C. (2014). A comparison of attitudes towards introduced wildlife in New Zealand in 1994 and 2012. *Journal of the Royal Society of New Zealand, 44*(40), 136–151. doi:10.1080/03036758.2014.944192.

Van Der Valk, T., Van Driel, J. H., & De Vos, W. (2007). Common characteristics of models in present-day scientific practice. *Research in Science Education, 37*, 469–488.

Yawson, R. M. (2012). An epistemological framework for nanoscience and nanotechnology literacy. *International Journal of Technology and Design Education, 22*, 297–310. doi:10.1007/s10798-010-9145-1.

Part V

Technology Teacher Education

Technology Teacher Education 44

John Ritz

Keywords

Community of practice • Pedagogical context knowledge (PCK) • Authentic learning • Cognitive constructivism • Epistemology • Methodology • Ontology • Pedagogy • Philosophy • Social constructivism • Values • Professional identity • Beginning teachers • Design and technology education • Methodological challenge • Conceptual framework • PCK taxonomy • Professions • Technology teach or educators • Curriculum • Future • Visions

This section of the *Handbook of Technology Education* focuses on Technology Teacher Education. Technology teachers are educated professionals who know the content and technical practices found within the vast discipline of technology. In addition to becoming familiar with the knowledge-base for understanding technological systems, teachers also need to be taught the nature of technology, the impacts of technology on individuals, society, and the environment, and plan for the integration of science, mathematics, social sciences, and humanities into technology education instruction. These abilities assist technology teachers in teaching and discussing with students the many ramifications of technology, including its uses and impacts. Technology teachers also need to be educated on methods of teaching and develop their abilities to teach technology knowledge and its related skills to all learners. Without technology teachers, people would have difficulty understanding how technological systems operate, thus not aiding societies to develop to more advanced levels (e.g., economically, socially, and politically). As new technologies emerge, it is the role of teachers and curriculum specialists to propose how to best teach this knowledge to learners. Not only do technology teachers need to understand the vast systems of technology, they also need to understand pedagogy

J. Ritz (✉)
Old Dominion University, Norfolk, VA, USA
e-mail: jritz@odu.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_72

(teaching others) and how best to translate this knowledge (pedagogical content knowledge) to learners. Without technology education teachers, most school-aged learners will not develop proper perspectives about technology and will need to search on their own to understand, apply, and assess the intelligent use of these old and modern technologies.

Wendy Slatter and Bev France, through their chapter on ► "Community of Practice: Pedagogical Strategies for Linking Communities of Practice to the Classroom" (Chap. 45), review technology education and other educational literature to provide a rationale for involving the technology and engineering community of experts into the education of students enrolled in technology education courses. Community of practice uses real-world experts to improve the knowledge of students related to the skills needed to apply technology to solve problems and to further explore future careers. The authors expose teachers' beliefs about the opportunities and methods used to involve outside experts within and outside the technology classrooms/laboratories. The chapter reviews two county's experiences with implementing communities of practice within technology education.

Grietjie Haupt, through her chapter on ► "Design in Technology Education: Current State of Affairs" (Chap. 46), provides a review of 5-years of research reported in major research journals that focus on technology education. She develops a schema for this mega-analysis of research. It reviews research on the philosophic approach to design education including analyses of knowledge in design, nature of designing, design processes, and values involved in designing. Her analyses find most research that has been undertaken has been on design processes, with about equal studies on knowledge in design and nature of designing. Fewer studies address values within designing.

Denise MacGregor, through her chapter on ► "Predictions and Realities: The Influences That Shape Beginning Design and Technology Teachers' Professional Identity" (Chap. 47), explores research about how teachers' professional identities are shaped. First she explores the literature of teacher identity, and then she reviews a 2-year longitudinal study of the changes in professional identity experienced by a group of newly prepared Australian technology education teachers. This research enables teacher educators to better prepare new teachers and the impacts personal reflection and the professional school community have on preparing successful technology teachers.

Michael de Miranda, through his chapter on ► "Pedagogical Content Knowledge for Technology Education" (Chap. 48), explains this concept and details why teachers need to understand this knowledge to effectively deliver instruction in technology education. A model is provided for readers to better understand this teaching concept. Furthermore, studies conducted by technology education researchers and research from science and mathematics education are used to illustrate research methodologies that can be used to further analyze the concept of pedagogical content knowledge.

John Ritz and Gene Martin report research findings concerning future ► "Visions of the Technology Education Profession by Technology Teacher Educators" (Chap. 49). They report the literature on professional discourse and what professionalism means to technology education and other professional fields. Summaries of three research studies are reported which focus on the current curriculum directions for technology teacher preparation and perceptions of newly prepared teacher educators and compares these to the perceptions of current doctoral students in preparation to become professors or secure other leadership positions in technology education. These findings are used to guide discussion on what might be the future of the technology education and the teacher preparation profession.

Community of Practice: Pedagogical Strategies for Linking Communities of Practice to the Classroom

45

Wendy Slatter and Bev France

Abstract

As learning and research into technology education has developed, it has been recognized that providing opportunities for authentic-based learning provides students with real world learning experiences. One way to provide this authentic context is by accessing relevant communities of practice representatives in the technology classroom as this provides opportunities for deeply contextualized learning to develop. But how do teachers actually respond to this demand? From a pedagogical standpoint, what does it take for technology teachers to organize a meaningful "visit" and then turn the experience into some form of technological practice? This chapter reviews two mentoring models that create access for students to authentic learning experiences and suggestions of the pedagogy that might support these ventures. This chapter then explores the pedagogical strategies that a group of New Zealand teachers used to link communities of practice to the classroom.

Keywords

Community of practice • Pedagogical content knowledge • Authentic learning

Contents

W. Slatter (✉) • B. France
School of Curriculum and Pedagogy, Faculty of Education and Social Work, The University of Auckland, Auckland, New Zealand
e-mail: w.slatter@auckland.ac.nz; b.france@auckland.ac.nz

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_49

Introduction

Lave and Wenger coined the term community of practice (CoP) in 1991 when they explored CoPs as a way of learning. Their social learning theory viewed knowing as being embedded in a practical experience of the world that is interpreted with reference to certain social practices related to what they are talking about and doing. Learning is regarded as being situated in an experience of meaning, as learners interpret the world. During this process learners are then given the chance to interpret that world in a new way. Lave and Wenger studied examples of apprenticeship style relationships where the apprentice learned by a process of peripheral participation alongside an expert in the field (Lave and Wenger 1991). Their well-documented study observed how apprentices learned in a community, participated within this community by attempting, completing, and eventually gaining mastery of tasks during a mutual engagement with the more skilled members of the community. Brown and Duguid (2002) furthered the idea of situated learning by suggesting that this is "knowing how to be in practice" rather than "knowing about practice" and suggested that this style of learning required a level of authenticity to be provided for the learner (p. 138). These ideas of using authenticity to develop enduring learning situations for students have become a focus for educationalists.

A Curriculum Focus for the "Authentic"

The basic premise of authentic learning is that students develop more engagement with their learning if they can connect what they are learning about inside the classroom to their real world outside the classroom door. There is the indication that such an experience is powerful to enhancing learning. Johnson (1997) suggested that such a learning environment "...filled with authentic problems and real situations" is rich and assists with "developing intellectual skills" (p. 170).

There is also the expectation that the authentic learning experiences should be relevant to the student's world. Newmann and Wehlage (1993) assert, "A lesson gains in authenticity the more there is a connection to the larger social context within which students live" (p. 10). Hennessy and Murphy (1999) also suggest that authentic classroom practice should be based on situations that are relevant and real to students' lives and hold some potential for situations they might find themselves in the future. Teachers are expected to provide real-world learning opportunities to their students; however, there is very little guidance as to how they are to navigate the gap between the classroom and the outside world. Snape and Fox-Turnbull (2013) suggest that student's access "real-world collaborative practice" as "the norm in technology education" (p. 53) and assert that these connections are very clearly articulated in the technology education definitions used in the New Zealand curriculum (Ministry of Education 2007).

The New Zealand Scenario

Technology education in the New Zealand curriculum has historically had a strong focus of authenticity and use of community expertise within the classroom situation (Slatter and France 2011a; Turnbull 2002). The original 1995 curriculum *Technology in the New Zealand Curriculum* (Ministry of Education 1995) encouraged teachers to use links with local communities to reinforce classroom activities. The most recent curriculum development in New Zealand furthers this idea, encouraging teachers to provide authentic learning opportunities for their students, in a manner that provides an insight into technologists' technological practice (Compton and France 2012a; Ministry of Education 2007). It is intended that the students' technological literacy is to be developed through three interrelated curriculum strands, which include the nature of technology, the characteristics of technological knowledge, and technological practice. In technological practice students are to be encouraged to "examine the practice of others" when developing their own technological outcomes (Ministry of Education 2007, p. 32). *The New Zealand Curriculum* (2007) also indicates that technological skills and knowledge should be "learned in context" (Technology, Learning area structure, para. 2).

The idea of authentic CoP links being used to help New Zealand students develop their technological practice was investigated by Compton and Harwood (2003). Compton and Harwood suggested that technology teachers needed to develop their pedagogy in order to utilize a CoP interaction in the classroom. They suggested that technology teachers' pedagogies "need to provide appropriate structure, combined with processes of intervention and a high level of flexibility, to ensure learning occurs within an environment that supports and encourages divergence and creativity" (Compton and Harwood 2003, p. 5). Snape and Fox-Turnbull (2013) reflect on the more recent *The New Zealand Curriculum* (2007) and the role of authenticity, commenting that "technology education programmes provide rich sources for authentic teaching and learning" (p. 62). Technology teachers are being challenged to provide authentically based "real" problems that students can think about, innovate, and solve. However very little is written about how teachers negotiate, navigate, and scaffold such learning experiences for their students. The authors assert that how to provide these realistic situations in the classroom environment is a pedagogical art. This chapter researched the pedagogy New Zealand teachers use to structure and provide relevant realistic technological situations, where the community of practice is linked to the classroom practice.

Technology Teachers' Pedagogical Content Knowledge

In New Zealand many technology teachers have often trained as specialists in particular subject fields prior to becoming teachers. As a result they bring specific subject-specific knowledge with them, which can influence their classroom practice. The combination of this subject-specific knowledge and the teacher training of how to deliver such knowledge in the classroom is referred to as pedagogical content knowledge (PCK) (Shulman 1986).

PCK describes an educational framework that can be used to describe the learning experiences that teachers scaffold for their students (Ball et al. 2008). Engelbrecht and Ankiewicz (2016) suggest that the PCK of a teacher includes their personal experiences, constructs, and viewpoint about what "good teaching" is, as well as their own belief of what the educational purpose of their subject is.

Williams (2016) suggests that there is limited research into technology teachers' PCK. He comments that technology education pedagogies should "...ensure students are active participants in the learning process, and [embed] student design activities in a social context" (p. 156). Mioduser (2015) also reflects on the need for technology education to develop effective pedagogical models that take into account the technological changes that are occurring at a rapid pace in our world outside of teaching.

Guiding Principles to Bring Communities Together

Compton and France (2012b) have reviewed the connective partnerships made between educational communities and areas outside of the educational arena. They suggest that creating successful connections that cross boundaries of practice is difficult to establish and often hard to maintain in a way that is beneficial to all parties. To support developing partnerships in an effective and efficient manner, there are five key principles that should inform people seeking to create such a relationship. These principles consider that:

- The world view and ontological positioning of the participants should be explicitly identified and discussed between themselves.
- The purpose of the interaction should be clearly indicated and should be linked to measurable outcomes and implementation plans.
- All participants should be aware of the purpose and role in achieving the intended outcomes.
- Initiatives should be practically coherent to translate purpose to real outcomes.

- Initiatives should acknowledge that stepping over boundaries into each other's worlds requires explicit management (pp. 226–227).

These principles could inform and frame the PCK of teachers seeking to engage with communities of practice outside the classroom.

Mentoring Models of Partnership

The Young Foresight Project

Barlex (2012) discussed the Young Foresight Project, which was a government-led initiative to introduce foresight thinking into the UK school curriculum. The project used mentor input, where mentors worked alongside students in the classroom and assisted them to extend their "designerly" thinking. The aim of the project was to "provide pupils with creative and flexible learning skills" (p. 113) and aimed to equip pupils with collaborative designing skills.

As an outcome, a teaching materials toolkit was developed for teachers. Included in the resources were suggestions of pedagogic approaches to promote students' capacity to develop these skills. The teachers' pedagogy needed to allow the pupils to find their designer voice, thus enabling them to identify what they thought was valuable in the designing of a product, all the while scaffolding the students to be able to express this and argue their corner.

Barlex (2012) identified that detailed guidance was required to help the teachers and mentors work together in positive ways for the students. This guidance included suggesting mechanisms that would support the development of successful relationships between teachers and mentors. These mechanisms included teachers and mentors:

- Developing a shared perspective
- Discussing their expert strengths together
- Negotiating and planning together what was to occur with the students' learning
- Using a collaborative reviewing and planning approach
- Identifying where the expert input was in the sessions
- Identifying the essential requirements for the lessons and determining who would source these, as well as with identifying who would implement these
- Modifying the industrial approaches of mentors to meet learners' abilities
- Identifying the mentors as experts to the students
- The teachers maintaining the partnership in the classroom environment (p. 121).

Barlex reflected that the Young Foresight project provided students and professional mentors a mechanism by which they tackled authentic design problems alongside each other, using active collaboration and creativity in a culturally authentic way.

Futureintech

Christie (2012) discusses the Futureintech initiative. It was organized and administered through the Institute of Professional Engineers New Zealand (IPENZ) and funded by the New Zealand Government's Trade and Enterprise. Futureintech is an organization that seeks to link young career professionals in technology-related fields to schools. In doing so Futureintech aims to interest and appeal to students and to ultimately inspire students to consider and undertake tertiary studies in technology. A Futureintech facilitator recruits and coordinates school-industry partnerships by sourcing graduates from industry ("Ambassadors") to work with schoolteachers. This relationship often takes the form of the Ambassadors visiting schools and providing assistance with school projects. The facilitator also contacts teachers and career advisors on a regular basis to keep them informed about the program and offer classroom assistance.

Christie (2012) describes the training that Ambassadors receive, which includes an overview of the Futureintech philosophy, information about schools, and their expectations, particularly when dealing with face-to-face interactions with schoolchildren. Futureintech also provides a bank of IT-based resources for teachers and Ambassadors to access that range from videos to printed literature in a range of technology-, mathematics-, and science-oriented fields.

The Young Foresight program (in the United Kingdom) and the Futureintech program (in New Zealand) are both examples of how industry and schooling have collaborated to provide a formal mentoring structure that teachers can access to bring the outside world experiences into a classroom. Both programs scaffold their mentors into the educational community of practice landscape, so they are better equipped to relate to the demands of that environment. But what happens if teachers enact a community of practice interaction independent of such organizations?

Teachers Making Connections

Slatter's (2007) research investigated how secondary school technology teachers planned and implemented units of learning that enabled students to access authentic technological practice through contact with a community of practice (CoP) representative. The objective of this research was to investigate how secondary schoolteachers accessed communities of practice and discover the implications this access had for their educational pedagogy. The research project interviewed a range of specialist technology teachers (food, textiles, electronics, graphics, and hard materials) and discovered that when teachers independently plan to access an associated community of practice, a complex relationship between the teachers, the students, and the CoP evolves.

As a result of this research, it appears that teachers used strategies of approach to CoPs that were either of a formally organized structure such as phoning contacts or using email to introduce themselves and explain what they wanted. However there were also opportune moments that presented to the teachers, where the teacher recognized that a link could be made to their classroom learning, and they essentially "cold canvassed" the CoP directly at that time (Slatter 2007).

Slatter and France (2011b) introduce and discuss the nature and form of the teachers' interactions with their chosen CoPs and identify what implications could be made about the planned CoP access and the resulting pedagogy of the teacher. It was discovered that a range of interactions occurred that were ultimately influenced by how the teachers' belief system and perceptions of the use of a CoP representative in their classrooms would occur. Two interaction strategies occurred. These interaction styles could be grouped into two main strategies that identified which party maintained control of the learning situation. Either the CoP was placed in control in the classroom or the teacher managed the classroom interactions (Slatter 2012). When the teacher managed the classroom interactions, they did so in a variety of ways. These interaction strategies will now be covered in more detail. All names mentioned are pseudonyms.

The CoP Representative in Control

When the CoP representative was placed in control, a style of interaction happened where they planned with the teacher and directly interacted with the entire class. Figure 1 illustrates this.

Janis' class worked with a local food bank developing main meal recipe ideas to go into the emergency food parcels that the CoP's organization provided to people in need. In this situation, the CoP representative was essentially "given" the teaching of the class.

When the CoP representative maintained the control of their interactions with the students and the teacher was present merely in a supportive role to the CoP, it was discovered that teachers using this style of interaction viewed their role as the "teacher" had altered, and they facilitated and enabled interactions rather than being the one in control (Slatter and France 2011b). Teachers also felt that their expectations of students' learning widened to a broader perception of students' learning in technological practice rather than a focus on the production of an item. When the teacher allowed the CoP representative direct interaction with students, a partnership evolved where both parties planned toward a common goal of working with the students. In this situation it appeared that the teacher was confident to employ a more fluid pedagogy. For a snapshot of this in action, read Bob's story later in this chapter.

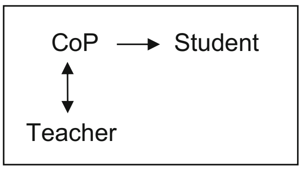


Fig. 1 CoP in control interaction style – Janis' class

Teacher in Control

Where teachers managed the interaction strategy, the control, ownership, and leadership by the teacher with the CoP created a partnership style where the teacher provided the direction and the CoP representative was less "up front and center" with the students. The teachers appeared to hold the common belief that they needed to maintain ownership of the teaching activities to ensure that the students would achieve the correct learning outcomes.

There were four different strategies that the teachers used, illustrated in Figs. 2, 3, 4, and 5.

Brian controlled when and where the electronics CoP representative would interact in his classroom environment by providing a set timetable for the CoP representative to come to school and work alongside the students with Brian taking control for classroom management and overall lesson direction.

Myrtle interacted directly with the food technologist CoP representative and completed site visits. Myrtle took that information back to her students and shared it in video, recorded interviews, and product information format.

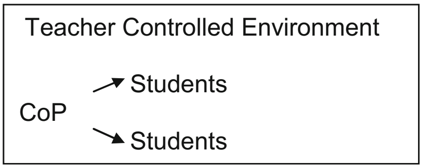


Fig. 2 Teacher in control – Brian's interaction style

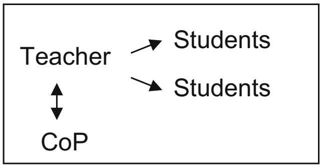


Fig. 3 Teacher in control – Myrtle's interaction style

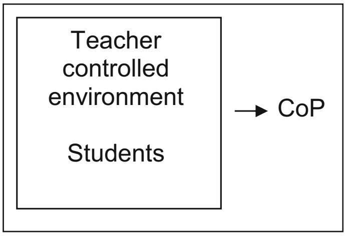


Fig. 4 Teacher in control – Sally's interaction style

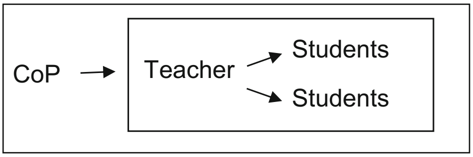


Fig. 5 Teacher in control – Eddie's interaction style

Sally took her students on a trip to the CoP environment, a food processing business, to see food safety and meal production being enacted in real time.

In Eddie's situation, the CoP representative (a building site developer) approached the school, asking if the students would like to design an outdoor area in a commercial complex. Eddie felt that the initial conceptualized design problem given was so broad it was difficult for the students to initiate design ideas, so Eddie intervened as a go-between, providing constructive design boundaries the students could work with.

In the teacher in control classrooms, the teacher acted as a form of filter between the information and interaction the CoPs were enacting and their students. The reasoning that teachers gave for utilizing this style of interaction strategy was based on their belief system that they, as teachers, had a better understanding of what needed to be gained for the students in the learning situation and so that demanded their control of the situation. This interaction style meant that one party provided direction and the other party took a lesser role in the relationship with the students. This meant that their planning was more carefully defined, in particular, about who was interacting with the students about what (Slatter and France 2011a).

Bob's Story: An Internet Company Logo Development

Bob's program was based around designing a logo for an Internet phone company and students were Year 12 (16 years old) in an older-styled graphics classroom in an urban New Zealand school (Fig. 6). The teaching program was characterized by Bob's careful planning in collaboration with the CoP representative so both parties had clearly defined expectations for the students. The initial connection Bob had with the CoP was assisted through a historical school-business link that his school ran where students were given "work experience" – that is, students were allowed time in the workplace environment to gain a snapshot taste of what working in that industry entailed. The business link coordinator in the school, Bob, and representatives from the Internet company met to establish initial ideas about how the project would proceed and what outcomes the Internet company might be able to see in the students' portfolios by a set date. From then on, meetings between Bob and the Internet company representatives were ongoing and scaffolded with emails and telephone contact.

Bob prepared a detailed lesson plan that considered the steps the design process should consider. He also prepared the students a workbook that scaffolded a

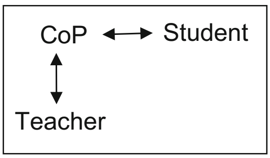


Fig. 6 CoP in control interaction style – Bob's story

suggested workflow and led students through protocols of working with a business client. Bob viewed his role as a technology educator to be, in part, assisting:

> . . .students learning to work, equip[ping] themselves with skills for the future. . .encourage them to think for themselves, and practice skills to be independent learners.

Although there were planned times that the CoP was going to be in class, Bob was very flexible in allowing additional un-negotiated access of the CoP to the class as the program ran. Bob did not action these un-negotiated access moments; they were situations generated by the CoP representatives or the students. These unplanned interactions meant that the CoP representatives turned up at the school at regular intervals to liaise with the students directly. The students were encouraged to actively research the client and independently approach the CoP representatives for meetings, materials, and ideas about supporting their solution development. Bob viewed his role as facilitating the relationship between the CoP representatives and the students through the task. He commented that the students were.

> . . .keen, keen to get their end result and integrate it into the business. . .the status of the project was high in terms of the kid's perception. And they [the CoP] actually took it really seriously, which was a real benefit.

Bob reflected on why he permitted so much flexibility in his teaching to allow the experiences to develop in the classroom:

> It gave an influence to the students, and opportunity to experience a real life activity that would develop as the student worked through the process; it wouldn't necessarily be set in concrete. It enabled both student and teacher to adapt what they do, to actually meet the need that existed. . . .

Bob's planning indicated that careful consideration had been placed on creating a holistic approach to the development of the students' technological practice as his unit plan was well scaffolded through the process and reflected the initial negotiations with the CoP representatives. Bob had a wider view of the learning that was to be undertaken by the students. This wider view enabled Bob to incorporate the unplanned interactions from the CoP representatives and the students within his planned work, as he understood the learning contributions that these interactions would create for his students.

The key indications from this research indicated that the pedagogy of technology teachers needed to be reflexive and responsive to change (Slatter and France 2011b). Williams et al. (2008) agree, and they suggest that when authentic problem-solving provides a context for learning, teachers need to "know how to adapt their instructional approach" (p. 320) for students. Another key finding was that the teachers' pedagogy was underpinned by a heightened belief that authenticity and situated learning was of importance in their classrooms (Slatter and France 2011b). Williams et al. (2008) also agree when they indicate "that learning is considered to be most effective when students are actively involved and learn in the context in which the knowledge is to be used" (p. 320).

Discussion

In Lave and Wenger's (1991) social learning theory about learning from and within communities of practice, human practice gave rise to a certain experience of the world where knowing was embedded in practical experiences, interpreted in respect to the certain social practices that occurred in that world. The PCK ideas of Shulman (1986) originally referred particularly to teachers needing to master two areas of practice – that is, the content knowledge about the subject they are teaching and knowledge of the curriculum framework under which their teaching practice is guided. There are indications that technology teachers' pedagogy needs to include developing ways that authentic learning experiences can be accessed in the classroom.

The idea of communities of practice dovetails into the idea of PCK as it helps to scaffold the content knowledge that teachers use to inform their teaching. It appears that what technology teachers learned, when learning to be participatory members of a community, has informed their teacher practice (Banks et al. 2004).

There is also the drive for authentically based experiences to be implicit within the New Zealand curriculum. The suggestion is that opportunities for students' learning should be based on authentic practice that is potentially gained by examining the practice of others (Ministry of Education 2007, p. 32). Snape and Fox-Turnbull (2013) suggest that technology programs in particular are rich for engaging authentic experiences for students.

How to access communities of practice that support technology teaching has been identified as collaborative programs that offer mentors in technological areas through the use of outside agencies. The UK's Young Foresight project offers designer mentors when students were designing (but not making) products and services with a future focus. The Futureintech program (NZ) offers a wide range of young engineers and technologists who are prepared to offer teacher and pupil support in New Zealand classrooms. From Slatter and France's (2011b) research, it appears that technology teachers have also developed pedagogical methods of accessing a CoP to provide authentic technological practice exposure for their students.

Of key importance, noted from each approach, is that ideas have to be brokered between the teachers, CoP resource people, and the students themselves to ensure that they become workable solutions in the classroom. It appears that structured conversations are a great first step, and both Barlex (2012) and Compton and France's works (2012b) offer some guidance as to how communities might come together.

CoP representatives can assist learners to better understand how technology education content is applied in real-world technology and design practices. The use of CoP representatives is also best used to showcase practices in business and industry settings that are not necessarily easily teachable in the classroom and can also inform students about potential career opportunities in technology.

Conclusion

Technology teachers have developed some pedagogical strategies for linking communities of practice to the classroom. This pedagogy was underpinned by a belief that providing opportunities for authentic learning to occur through student exposure to communities of practice was important. It appears that developing a common vision and maintaining professional trust and respect between technology teachers and communities of practice assisted in making connections where pupils were given the opportunity to experience authentically framed learning experiences. Scaffolded appropriately, it appears that deep and meaningful learning can occur from these authentic learning experiences.

Cross-References

► Authentic Learning and Technology Education
► Pedagogical Content Knowledge for Technology Education

References

Ball, D., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education, 59*, 389.

Banks, F., Barlex, D., Jarvinen, E., O'Sullivan, G., Owen-Jackson, G., & Rutland, M. (2004). DEPTH – Developing professional thinking for technology teachers: An international study. *International Journal of Technology and Design Education, 14*(2), 141–157.

Barlex, D. (2012). The Young Foresight project. In B. France & V. Compton (Eds.), *Bringing communities together connecting learners with scientists or technologists*. Rotterdam: Sense Publishers.

Brown, J. S., & Duguid, P. (2002). *The social life of information*. Boston: Harvard Business School Press.

Christie, A. (2012). Futureintech. In B. France & V. Compton (Eds.), *Bringing communities together connecting learners with scientists or technologists*. Rotterdam: Sense Publishers.

Compton, V., & France, B. (2012a). Working with technologists on technology curriculum development and implementation. In B. France & V. Compton (Eds.), *Bringing communities together connecting learners with scientists or technologists*. Rotterdam: Sense Publishers.

Compton, V., & France, B. (2012b). Mining multiple experiences. In B. France & V. Compton (Eds.), *Bringing communities together connecting learners with scientists or technologists*. Rotterdam: Sense Publishers.

Compton, V., & Harwood, C. (2003). Enhancing technological practice: An assessment framework for technology education in New Zealand. *International Journal of Technology and Design Education, 13*, 1–26.

Engelbrecht, W., & Ankiewicz, P. (2016). Criteria for continuing professional development of technology teachers' professional knowledge: A theoretical perspective. *International Journal of Technology and Design Education, 26*, 259–284.

Hennessy, S., & Murphy, P. (1999). The potential for collaborative problem solving in design and technology. *International Journal of Technology and Design Education, 9*, 1–36.

Johnson, S. D. (1997). Learning technological concepts and developing intellectual skills. *International Journal of Technology and Design Education, 7*, 161–180.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Ministry of Education. (1995). *Technology in the New Zealand curriculum*. Wellington: Learning Media.

Ministry of Education. (2007). The New Zealand curriculum. Updated 2014 Apr 8; cited 2016 June 14. Available from http://nzcurriculum.tki.org.nz/The-New-Zealand-Curriculum/Technology/Learning-area-structure

Mioduser, D. (2015). The pedagogical ecology of technology education: An agenda for future research and development. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education*. Singapore: Springer.

Newmann, F. M., & Wehlage, G. G. (1993). Five standards of authentic instruction. Educational leadership. *Association for Supervision and Curriculum Development, 50*(7), 8–12.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Slatter, N. W. (2007). *Making technology education real: Accessing a community of practice*. Unpublished masters thesis, University of Auckland.

Slatter, W. (2012). Teachers making connections. In B. France & V. Compton (Eds.), *Bringing communities together connecting learners with scientists or technologists*. Rotterdam: Sense Publishers.

Slatter, W., & France, B. (2011a). The teacher – Community of practice – Student interaction in the New Zealand technology classroom. *International Journal of Technology and Design Education, 21*, 149–160.

Slatter, W., & France, B. (2011b). Taking part in the dance: Technology teachers interacting with communities of practice. *International Journal of Technology and Design Education, 21*, 217–233.

Snape, P., & Fox-Turnbull, W. (2013). Perspectives of authenticity: Implementation in technology education. *International Journal of Technology and Design Education, 22*, 51–68.

Turnbull, W. (2002). The place of authenticity in technology in the New Zealand curriculum. *International Journal of Technology and Design Education, 12*, 23–40.

Williams, P. J. (2016). Research in technology education: Looking back to move forward . . . again. *International Journal of Technology and Design Education, 26*, 149–157.

Williams, P. J., Iglesias, J., & Barak, M. (2008). Problem based learning: Application to technology education in three countries. *International Journal of Technology and Design Education, 18*, 319–335.

Design in Technology Education: Current State of Affairs

46

Grietjie Haupt

Abstract

Three pressing needs that are widely acknowledged are conceptions of designing, the pedagogy of teaching designing in technology to general education students, and how design activities should be taught by teachers. As such, this chapter reflects on the development of design in technology education in the past five years. The purpose is to trace the current status of design in technology in the context of its sketchy history, while integrating questions that need to be interrogated in its enduring endeavor towards maturity. This chapter draws from literature that was published between 2011 and 2016; therefore, the work engaged herein was embarked upon to review the recent past on an international scale, but also to provide a potential foundation for future research, curriculum development, and teaching design in technology education. It is aimed to be helpful to researchers and tertiary educators in the field of technology teacher education, as well as to stimulate discourse in the ongoing interest in design as an activity that is needed in this field.

Keywords

Cognitive Constructivism • Epistemology • Methodology • Ontology • Pedagogy Philosophy • Social Constructivism • Values

Contents

G. Haupt (✉)
Department of Science, Mathematics and Technology Education, University of Pretoria, Pretoria, South Africa
e-mail: grietjie.haupt@up.ac.za

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_48

Introduction

As with any subject's curricula, incoherence, controversy, dichotomies, and misunderstandings are also present in teaching preservice teachers on a tertiary level, as well as teaching design in technology education at school level. In a preliminary quantitative and qualitative review of recent literature between 2011 and 2016, the author found no specific analysis of the underlying founding philosophies of current technology teacher education practice. Similarly, no recent metastudy was found that particularly focused on combining the philosophy and pedagogy of in-service teaching practice with professional design education that applies to design in technology education. Therefore, the author set out to ask the following research questions using a metastudy research design:

1. What are the common pedagogies applied in current teacher education in a design context?
2. What are the common educational issues attended to in current teacher education in a design context?
3. What are the common underlying philosophical approaches in current teacher education within a design context?

Preliminary Literature Review

The complexity of the decisions required in preparing teachers to teach design literacy through technology education is well known. McCormick's (1997) exposition of the difference between conceptual and procedural knowledge is a valuable contribution in starting to understand this complexity. The historic tension between beliefs about the end goal of design education is also important in deciding about the content and how to transfer it effectively to design teachers. However, the complexity and higher order thinking of design do not have to be reduced in the teaching and learning thereof. In contrast, the International Technology Education Association's (ITEA) (1996) understanding of design literacy clearly excludes the possibility of producing people who are competent in the practice of designing. This exclusion has serious implications for the depth embedded in curriculum design for the design sections in technology education. It also has a politically charged liberal undertone, which is bound to conflict with the humanist point of view that considers the design ability of talented individuals who become professional designers (Buchanan 2001).

The current socio-enviro-economic pressure to integrate value-driven sustainability education has been the topic of some studies, in particular, that of Pavlova (2013) and Middleton (2009). However, these are not sufficiently developed to guide teacher education effectively. Furthermore, what seems to be lacking is an understanding of the integration of value-driven decision-making as part of the ontology of designing in technology education projects. The emphasis on the accommodation of Science, Technology, Engineering, and Mathematical (STEM) content in technology education (Williams 2011) is also relatively new in the technology arena, and it has equally important implications for design education. This integration emphasizes the need for decisions that are made in the processes of designing to be based on a scientific base of knowledge about the forces of nature, where knowledge tends to be technical knowledge.

All of these emerging foci, and the continued shifts in emphasis on knowledge, process, and products, emphasize the responsibility of faculty to ensure that the design part of technology curricula remains central to bridging the gap between opposing viewpoints. This part of the curriculum should also contribute to shaping a balanced teaching and learning space where appropriate knowledge, methodologies, and values are transferred, while respecting and fostering the intellectual nature of the act of designing.

Centrality of Designing in Technology Education

The centrality of design in technology and technology education is widely acknowledged. One of the most powerfully worded expressions of this sentiment is Mc Cracken's (2000) statement:

> As a human soul is to the body, design is to technology. It is important to understand the interdependence and complementary nature of technology and design. Like the inseparable relationship between body and soul, technology is incomplete without design. Design cannot be fully appreciated without an understanding of technology. If technology is to be fully understood, then the concepts of design need to be understood. (p. 87)

Designing has also been described as having its own knowledge (de Vries 2005; Navaez 2000; Vincenti 1990) and as complex problem solving of a higher order (Goel 1995; Newell and Simon 1972; Visser 2004). This is due to the ill-structured nature of design problems (Goel and Pirolli 1992), which have their own unique methodology (Ferguson 1992) embedded in designerly ways of knowing (Cross 2007) in which designers express a variety of value systems when making design decisions. Their intention is directed at outlining the potential solution to an ill-structured or wicked (Rittel et al. 1972) context-bound problem. During these processes, designers typically represent their thoughts and knowledge through various types of representations, rather than through verbal, declarative statements only (McCormick 1997).

The idea of incompleteness, ambiguity, and vagueness is central to this interpretation of "design," suggesting likelihood and expectation. Incompleteness implies that it is in-process, while ambiguity and vagueness are attributed to a state of uncertainty. This is overcome by multiple iterations that are activated by continuous reflection (Schön 1983), and the evaluation of new information that emerges unexpectedly from internal and external sources (Gero and Yan 1994; Haupt 2015). The systemic nature of designing thus requires engaging in activities that are focused on filling in the gaps, and moving from uncertainty to certainty while ambiguity turns into clarity.

Following the early attempts to demarcate design as activity, Mitcham (2001) places designing as an engineering-orientated activity in perspective, where design implies drawing up the plans first and implementing them through making afterwards. Equally important is Waks' (2001) article in which he positions Donald Schön's viewpoints in terms of Dewey's Educational and Technology Theory. Schön considers design as a reflective process during which knowledge is contemplated and acquired during the design process in a studio-based environment. In contrast, Dewey's view of the reflective process is one of a critical, scientific inquiring process that takes place in a laboratory and is removed from actual technological activities.

The relevance of theorizing about design and its role in technology is significant. Since 2001, a growing body of research has been reported with a large proportion devoted to design-related studies in technology education, confirming its prominence in research, teaching practice, and teacher education. In 2004, Warner and Morford conducted an empirical study establishing the status of design in technology teacher education in the United States. Their study focused on academic programs at local universities comparing their technique-based and synergistic approach. Technique-based teaching for these researchers implies teaching and learning the basic skills required including technical drawing and model making. Synergistic-based teaching and learning, in turn, implies the combination of technical skills with the overall thinking processes of design.

In 2008, Johnson and Daugherty found that research on design ranked amongst the top five most researched topics published between 1998 and 2008. Following this report, Ritz and Martin (2013) conducted a Delphi study in which they found that experts in the technology education fraternity consider design-related issues among the most-needed research topics. Therefore, making credible analyses and inferences about the focus and status of literature that defines designing as one of the technological processes evident in real life situations (Lawson and Dorst 2009; Mitcham and Holbrook 2006) requires a well-balanced perspective of the field. This perspective could maintain the complexity of the field while making its underlying foundation structurally accessible to inexperienced student teachers and teaching practitioners. Such a framework is presented in the following section.

Conceptual Framework

From the preliminary literature review, a conceptual framework was developed to encompass the various pedagogic foci and underlying philosophical conceptions of designing that were observed in empirical studies involving teaching practice. Pedagogy is viewed from a practical perspective, considering three modes of transfer: cognitive constructivist, social constructivist, and technological. It also considers a focus on curriculum design and assessment. Figure 1 represents the framework used to analyze the data. Designing is approached from a philosophical perspective, considering its knowledge, the nature of design thinking, its methodologies, and the role of values when making design decisions.

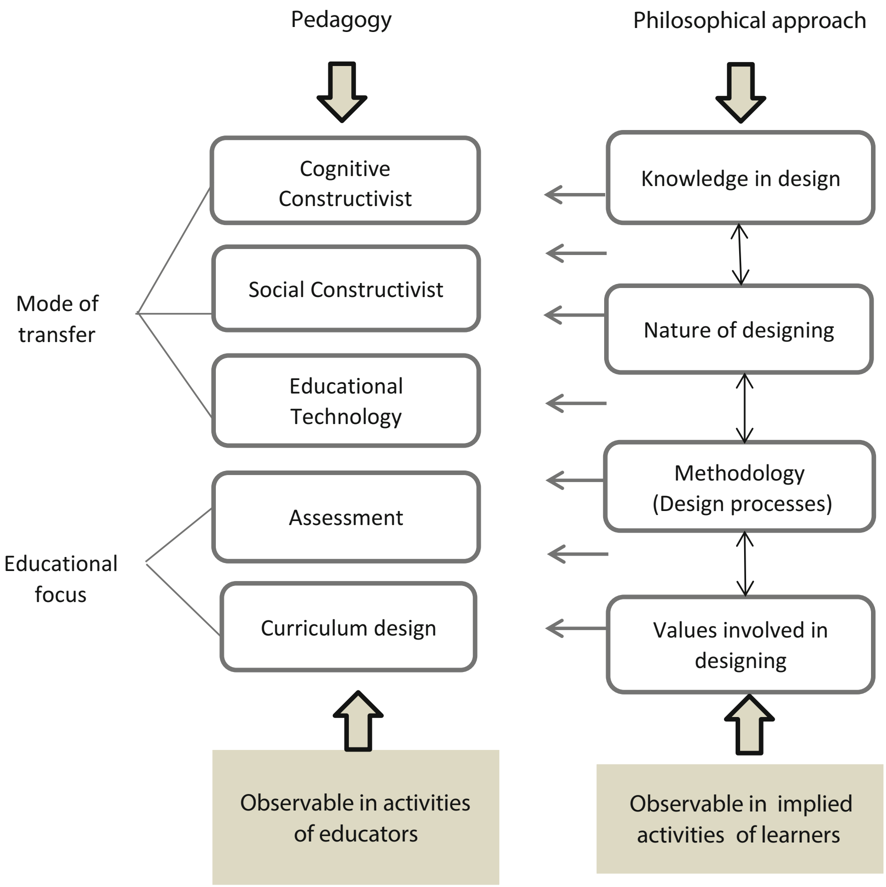


Fig. 1 Conceptual framework for analyzing current design-related literature

The concepts presented in Fig. 1 were used as an a priori data structuring framework guiding the final categorization and classification of the data. The categories were not mutually exclusive as they depended on the context. In many cases, articles had an integrated approach and therefore it was possible to find more than one category and focus in a single article. The data analysis, coding, and interpretations throughout this study were guided by the following framework:

In the framework used to guide this section, the category Pedagogy included two subcategories: mode of transfer and educational focus. Mode of transfer included three subthemes that were identified as approaches to teaching and learning:

- Cognitive constructivism: The focus is on individual performance, internal rigor, and processing competence, and knowledge construction with the aid of scaffolding and other constructivist teaching strategies.
- Social constructivism: The focus is on knowledge that is coconstructed using external, social, and is externally facilitated outside the agency of the teacher.
- Educational technologically: Teaching that is facilitated and supported by digital and other technological learning support materials and means.

The education focus included two subthemes:

- Assessment: The focus is on assessment approaches, strategies, tools, and their effectiveness.
- Curriculum design: The focus is on prescribed or adaptations of required content, concepts, and procedures.

The category Philosophical approach consisted of four subcategories involving acknowledged worldviews (Franssen et al. 2009), epistemology, ontology, methodology, and values:

- Epistemology: Knowledge types that are needed for designing, and the sources of such knowledge in designing.
- Ontology: Topics on the nature of the mental processes, types of thinking, and psychology characteristics involved in the activities of designing as a holistic and systemic process.
- Methodology: Themes focusing on design processes that suggest the structuring of design procedures and strategies.
- Values: Assuming both teleological and axiological systems including attitudes, efficacy judgments, ethics, the effects of technology and artifacts, social, cultural, environmental, technical and economic values, and environmental sustainability.

It is possible to have more than one approach in mind at the same time, therefore the framework allowed for an overlap between philosophical assumptions.

Reviewing Methodology

The purpose of this study was to provide a synthesis of the current literature that reports on practices of transferring design from concepts and capabilities, as represented in technology teacher education in particular, and in teaching practice in general. A thematic analysis (Braun and Clarke 2006) was used as it allowed the researcher to use an a priori flexible conceptual framework to identify relevance. This practice is in line with the critical realist approach to analysing qualitative data (Danermark et al. 2006). The codes for categorizing the themes in the articles were selected to provide a general, yet descriptive term that could be used to generate frequency counts across all of the articles.

Since 2011, the focus of research on design has been overtaken by a focus on curriculum. According to this study, design now sits in the second position, possibly due to the ongoing changes to school curricula worldwide, and in particular due to technology education now being intertwined with STEM, thus rekindling researchers' interest in its new scope and implied pedagogies. However, according to Williams (2016), teacher education only ranks seventh on the list of most common topics researched.

Only empirical studies were considered in the review of studies from 2011 to 2016, therefore reviews, commentaries, and opinion pieces did not form part of the sample. From a first layer of investigation and search for themes that related to design in technology education, a second layer of reading involved the identification of subthemes or foci that stood out as repetitive. The third holistic reading focused on identifying literature that reported directly on teacher education within a design-related context. As the process progressed, it became clear that the total number of publications involving teacher education could not be connected with designing per se. It also became evident that the "teacher education" group on its own was too small to be significant, resulting in a limitation of the findings. The majority of such publications directly involving teacher education focused on faculty involvement in curriculum design and the reinforcement of conceptual knowledge. Therefore, the author broadened the scope to include publications reporting on in-service practice. This was based on the assumed correlation between what is learned in initial teacher education and what is practiced in classrooms by in-service teachers as a result of ongoing teacher development and knowledge reinforcement practices (Musset 2010). The sample also included relevant professional design education studies based on the assumed correlation between generic design practices and knowledge attended to in professional design education and general technology education (Van Dooren et al. 2014).

The "teacher education" coding was thus expanded to include literature focusing on in-service teaching practice with inferred implications for teacher education. Although the small number of complying articles and papers in itself was informative of the state of teacher education research, the author believes that much valuable implications for teacher education objectives and outcomes could be inferred.

Review of Current Literature

For reasons of economy, the author examined research that had been published in three of the top technology education journals, as acknowledged by the technology education research community (Johnson and Daugherty 2008): (a) *International Journal of Technology and Design Education (IJTDE)*; (b) *Design and Technology Education (D&TE)*; and (c) *Journal of Technology Education (JTE)*. These journals were selected as they were considered as representative of what is currently happening in the English speaking countries in Europe, UK, USA, and Scandinavia, while an Asian and limited Southern African representation is also emerging. However, in tracing the current status of a particular section in the education practice, in itself, there is a limitation to relying on research articles only and not including an empirical research itself. Published research is not necessarily a true reflection of the entire spectrum of educational practice, but it is limited to what researchers choose to research and manage to get published. The risk of metastudies focusing on reports on the past is that "the field becomes understood by the research undertaken" (Jones et al. 2013, p. 204). One should therefore be sensitive to the unreported reality that coexists in the real world of teaching technology.

Coding took place in four phases. Phase one involved identifying empirical studies from the total number of items published in each volume from each journal in the sample. Phase two entailed assigning codes to the categories of design, teacher education, teaching practice implications, and pedagogic approach. To determine reliable coding, a second coder reviewed and coded a subset of articles from IJTDE, D&TE, and JTE. This resulted in 37% of the codes being examined by another person. When coding disagreement occurred, the coders discussed and resolved differences. Codes that could not be resolved were given to a third coder who independently assigned a final code. Discussions to achieve consensus with the original coder contributed to the reliability of the analyses. Once articles containing the particular combination of design, teacher education, and teaching were identified, phase three involved assigning codes to the categories Pedagogy and its three subcategories (see Table 1). Phase four involved assigning codes to the philosophy category and its four subcategories (see Table 2).

Analysis of the Current Status of Design in Technology Education

From the data analysis, the total number of articles pertaining to the focus of this chapter tallied to a total of 347 articles that were published in the selected journals between 2011 and 2016. From this total, 279 articles counted as empirical studies including teacher education, in-service teaching practice, and professional design education. As such, 194 or 70% of the empirical studies were identified as design-related. An overview of the statistics is broken down in Table 1.

From the total of 347 articles examined, only 12 articles of the total, or 3.1%, explicitly addressed teacher education, which reflects the focus of researchers on issues other than designing. Of the total of 12 explicit teacher education studies,

Table 1 Total number of design-related empirical studies published between 2011 and June 2016 in selected technology education journals

Title of journal	Years reviewed	Total no. of articles	Empirical studies	Design-related focus	Teacher education
International Journal of Technology and Design Education (IJTDE)	2011–June 2016	208	168	111	5
Design and Technology Education (D&TE)	2011–June 2016	85	73	59	4
Journal of Technology Education (JTE)	2011–June 2016	54	38	24	3
TOTAL		**347**	**279**	**194**	**12**

Table 2 Distribution of pedagogic approaches and foci within the context of teacher education, general technology education teaching practice, and professional design education

	Mode of transfer			Educational focus	
	Cognitive constructivist	Social constructivist	Educational technology	Curriculum development/ design	Assessment
Total no.	80	51	44	16	24
Percentage of total no. of articles in sample	41%	26%	23%	7%	12%

curriculum development and the reinforcement of conceptual knowledge conflated designing with the broad concept of "technological knowledge." It did not address philosophical issues that put the spotlight on designing as a unique activity with its own knowledge, intellectual processes, and methodology removed from industrial methodologies involving the life cycle of artifacts. Similarly, the pedagogy issues addressed in the sample covered issues related to macrocurriculum changes, curriculum development, and institutional assessment practices, which have been enforced by country-bound curriculum and policy changes and also lack guidance for teacher training on a micro level.

Pedagogy Trends

The obvious gap in the literature focusing on teacher education in combination with designing resulted in the author considering studies that reported on in-teaching practice potential as well as professional design education articles with implications for teacher education. The focus in this category was therefore on teacher strategies and not on learning. Consequently, the remainder of this discussion integrates all three of these contexts. In the category of empirical studies, three broad pedagogic approaches and two educational foci were found to dominate, as summarized in Table 2. There was potential for an overlap between pedagogic approach and education focus, although it was not considered for analysis and interpretation in this study.

From Table 2, it is clear that the majority of the studies, 80 out of 194, reported on teachers following a cognitive constructivist approach to teaching designing. Pedagogic concepts identifying these approaches included "transfer of knowledge," "mental models," "problem solving," "cognitive apprenticeship," "technical competence," and "technologically literate." Most of these points to the transfer of knowledge through individual pathways, and to improving isolated or integrated technological concepts such as robotics, or connecting STEM with technological conceptual knowledge, or learning particular processing skills. While cases where educational technology was used as mode of transfer tended to connect with social constructivist approaches, where the focus was on collaborative work, using digital software, forming networks and communities of learning (CoL), authentic learning, and participatory design.

From case studies reporting on the use of robotics as a pathway to construct cognition through direct manipulation, much scaffolding interventions from the teacher are necessary to ensure meaningful learning (Castledine and Chalmers 2011; Slangen et al. 2011). When handled adequately, learners of a young age have little difficulty in gaining cognitive and conceptual information. They are able to solve problems and develop holistic conceptualizations of robots that have psychological characteristics reflecting that of humans or animals, embedded in their design and construction. Similarly they understand that robots have technological characteristics. These entail materials used to construct objects, also resulting from human engineering (Castledine and Chalmers 2011). However, how to effectively integrate the use of educational technology such as LEGO® with real-world contexts needs more understanding and research.

Philosophical Trends

Table 3 is a summary of the distribution of philosophical approaches within the combined context of teacher education, teaching practice, and professional design education.

The advantage of these abstract categories was that it was possible to group otherwise loose standing themes into philosophical approaches on which curriculum design for teacher education can be built. The knowledge category was the third largest category, with a total of 63 out of 194 articles. Conceptual knowledge and understanding, procedural knowledge, and STEM integration were frequent themes. Artifact analysis, norms, and knowledge of effectivity perceptions also counted as knowledge subthemes. Similarly, fragmented competencies, such as visualization as graphic communication and graphicacy, and making or modeling were considered as knowledge when dislodged from a particular design task. Predominantly, this group combined with curriculum-related studies and cognitive constructivist and technology education pedagogy. A Norwegian study, in which the researcher

Table 3 Distribution of philosophical approaches within the context of teacher education, general technology education, teaching practice, and professional design education

	Knowledge (Epistemology)	Nature of intellectual processes and psychological characteristics (Ontology)	Design processes (Methodology)	Values (Teleology + Axiology)
Total no.	63	70	78	21
Percentage of total no. of articles in sample	32%	36%	40%	11%

(Esjeholm 2015) analyzed crosscurricular design projects, found that insufficient conceptual technological knowledge constrains creative solution production embedded in procedural knowledge. Confirmation that novices in professional design contexts do not know what they need to know as they tend to ignore conventional knowledge and processes materialized from a study by Osmond and Tovey (2015). The importance of this tendency is the warning it flags to educators to not engage their students in too much freedom of experimentation without considering conventional knowledge. Not only do such students dwell for too long in areas of uncertainty, but their eventual solutions are typically of a weaker quality than of their counterparts. This implies that irrespective of the methods teachers employ to stimulate creativity, it is yet dependent on domain specific technological knowledge, a notion substantiated by empirical and theoretical expertise studies (Haupt 2015; Lawson and Dorst 2009; Vincenti 1990).

It seems that, for some countries, the solution to solving the knowledge acquisition problem is in the introduction of STEM in design curricula (Ritz and Fan 2015). Although this study is not directly connected to design education, it does reflect important attitudes towards the inclusion and delivery of particular content of knowledge prioritized by curricula developers and their respective countries' economic and political drivers. Whereas some studies focusing on the integration of Mathematics and Biology are emerging, as discussed further on, it seems the field still does not have sufficient studies to guide design education researchers and teachers in the effective integration of physics and chemistry concepts. Food technology and production as topics for research are once again appearing on the horizon. However, these tend to focus primarily on curriculum issues (Rutland and Owen-Jackson 2015) and not on empirical research. However, it does bring to the forefront the important question of how much scientific knowledge in understanding twenty-first century food design practice is needed, instead of focusing on mundane production of food as a life skill without scientific knowledge.

The ontology category was the second largest, with 70 out of 194 articles. This category produced the widest variation of subthemes. Isolated mental processes that contributed to designing artifacts and solving overarching social or fragmented technological problems were considered in this group. Subthemes included goal orientation, intention-focus, representation, information processing, and decision making. Creativity and innovative thinking, in line with the twenty-first century skills requirement, were frequently observed. In turn, design cognition terms such as problem structuring, internal-external processing, systemic thinking, internal visualization through imagination, and sudden-moment-inspiration were emerging themes. Case studies (Lin 2016) focusing on the learning of spatial abilities indicate that it is possible to enhance holistic thinking, which result in more effective solution strategies versus fragmented understanding of untrained students. Scaffolding remains the primary method of teaching spatial problem solving skills (Youssef and Berry 2012). The emergence of social constructivism in subthemes combining cognition cultural memory is interesting. Problem solving and iteration as themes are still present, as is the cognitive role of sketches. Other subthemes included metacognition and types of thinking, such as divergent thinking, critical thinking, design thinking, holistic thinking and systemic thinking. The emergence of the integration of mathematical reasoning was significant as this includes the notion of proportional reasoning strategies, which logically connects with considering the shapes of artifacts in a design context. A study conducted by Finnish researchers (Kokko et al. 2015) attended to the integration of multidisciplinary knowledge in design and technology contexts to solve real-world problems collaboratively. It emphasized the prominent role that practical craft tasks can play in the integration of abstract mathematical knowledge. However, it also confirms that the active teacher-student collaboration is nonnegotiable for effective design thinking to take place. In an Asian case study (Ke and Im 2014), these researchers considered maths-computer game design in collaborative contexts and the dilemma of structured group dynamics interfering with teachers' focus on design cognition processes. Despite the clear collaborative cognitive benefits of working with structured groups, the researchers warned against the dangers of teachers spending too much time on training learners in "group work" while trying to facilitate design thinking.

The methodology category was found to be the largest at 40% of the total of 194 articles. Although the distinction between the ontology and methodology groups was at times difficult to make, in general, the rule was that the sequencing of activities, or practical strategies contextualized in a design process, as a whole, counted as methodology. The subthemes found in this group were researching, interpreting, investigating, ideating, exploring, discovering, concept developing, evaluating, reflecting, communicating, storyboarding, sketching, drafting, and heuristics. These encompassed cognitive and social constructivist, as well as educational technology pedagogy.

Richness in the technology and design education journals, contributing to the knowledge of the design process methodology, is currently emerging through the influx of professional design education research in the journals considered for this chapter. In one such study, the researchers (Xiang et al. 2015) described the role of mental models, emphasizing the usefulness of generating ideas by using hierarchical models of the nature of artifacts. In another case study by Santulli and Langella (2011), these researchers investigated a reviving methodology of biomimetic design in professional design education. These researchers suggested that, although it is possible in theory to combine biology concepts with existing design strategies, typical design students lack depth of understanding selected biology analogies to make well-suited choices to base their design ideas. In a study on advanced engineering students, Winkelmann and Hacker (2011) reported on an experiment, which was conducted to find out how useful the provision of a generic answering system complimenting a technical requirements checklist was when students were framing their design tasks. The researchers indicated a significant difference in the quantity and quality of design ideas stemming from such an exercise, contributing to the stimulation of students' metacognitive processes. Adding to these newcomers, a much-needed area of design education research, relying on professional design knowledge, is that of a human-centered design approach. Such a study was undertaken by Klapwijk and Van Doorn (2015). Using a context-mapping procedure, interdisciplinary knowledge of users and the dual nature of artifacts intended to satisfy the users' contextualized needs, seemed to be a successful teaching strategy. All these studies from the professional design education contexts emphasize the important role of multidisciplinary knowledge, experimenting with generic techniques from the professions, a lesson well-worth learning by technology and design educators. Adoption of the significance of knowledge from experts in design education on primary and secondary levels seems to be emerging.

The smallest category with the lowest count was that of values. A mere 21 studies were found to focus on values of some kind. This trend is in line with what Johnson and Daugherty found in 2008. However, as was the case in the past, the more popular subthemes in the value group were found in the subthemes of gender, perceptions, attitudes, choices, and motivation. What has been neglected then and currently is the deeper exploration of the complexity of values connecting with multiple disciplines, including environmental studies, economics, cultural studies, aesthetics, and politics. Such neglect might be ascribed to the lack of immersion of design educators in the conceptual areas of these multidisciplinary knowledge fields, including STEM, as indicated earlier. The result is that the logical combination of epistemological values, including engineering norms, and scientific principles in mechanics, electricity, and electronics were absent in the literature explored for this chapter. Food technology studies were not connected to values, only to knowledge. Despite past experiences of a flood of value-related studies, it is still an underexplored area in technology education (Martin 2012; Pavlova and Pitt 2007). This can be ascribed to its complexity and the difficulty of providing logic structures which can be used to frame its study (Layton 1992; Prime 1993).

Conclusion

As indicated in the analysis and discussion of the data, and also in the various studies analyzed (Johnson and Daugherty 2008; Williams 2016), teacher education and professional development are underrepresented in the literature. Twelve out of 194 empirical studies published in the past five years in recognized journals connected teacher education to designing in technology education. Of these, the majority focused on curriculum and assessment issues rather than on the transfer of designing literacy, thus the current trends will continue unabated. This means that trends need to be derived from in-service teaching practice research. It proved useful in this analysis to also include current professional design education trends. As far as pedagogy is concerned, the current trend in all contexts of design education considered here continues (moving from cognitive to social constructive pedagogy), as found by Williams (2016). However, the numbers were still in favor of cognitive pedagogy in this study.

Studies exploring philosophical approaches, including epistemology, ontology, methodology, and values, indicate a downward movement in the epistemology category for technological literacy in favor of designing. The author found designing as theme to account for 70% of the total of empirical studies reported on in the sample used for this study, showing a continued interest in design-related research. No particular area in the epistemology category stood out. However, STEM integration in both conceptual knowledge and reasoning strategies were themes that emerged. Similarly, there seems to be a steady growth in the number of ontology-related studies. This seems to be an ongoing trend, which Williams (2016) has also noted, and a positive reaction to past calls made by Zuga (1992) for a deeper understanding of higher order cognitive issues in design thinking. Similar recent calls from experts, as reported by Ritz and Martin (2013), emphasize the ongoing need for such studies due to their complexity and difficulty in uncovering the unseen cognitive processes of designers (Goel 1995). In turn, the downward trend of focusing on values can be seen as positive by some who consider it to be a saturated area of research in design and technology education (Martin 2012). This is dependent on how broad or narrow the notion of values is to be considered. Researchers such as Pavlova and Pitt (2007) have shown that there are targets of value judgments other than attitudes, perspectives, and gender issues. As a result, the scope has now been broadened beyond environmental sustainability to include social sustainability. Using the pedagogy-philosophical framework proved to be useful in suggesting a number of future areas for exploration:

1. A concerted effort needs to be made in contributing to the micro level of faculty interpreting. Transferring macro rulings into micro decisions seems necessary if those involved in teacher education are to learn from each other.
2. Explore interconnections between the various categories and subcategories in the framework to create interesting networks of combinations (e.g., STEM in epistemology with critical types of thinking in ontology during the early phases of the design process and applying selected value system judgments when making decisions).
3. Explore the relevance of generic design thinking strategies found in professional design education, including architecture, industrial design, and interior design in design projects within the technology education curriculum.

Enriching one's understanding of the current status of designing in technology education necessitates connection making between this chapter and some of topics the remaining chapters in this book focus on. These include philosophy of technology and engineering, history of technology education internationally, STEM/interdisciplinarity, Slöyd and technology, engineering concepts, sketching and drawing, creativity and emotions, technology education as a practice-based discipline, collaborative design work, teacher education, assessing creativity, and social and ethical issues. Much scope for further research is provided by the diversity, yet interconnectedness between topics such as animation, in turn, connecting design education with the use of (SciFi) movies and children's holds an inspiring promise for enhancing teacher education, classroom practice, and research.

References

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*, 77–101.

Buchanan, R. (2001). The problem of character in design education: Liberal arts and professional specialisation. *International Journal of Technology and Design Education, 11*, 13–26.

Castledine, A.-R., & Chalmers, C. (2011). Pre-school pupils aware and able – Problem solving with Lego. *Design and Technology Education, 16*, 19–27.

Cross, N. (2007). *Designerly ways of knowing*. Birkhauser Verlag AG: Basel.

Danermark, B., Ekstrom, M., Jakobsen, L., & Karlsson, J. C. (2006). *Explaining society: Critical realism in the social sciences*. Oxon: Routledge.

De Vries, M. J. (2005). *Teaching about technology. An introduction to the philosophy of technology for non-philosophers*. Dordrecth: Springer.

Esjeholm, B.-T. (2015). Design knowledge interplayed with student creativity in D&T projects. *International Journal of Technology and Design Education, 25*, 227–243.

Ferguson, E. (1992). *Engineering and the mind's eye*. Cambridge: MIT Press.

Franssen, M., Lokhorst, G.-J., & Van De Poel, I. (2015) Philosophy of Technology. IN E.N. Zaha (Ed). The stanford encyclopedia of philosophy. Fall Edition. https://plato.stanford.edu/archives/fall2015/entries/technology/.

Gero, J. S., & Yan, M. (1994). Shape emergence by symbolic reasoning. *Environment and Planning, 21*, 191–212.

Goel, V. (1995). *Sketches of though*. Cambridge: MIT Press.

Goel, V., & Pirolli, P. (1992). The structure of design problem spaces. *Cognitive Science, 16*, 395–429.

Haupt, G. (2015). Learning from experts: Fostering extended thinking in the early phases of the design process. *International Journal of Technology and Design Education, 25*, 482–520.

ITEA. (1996). *Technology for all Americans: A rationale and structure for the study of technology.* Reston: International Technology Education Association.

Johnson, S. D., & Daugherty, J. (2008). Quality and characteristics of recent research in technology education. *Journal of Technology Education, 20*, 16–31.

Jones, A., Bunttin, G. C., & de Vries, M. (2013). The developing field of technology education: A review to look forward. *International Journal of Technology and Design Education, 23*, 191–212.

Ke, F., & Im, T. (2014). A case study on collective cognition and operation in team-based computer game design by middle-school children. *International Journal of Technology and Design Education, 24*, 187–201.

Klapwijk, R., & Van Doorn, F. (2015). Context-mapping in primary design and technology education: A fruitful method to develop empathy for and insight in user needs. *International Journal of Technology and Design Education, 25*, 151–167.

Kokko, S., Eronen, L., & Sormunen, K. (2015). Crafting maths: Exploring mathematics learning through crafts. *Design and Technology Education, 20*, 22–31.

Lawson, B., & Dorst, K. (2009). *Design expertise*. Oxford: Architectural Press.

Layton, D. (1992). Values and design and technology. In C. Budgett-Meaking (Ed.), *Making the future work*. London: Longman.

Lin, H. (2016). Influence of design training and spatial solution strategies on spatial ability performance. *International Journal of Design and Technology Education, 26*, 123–131.

Martin, M. (2012). Values in design and technology education: Past, present and future. In T. Ginner, J. Hallstrom, & M. Hulten (Eds.), *PATT 26* (pp. 309–314). Stockholm: Linköping University.

Mccormick, R. (1997). Conceptual and procedural knowledge. *International Journal of Technology and Design Education, 7*, 141–159.

Mc Cracken, J. (2000). Design: The creative soul of technology. In E. Martin (Ed.), *Technology education for the 21st century: 49th yearbook, council on technology teacher education*. Peoria: Glencoe/McGrawHill.

Middleton, H. (2009). Problem-solving in technology education as approach to education for sustainable development. *International Journal of Technology and Design Education, 19*, 187–197.

Mitcham, C. (2001). Dasein versus design: The problematics of turning making into thinking. *International Journal of Technology and Design Education, 11*, 27–36.

Mitcham, C., & Holbrook, J. B. (2006). Understanding technological design. In J. S. Dakers (Ed.), *Defining technological literacy: Towards an epistemological framework*. New York: Palgrave MacMillan.

Musset, P. (2010). Initial teacher education and continuing training policies in a comparative perspective. In *Current practices in OECD countries and a literature review on effects*. Paris: Organisation for Economic Cooperation and Development.

Navaez, L. M. J. (2000). Design's own knowledge. *Design Issues, 16*, 36–51.

Osmond, J., & Tovey, M. (2015). The threshold of uncertainty in teaching design. *Design and Technology Education, 20*, 22–31.

Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs: Prentice-Hall.

Pavlova, M. (2013). Teaching and learning for sustainable development: ESD research in technology education. *International Journal of Technology and Design Education, 23*, 733–748.

Pavlova, M., & Pitt, J. (2007). The place of sustainability in design and technology education. In D. Barlex (Ed.), *Design and technology for the next generation*. Whitchurch: Cliffe Co Communications.

Prime, G. M. (1993). Values in technology: An approach to learning. *Design and Technology Teaching, 26*, 30–36.

Rittel, H. W. J., Grant, D. P., & Protzen, J. (1972). Second-generation design methods. In Group, TDM (Ed.), *DMG 5th anniversary*. Delft: DMG.

Ritz, J. M., & Fan, S.-C. (2015). STEM and technology education: International state-of-the-art. *International Journal of Technology and Design Education, 25*, 429–451.

Ritz, J. M., & Martin, G. (2013). Research needs for technology education: Highlights of a preliminary analysis. In P. J. Williams & D. Gedera (Eds.), *PATT27*. Christchurch: University of Canterbury/ University of Waikato.

Rutland, M., & Owen-Jackson, G. (2015). Food technology on the school curriculum in England: Is it a curriculum for the twenty-first century? *International Journal of Technology and Design Education, 25*, 467–482.

Santulli, C., & Langella, C. (2011). Introducing students to bio-inspiration and biomemetic design: A workshop experience. *International Journal of Technology and Design Education, 21*, 471–485.

Schön, D. A. (1983). *The reflective practitioner*. London: Temple-Smith.

Slangen, L., Van Keulen, H., & Gravemeijer, K. (2011). What pupils can learn from working with robotic manipulation environments. *International Journal of Design and Technology Education, 21*, 449–469.

Van Dooren E, Boshuizen E, Van Merrienboer J, Asselbergs T, Van Dorst M. Making explicit in design education: Generic elements in the design process. International Journal of Technology and Design Education 2014;24:53–71.

Vincenti, W. G. (1990). *What engineers know and how they know it*. Baltimore: John Hopkins Press.

Visser, W. (2004). *Dynamic aspects of design cognition: Elements for a cognitive model of design*. Rocquencourt: Institut National de Recherche en Informatique en Automatique.

Waks, L. J. (2001). Donald Schon's philosophy of design and design education. *International Journal of Technology and Design Education, 11*, 37–51.

Warner, S. A., & Morford, L. L. (2004). The status of design in technology teacher education in the United States. *Journal of Technology Education, 15*(2), 33–45.

Williams, P. J. (2011). STEM education: Proceed with caution. *Design and Technology Education, 16*, 26–35.

Williams, P. J. (2016). Research in technology education: Looking back to move forward ... Again. *International Journal of Technology and Design Education, 26*, 149–157.

Winkelmann, C., & Hacker, W. (2011). Generic non-technical procedures in design problem solving: Is there any benefit to the clarification of task requirements? *International Journal of Technology and Design Education, 21*, 395–407.

Xiang, W., Sun, L., Chen, S., Yang, Z., & Liu, Z. (2015). The role of mental models in collaborative sketching. *International Journal of Technology and Design Education, 25*, 121–136.

Youssef, B. B., & Berry, B. (2012). Learning to think spatially in an undergraduate interdisciplinary computational design context: A case study. *International Journal of Design and Technology Education, 22*, 541–564.

Zuga, K. F. (1992). *Thoughts on technology education research*. First AAAS Technology Education Research Conference, Seattle.

Predictions and Realities: The Influences That Shape Beginning Design and Technology Teachers' Professional Identity

47

Denise MacGregor

Learning to teach, like teaching itself, is always a process of becoming: a time of formation and transformation, of scrutiny into what one is doing, and who one can become.

(Britzman 1991, p. 8)

Abstract

This chapter reviews the formation of professional identity and how it can be effectively developed by Design and Technology teachers. All teachers form a professional identity of themselves as teachers. When many begin to teach, they try to fashion their professional identities toward those who they vision as master teachers. However, after new teachers get acclimated to the school environment within they work, they begin to take on a professional identity of their own. The professional identity of Design and Technology teachers is influenced by their command of the knowledge of Design and Technology, the skills they have mastered in using materials and equipment and passing these skills onto the students they teach, their perceived worth by fellow faculty members and school administrators, the value that students see within them, and how the local community views these instructional programs.

Overall the formation of professional identity is a dynamic and formative process. Mentoring by faculty at a teacher preparation institutions and faculty within the school environment assists new teachers to develop themselves and form their own professional identity. As the feeling of worth of a Design and Technology teacher takes shape, it can lead toward a commitment to the teaching profession. If impressions of teaching worth are not established, teachers can easily become dissatisfied with teaching and consequently leave the profession. It is important that the teaching community takes the time to mentor new teachers and keep their professional identity expanding in positive ways.

D. MacGregor (✉)
University of South Australia, Adelaide, SA, Australia
e-mail: Denise.MacGregor@unisa.edu.au

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_46

This chapter explores the concept of teacher professional identity and how it is developed. Included are a review of factors that shape the identity of Design and Technology teachers. A case study on the development of professional identity of new Design and Technology teachers is presented showing what can be learned from their experiences. Finally, some conclusions are made which the Design and Technology community can use to better prepare its teaching force.

Keywords
Professional identity • Beginning teachers • Design and technology education

Contents

Introduction

When pre-service teachers commence and complete their university study, they hold varied personal narratives about their professional identity as educators (Groundwater-Smith et al. 2007; Smith 2007). These perceptions have been shaped by many constructs including personal and professional histories (Furlong 2013), the content of university courses (Zuga 1991; Smith 2007), school- and community-based experiences (Lortie 1975), and interactions and conversations with peers, university and school staff, friends, and family. Once pre-service teacher's transition into their teaching roles, the community of practice (Wenger 1998) widens, and these perceptions are influenced further by the diversity and complexities of the school context itself (Coldron and Smith 1999).

In this chapter, identity is not viewed as a *fixed product* of the individual; instead, it is to be considered as being a *socialized and socializing process* in which identities can be accepted as well as reshaped (Furlong 2013). Thus, identity formation is conceptualized as a dual process, involving both identification and negotiability (Wenger 1998). Wenger argues that "we cannot become humans by ourselves" (p. 146). Similarly, we cannot become teachers by ourselves. It is the interconnectedness of experiences, interactions with others, and knowledge that merge to shape the professional identity of the beginning teachers.

This chapter draws on the literature to argue that teacher professional identity stands at the core of the teaching profession in that it provides a framework for teachers to construct their own ideas of how to be, how to act, and how to understand their work and their place in society (Beauchamp and Thomas 2011). Furthermore, the concept of professional identity is related to beginning teachers' self-concept which is composed of both how they see themselves and how they perceive others to see them in their teaching roles. The literature argues further that it is these concepts that not only strongly determine the way in which beginning teachers teach but also the way in which they continue to develop as teachers.

Identity Theory

The question of "what is identity?" has been debated in the social science literature for over 50 years ever since Erikson (1968, 1980) drew on the work of Freud (1930–1965) to argue that identity is "the coherent picture one shows both to oneself and to the outside world" (Erikson 1980, cited in Schwartz 2001, p. 8). Central to definitions of identity at that time were the terms, "the sense of self" and "one's self-concept." Current research (Cohen 2008; Gee 2001; Soreide 2006; Watson 2006) continues to argue that identity can be described in terms of a sense of self; however, it is also contended that identity is relational, to do with recognition of sameness and difference between ourselves and others. Identity is not viewed as something that is fixed or unchanging. It is not a product that one possesses, but is shaped as one progresses through life. Informed by the work of Foucault (1990), this view argues that identity only has meaning within a chain of relationships. Foucault termed this "the arts of self" (p. 26) as he referred to identity as a work of art where one consciously or unconsciously constructs one's self into who one wants to be through past and current experiences, social influences, and interactions, coupled with an understanding of one's self through reflection.

Directly associated with the relational nature of identity formation is the concept of symbolic interactionism (Cohen 2008; O'Connor and Scanlon 2005). Symbolic interactionism is based on an assertion that individuals act according to their interpretation of the meaning of their world. The concept is also underpinned by the belief that one has multiple selves and that one's self-perception is shaped and developed through social interaction with both the familiar and unfamiliar. The result is that one may act and react differently in and within different social and professional situations. Thus, it can be argued that individuals become who they are because of what they do. For instance, a teacher may adopt a teacher persona or situated identity that provides a sense of affiliation or sameness. The close connection between identity, interaction, and practice was also articulated by Wenger (1998) in his examination of communities of practice. Wenger argues that identity is produced as a lived experience of participation within specific communities, through engagement with members of that community, acquiring competence in it, taking on its perspectives, and aligning oneself with it.

A postmodernist view of identity recognizes the impact of rapid social change and the diversity of people's lives in creating and recreating their individual identities. In this view identity is recognized as being dynamic, that is, ever changing in response to experiences. It is argued further that the implication of such a view is that one should think about identity as an ongoing process of identification, a process of interpreting (and reinterpreting) oneself as a certain kind of person in a given context (Gee 2001). The work of identity can be viewed as always ongoing, something that we constantly renegotiate during the course of our lives.

Gee (2001) and Beauchamp and Thomas (2009) argue that identity is multifaceted in that it changes over time and through the influences of a range of internal factors such as emotion (Zembylas 2003) and external factors on the individual, such as life experiences (Flores and Day 2006; Sachs 2005). Gee (2001) recognizes identity as a kind of person within a particular context and identifies four perspectives through which identity may be constructed. They are:

1. Nature – identity (developed from one's natural state)
2. Institution – identity (derived from a position recognized by authority)
3. Discourse – identity (resulting from the dialogue of others about oneself)
4. Affinity – identity (determined by one's practices in relation to external groups) (Gee 2001)

Gee's (2001) emphasis when examining identity is on the multifaceted aspect of identity as the four perspectives are not separated from each other but rather interrelate and connect in complex ways. Acknowledging the four perspectives, however, enables attention to be focused on each of the aspects that form and sustain identities. Based on Gee's four perspectives, the professional identity of the beginning teachers in the case study presented in this chapter could be shaped by their own beliefs and understandings (nature), the school contexts in which they teach (institution), the dialogue of colleagues and students (discourse), and an affiliation with colleagues (affinity). Similarities can be drawn from the discussion on identity formation presented in the preceding section of the review of the literature. Wenger (1998) defines identity formation as a dual process, involving both identification and negotiability within a community of practice. According to Wenger, negotiability allows us: "[t]o make meanings applicable to new circumstances, to enlist the collaboration of others, and to make sense of events or assert our membership" (p. 197). Both Wenger and Gee (2001) agree on the multifaceted nature of identity in that it involves multiplicity and fluidity in and across contexts.

The emphasis within a postmodernist view is also on the role that narrative, language, and thought play in our interactions and experiences with others. The narrative rendering of identity is reflected in the work of Clandinin (1993, 2007) and Clandinin and Connelly (1998, 2000) who suggest that our identities are the stories by which we live. Clandinin (2007) argues that the ontology of lived experience enables professional identity to be viewed as relational, temporal, and continuous: "relational" because professional identity can be shaped by the social and cultural constructs of others in specific contexts, "temporal" in the sense that narratives can capture perceptions of professional identity at a particular moment in time, and "continuous" because professional identity changes in response to life and professional experiences. Bullough (2005), Clandinin (2007), Clandinin and Connelly (1998, 2000), Cohen (2008), and Soriede (2006) argue from the field of identity and narrative inquiry that it is the interconnectedness and intersection of our experiences, place and knowledge that merge to become identities in the sense of our narratives, or stories by which we live. Bullough (2005) argues further that "It is within intersection that personas (or situated identities) reveal themselves, are or are not reorganised by others, and are judged as fitting–contextually appropriate or inappropriate to the rules, duties and meanings of an established storyline" (p. 240).

Stories told are spoken to specific persons, to an audience, and as the audience changes so too do the stories. Soreide (2006) termed such stories as ontological narratives, narratives about the nature of existence, and suggested that these are the stories "We tell in an effort to make sense of how we experience ourselves and how we would like to be understood in order to bring structure to our lives in particular contexts" (p. 527).

By exploring the language that one uses to share one's beliefs, experiences, and opinions, aspects of one's identity become apparent. It can be argued further that the shaping of identity is also mediated through the telling of the story and to the feedback that one receives in relating the story. When stories are written, as is the case for the study that informs this chapter, the "narrative is frozen and becomes a thing, a statement captured in a specific moment of time" (Bullough 2005, p. 241).

While the concept of identity is defined in various ways in the literature, it is also used in different ways when exploring teacher professional identity. What follows is a review of the literature which investigates professional identity in the context of teaching and, more specifically, the nature of identity formation for beginning teachers.

Professional Identity of Teachers

In becoming a teacher, beginning teachers must decide how they want to be viewed by others and how they want to view themselves; that is, they must negotiate a new identity. This entails adapting personal understandings and ideals to the contextual expectations of schools and education generally. As a consequence, beginning teachers need to develop a sense of professional identity that enables them to "incorporate their personal subjectivities into the professional and cultural expectations of what it means to be a teacher" (Alsup 2006, p. 27). Thus, developing a professional identity involves finding a balance or coherence between aspects of personal and professional identity. Failure to find this coherence may result in tension in that "what is found relevant to the profession may be in conflict with the personal desires of [beginning] teachers and what they experience as good" (Beijaard et al. 2004, p. 109).

Beijaard et al. (2004) identify three essential features of teacher professional identity. The three features are that it:

- Is a constantly evolving phenomenon
- Involves both a person and a context
- Comprises the notion of agency

As a result of the evolving nature of teacher professional identity, Thomas and Beauchamp (2011) caution that understanding teachers' professional identity and the issues related to it can be difficult and complex. When pre-service teachers commence their teacher education programs, aspects of their identities may be challenged or confirmed by themselves and others, often resulting in adjustment. Once pre-service teachers commence teaching, this shift will continue as they progress throughout their careers. Coldron and Smith (1999) suggest that, from the beginning and during their careers, teachers are engaged in creating themselves as teachers. For beginning teachers, the development of a professional identity appears to be a central element in the transition from pre-service teacher to beginning teacher (Thomas and Beauchamp 2011). The literature suggests further that developing a strong sense of professional identity as a beginning teacher may be crucial to well-being and ultimately to long-term retention as a teacher. For example, in O'Connor and Scanlon's (2005) research on what it means to be a teacher and, more specifically, how teachers come to terms with the public demands of the teaching role, it became evident that both interaction with others and the role of thought (self-reflection) played a significant determining role in not only how one understood one's self, but, more importantly, how one dealt with the complexities that teachers faced. In recent years, the notion of reflectivity has become incorporated into many pre-service and in-service teachers' views of what it means to be a professional (Furlong and Maynard 1995). The capacity to think about and reflect on experiences and to make considered judgments enables teachers to modify their professional practice and develop their professional knowledge and identity. Johnson et al. (2012) argue further that "teachers who engage in self-reflection seek to understand themselves, their students and their schools within the wider context of social, cultural, economic and political influences in society" (p. 82). Johnson et al. posit that the ability to reflect enables beginning teachers to challenge and develop their beliefs, assumptions, values, and practices and to negotiate the contradictions and tensions associated with beginning to teach.

Central to the formation of teacher professional identity is the notion of self within the school context. Schools are socially produced and culturally constructed contexts (Sloan 2006). They can be viewed as places that provide specific histories, experiences, and knowledge that can shape the stories that tell others who we are. As a result, beginning teachers are exposed, within a school context, to a range of professional characteristics or dispositions that can be adopted by the individual. It can be argued that the construction of teacher professional identity involves making choices in regard to these traditions, characteristics, and dispositions, and, in so doing, one professionally locates oneself while informing others of one's identity. The beginning teacher, for example, may seek to not oppose the history, nor question the experience or knowledge of the context, instead choosing to identify with existing traditions.

However, O'Connor and Scanlon (2005) argue that beginning teachers must have the opportunity to integrate their own identity into their teaching role as it is this combination that brings individuality and uniqueness to one's teaching. This means that beginning teachers also need to reconcile what their understanding is of what it means to be a teacher regardless of the expectations of others, the students they teach, their colleagues, and the wider school community. This may mean building bridges between differing discourses, expectations, and assumptions. When building these metaphorical bridges, beginning teachers need to shape a professional identity with which they are at ease and one that enables them to actively pursue the goals that they value (Alsup 2006).

Influences that Shape Beginning Teachers' Perceptions of Professional Identity

The perceptions of professional identity that beginning teachers hold have been shaped by a range of social, political, and educational constructs and reflect influences of the past, the present, and, perhaps, a vision for the future (Flores and Day 2006). From the findings of their 2-year, longitudinal study of 14 middle-school beginning teachers in the UK, Flores and Day suggest that there are three key mediating influences on the formation of professional identity of beginning teachers. These influences are:

1. Pre-teacher identity – shaped through schooling experiences
2. Past influences – personal and professional histories and teacher education programs
3. Contexts of teaching – school cultures including school leadership, mentoring, and tenure of employment

The fact that everyone has had an educational experience makes teaching one of the most familiar professions. As a result, it is taken for granted that we all know what a teacher is and does (Britzman 1999). Britzman argues further that "schooling fashions the meanings, realities, and expectations of students; thus, those learning to teach draw from their subjective experiences constructed from actually being there" (p. 313). As a consequence, pre-service teachers commence teacher education programs with a preconceived image of what it means to be a teacher. Mayer (2006) also suggests that the narratives of professional identity that beginning pre-service teachers bring to their study are diverse, a result, in some instances, of the changing profile of those entering the field of education. A growing percentage of pre-service teachers who commence study are mature age or *career switchers* (Richardson and Watt 2006), and the memories they hold of teaching are from some time ago. In Design and Technology education, there is a high percentage of mature age pre-service teachers, including career switchers, and these pre-service teachers draw on life experiences (such as technical and trades' backgrounds) to inform their professional identity (Bussey et al. (2000) as cited in Smith (2003)).

However, teacher education programs should provide the knowledge base from which pre-service teachers can build and reshape their identity and their understanding of what is relevant to teaching. Lamote and Engels (2010) state that the role of the university teacher educator is to support the professional identity development of pre-service teachers in ways that correspond with contemporary views on learning and teaching. This sentiment is particularly relevant to the role of the Design and Technology teacher educator, as the evolving nature of the field necessitates a critique of and a possible challenge to the more traditionally held views regarding the Design and Technology teacher's identity MacGregor (2013).

Once pre-service teachers commence teaching, Reynolds (1996) believes that it is the school culture that informs and determines to a large extent the way that beginning teachers perceive their professional identity. Reynolds argues further that the school environment itself, including school leadership, teachers, students, and the wider school community, is just as strong a determinant in shaping professional identity as the individual. The school culture in which beginning Design and Technology teachers locate themselves can be further complicated by a number of subject-specific issues including the perceived status of the discipline in some schools, the skills-based and resource-reliant nature of the subject, and the need for teachers to demonstrate a clear understanding of occupational health, safety, and welfare (OHSW) issues to ensure personal and student safety. As a result, the school culture often provides very clear expectations about who, what, and how the Design and Technology teacher will teach, and, in so doing, assumptions are made about the identity that the beginning teacher will need to assume.

Fernandez (2000) has argued that there is widespread acceptance of the role that school leadership can play in developing school cultures that promote professional development for beginning teachers. A common trait of effective school leadership is the ability to build, promote, and maintain a professional school community through which teachers, including beginning teachers, are able to develop a sense of self-efficacy and self-worth. Fernandez argues further that effective leadership works in collaborative ways to create common goals, a vision for the future and standards for the school. More recent literature (Johnson et al. 2012) has revealed a growing emphasis on teacher collaboration as a key factor in supporting not only beginning teachers but all teachers in continued professional growth and development. Similarities can be drawn here with the role that mentoring plays in shaping beginning teachers' professional identity.

The theory behind mentoring and induction programs is that teaching is complex and that some aspects of teaching can only be acquired in the context of a school (Feiman-Nemser 2001). As a consequence, existing research has concluded that schools have an obligation to provide a supportive environment through which beginning teachers can further develop their professional knowledge and an understanding of their role as a teacher (Carter and Franci 2010; MacGregor 2012; Short and MacGregor 2015). Carter and Franci (2010) describe mentoring as a process that "mitigates teacher isolation, promotes the concept of an educative workplace and that leads to the creation or understanding of consensual norms in schools or faculty" (p. 250). More specifically, research has found that mentoring is used to address issues of teacher survival, skill development, and, ultimately, retention in the profession. Carter and Francis argue strongly that those who undertake the role of mentor have the potential to play a significant role in assisting beginning teachers in not only developing their professional knowledge but also their professional identity.

What the literature (Carter and Franci 2010; MacGregor 2012; Short and MacGregor 2015) clearly states is that the success of the mentoring process is reliant on the relationship that develops between the mentor(s) and the beginning teacher. However, the literature also highlights that the success of this process can be deemed to be "hit and miss." Carter and Franci (2010) have posited that less emphasis should be placed on the notion of assigning one mentor to a beginning teacher. Instead, the provision of professional environments in which mentoring relationships can develop with a number of teachers, or "significant others," should occur. As part of their research into mentoring and workplace learning, Carter and Francis revealed that the most effective mentoring processes emerged from a positive organizational climate in schools, that is, when the school had an established whole school ethos of supporting beginning teachers. The aim of mentoring and induction programs should be to provide a supportive and encouraging environment where beginning teachers can survive, learn, and succeed.

An emerging issue that appears to significantly impact on the ability of beginning teachers to develop a sense of professional identity is that of tenure of employment. Pietsch and Williamson (2010) identify that the context for employment for beginning teachers in Australia has changed markedly over the last 20 years with many graduating students now making the transition into teaching in an uncertain employment context. The result, as argued by Pietsch and Williamson, is that "the opportunity to develop an understanding of the profession, of themselves as teachers and of the means to professional competence, is constrained for many by fragmented initial employment experiences" (p. 333). Pietsch and Williamson's research identified that the tenure of employment into which beginning teachers commenced their profession had a significant effect on their ability to not only develop their professional knowledge but on their continuing commitment to the profession and on their self-confidence and self-image as teachers.

Shaping the Identity of Design and Technology Teachers

Connelly and Clandinin (1999) use the term *collective identity* in arguing that the commonalities in the stories one tells about identity become a core identity that frames who one is within a specific context. For example, when applied traditionally and generically to Australian secondary school Design and Technology educators, the collective identity would include male, middle-aged, white, and Australian. Observation has suggested that these educators would be seen as being "good at making artifacts with their hands" and adept at engaging students (particularly boys) who are disinclined toward learning in other areas of the curriculum. One could argue that this is a collective identity for Design and Technology teachers that has remained unchallenged and unchanged for half a century. Staples (2003) suggests that many constructions of collective identity in Design and Technology education focus explicitly on the teachers' functional roles, that is, the "transmission of specific subject know-how" (Staples 2003, p. 300). In more recent times, political, social, and educational change has caused this collective identity to be challenged. In addition, the context in which beginning Design and Technology teachers locate themselves can be further complicated by a number of subject-specific issues including the perceived status of the discipline in some schools, the skills-based and resource-reliant nature of the subject, and the need for teachers to demonstrate a clear understanding of occupational health, safety, and welfare (OHSW) issues to ensure personal and student safety. As a result, the school context often provides very clear expectations about who, what, and how the Design and Technology teacher will teach, and, in so doing, assumptions are made about the collective identity that the beginning teacher will need to assume.

Curriculum Change

Internationally and nationally, Design and Technology education at a curriculum level has changed dramatically over the last 10–30 years, starting with a transition from vocational to general education followed by a return to vocational education through a series of curriculum reforms and, more recently, to a growing emphasis on the adoption of an integrated Science, Technology, Engineering and Mathematics (STEM) pedagogy (ACARA 2016). In Australia, these changes have largely been an attempt to align classroom pedagogical practices with contemporary developments in Design and Technology education in the UK and Europe.

The most influential of these changes within Australia was the introduction of a national curriculum in 1994 (Australian Education Council [AEC] 1994a, b). The Technology Statement and Profile (AEC 1994a) as a curriculum document encouraged teachers to move away from a narrow instructional craft orientation to one which acknowledged the consequences of technology from a social perspective. The pedagogical shift was one that moved from a didactic to a constructivist approach to teaching and learning (Middleton 2006).

In 2001, the introduction of the South Australian Curriculum, Standards and Accountability (SACSA) framework (DETE 2001) built on the changes introduced through the National Statements and Profiles to herald a new stage in the development of the field. In these curriculum documents, the learning area of technology education was renamed Design and Technology education. The renaming from technology education served to emphasize the explicit place that design should hold as a core methodology (MacGregor 2002). SACSA provided educators with both a framework for planning and opportunity to reshape teaching practice. Curriculum development over the last 10 years has seen a move away from specific skilling or "the transmission of subject specific know-how" (Staples 2003, p. 300), known as manual arts or technical studies, to a more general education. A general education in Design and Technology currently adopts a holistic approach to teaching and learning and is characterized by the development of a core of capabilities and values that include higher-order thinking processes to create sustainable design-based solutions.

For some experienced teachers, there has been a reticence to embrace curriculum change. This is further amplified when one realizes that professional profile data (Department of Education and Child Development [DECD] 2010) has revealed that the largest cohort of Design and Technology teachers (32.9%) in the state in which this case study was undertaken were in the 50–59-year age group with 10.8% in the 60 and over group compared with only 16.7% who were in the 20–29-year age group. As a consequence, a high percentage of Design and Technology teachers may be looking toward retirement. As a consequence, the idea of adopting and implementing curriculum with a broader subject content knowledge focus and pedagogical approach may receive limited priority.

Barlow (2002, 2012) argues beginning Design and Technology teachers are being confronted by a situation where they are generally required to possess a significantly different and more expansive knowledge base compared to that of their more experienced colleagues. The emergence of new technologies such as computer modeling, 3-D printers, rapid prototyping, and laser cutters is encouraging creativity, design thinking, and problem solving and represents an increasing knowledge base (Barlow 2012). The latest Australian Technologies curriculum (ACARA 2012) has heralded further changes as it encourages teachers to further expand their professional knowledge to enable students to understand and engage with a range of traditional, contemporary, and emerging digital technologies.

Teacher Education Programs

Teacher education programs provide a knowledge base from which pre-service teachers can build their understanding and identify what is relevant to teaching. Bullough (2005) and Beijaard et al. (2004) highlight the importance of teacher education programs in recognizing professional identity development as being a crucial aspect of the courses that are taught. Beijaard et al. (2004) argue that "it is the ongoing integration of what is individually and collectively seen as relevant to teaching that enables the professional identity formation process of pre-service teachers to be supported" (p. 123).

In an extensive study of the relationship between the time spent studying and the development of Design and Technology pedagogical content knowledge (PCK) in England and Wales, Atkinson (2011, 2012) revealed a clear correlation between the two. More specifically, Atkinson's research indicated that an increase in the length of time spent studying at university facilitated the development of positive attitudes and beliefs about teaching Design and Technology. That is, when pre-service teachers had the opportunity to complete a university-based undergraduate program in Design and Technology, they developed the conceptual tools and the procedural and physical skills required to teach successfully.

While the culture of the Design and Technology undergraduate teacher education program, on which this study is based, places emphasis on the development of PCK (pedagogical content knowledge), it has also developed a culture that encourages pre-service teachers to critique the use of and consequence of technology and to engage with associated issues, such as sustainability and preferred futures. The program also encourages pre-service teachers to redefine the discourse of the past and to reflect upon and question their assumptions, beliefs, and values about what it means to a teacher of Design and Technology.

In an extensive study of the resilience of 60 beginning teachers in Australian schools, Johnson et al. (2012) found that:

> Those (beginning) teachers who are socially and emotionally responsive in their professional relationships, and who have a personal commitment to the broader moral and ethical dimensions of teaching are more likely to succeed in shaping a satisfying professional identity that takes account of the person within. (Johnson et al. 2012, p. 77)

That is, beginning teachers who have a voice in shaping who they become based on their personal and professional beliefs are more likely to not only remain in the profession but to be able to bring about change. It could be argued further that as the past collective identity of Design and Technology teachers is questioned and challenged that beginning teachers are provided with an opportunity to inform and impact on its reformation.

The first part of this chapter has examined the literature concerning identity theory and professional identity including the influences that serve to shape beginning teachers' professional identity. In doing so, the chapter identifies that teacher professional identity formation is a relational and dynamic process, shaped by life histories, teacher education programs, the school context, and ultimately by the individual. The implication of such a view is that one should think about identity, particularly for beginning teachers who are establishing their sense of self in the role of teacher, as an ongoing process of identification. What follows is an example that showcases the development of professional identity of newly prepared Design and Technology teachers.

A Case Study: Developing Professional Identity

To achieve a rich and detailed portrayal of how beginning teachers constructed and reconstructed their perceptions of professional identity over time, a qualitative approach was adopted, combining narrative inquiry and case study methods. Over the last two decades, the use of narrative research has drawn on teachers' stories to produce detailed understanding about teaching and teacher identity. Clandinin (2007) argues that narrative is especially suited to conveying the complexities of the classroom, the nature of teachers' knowledge, and the development of professional identity. For this reason, the adoption of a narrative methodology was deemed the most relevant and appropriate to achieve valid and insightful findings. More specifically, the use of a narrative inquiry enabled the collection of data with a high level of authenticity. Clandinin states that qualitative case study has emerged as a critical part of the pedagogy of law, business, medicine, and education. When applied to research in education, it has often focused on teaching issues or dilemmas. In this collective case study, a group of 20 beginning Design and Technology teachers represented the bounded phenomenon (Merriam 1988). In other words, the beginning teachers were bound by the experiences of being recent graduates from the same undergraduate Design and Technology teacher education program, the activity of being beginning teachers teaching Design and Technology education in Australian secondary schools, and the 15-month duration of the study.

The study was conducted in two stages: the university stage and the in-school stage. The participants for Stage 1 of the study were 20 beginning Design and Technology teachers who had recently completed their final year of a 4-year undergraduate teaching program with a teaching major in the field of Design and Technology Education, including food and textile technologies. There were 6 females and 14 males. They ranged in age from their early twenties to their last thirties; nine of the cohort had previous work experience in industry. The first stage of the study was conducted on the campus of the university in which the pre-service teachers had recently completed their undergraduate study. The participants for Stage 2 of the study were a group of ten beginning teachers selected from the 20 participants from Stage 1. There were nine males and one female, and five of the cohort had previous industry experience. The setting for the second stage of this study was the varied schools in which participants had commenced teaching. For human subject protection, pseudonyms have been used throughout this chapter to present the findings.

Data were collected over a 15-month period with Stage 1 data collected during the last few months of university study and Stage 2 after 6 weeks, 6 months, and 12 months of in-service teaching. Data were collected using a questionnaire that included open-ended text response questions, a teacher professional knowledge framework, three semi-structured interviews, and reflective e-journal entries. The type of data analysis adopted for this collective case study was narrative analysis (Yin 2003). As a consequence of adopting a narrative case study approach, it was possible to adopt both a micro- and macroanalysis of the data (Creswell 2013). That is, while the intent of this particular analysis was to gain an insight into the experiences of individual participants within the particular case, commonalities or differences in the experiences could also be identified across cases.

Case Study Findings and Discussion

Stage 1: Predictions – What factors do you think will influence and continue to shape your professional identity once you commence teaching? The constructions of professional identity that the pre-service teachers held at this stage were yet to be made public, to possibly be critiqued, affirmed, or challenged. They had not yet had the opportunity to demonstrate or to tell others who they were professionally. As a consequence, there was limited certitude in their perceptions regarding their professional identity. It was not easy for the pre-service teachers to describe their emerging professional identity in words. The most frequent response was that it was how they viewed themselves at that particular point in time, that is, as a beginning teacher about to commence their teaching career. They were, as one participant commented, “standing on the edge looking in.” The pre-service teachers were yet to develop the socially produced aspect of their identity that would be shaped through the experiences within the school context.

However, it became clearly evident from the findings that when the pre-service teachers commenced teaching, they did not enter a context as empty vessels. Their teaching identities had already been mediated through past experiences, including their own schooling, work histories, and university study. The early notions of professional identity, or of seeing oneself as a teacher, were often expressed at this stage through descriptions of particular characteristics that the pre-service teachers believed would contribute to the successful execution of their role as teachers.

For instance, Kim cited her youth and connection with young people as aspects of her professional identity that would enable her to be successful as a teacher:

> I see myself as a young educator, who is passionate about the learning area. I am motivated to learn as well as teach. I can relate well to students, due to my age (young), my teaching style and my interests, which will be similar to the older students I teach. I am also able to maintain the boundaries between professional relationships and friendships. (Kim, written response to questionnaire)

The findings also suggested that positive attributes were juxtaposed with feelings of self-doubt. This was particularly evidenced when responses were voiced about being in a state of transition from student to teacher. For example, Brenton stated that he had difficulties in defining his professional identity and that he still saw himself as a university student who was on the cusp of change.

Findings revealed an additional level of struggle that was evident when participants were defining their professional identity. It was a struggle that presented itself on two levels. One level was through the expectations held by others regarding the roles that beginning teachers were expected to play, and the other level was through the expectations that one had of oneself in these roles. It was significant to note that 14 of the 20 participants related their responses in terms of how they believed others might perceive their identity rather than in terms of how they perceived it themselves.

As voiced by Evan: “I tend to see myself through the perceptions of others, so I hope they see me as a valuable asset in a school” (Evan, focus group discussion).

Pre-service teachers acknowledged the role that schools and, more specifically, the reactions of students toward their teaching and the support of colleagues would have in continuing to shape their professional identity.

As Simon stated:

> It will be the reaction from the students you teach that will influence how you teach and change how you think you are going. This will impact on how you see yourself as a teacher. You need to be able to enjoy yourself, to have a sense of satisfaction – if you have this, I

think you will see yourself as doing OK as a teacher. (Simon, written response to questionnaire)

Pre-service teachers felt that their professional identity would be shaped by the level of confirmation or acceptance they gained from students and colleagues. If affirmation was forthcoming, it would immediately identify a positive aspect of one's professional identity, an aspect that, as a consequence, would be reinforced and strengthened. The data also made continued significant reference to developing collegial relationships, being accepted, and having opportunities to interact with colleagues in the school.

As Isaac stated: "It will be the support from school staff, how you are valued in that environment, how much the learning area (Design and Technology) is valued in the school that will influence your identity" (Isaac, written response to the questionnaire).

Travis identified more specifically the need for conversations and discussions with Design and Technology colleagues as a means of identifying who you are as a Design and Technology teacher. Travis indicated further that it would be through these conversations that one may have to "defend what you do and, in doing so, this will shape your identity" (Travis, focus group discussion).

These findings highlighted the significant role that the development of positive relationships with colleagues and students was predicted to have in shaping professional identity. While mentoring was not specifically identified as an aspect of relationship development, participants stated that having the opportunity to converse and engage in discussions with colleagues would enable them to identify who they were as Design and Technology teachers. The need for clarification, affirmation, and acceptance in their role appeared to be of paramount importance as a predicted influence in shaping participants' professional identity.

Stage 2: Realities, after 6 weeks of teaching – What were the influences that contributed to shaping your professional identity when you commenced teaching? At just 6 weeks of teaching, the findings revealed that elements of the predictions made several months earlier by the pre-service teachers were becoming a reality. Strong and continued references were made to how the beginning teachers believed they were being perceived by and ultimately accepted by staff and students. These perceptions predominately centered on the beginning teacher's classroom practice: developing relationships with their students was seen as being an integral part of their professional identity. For example, Brenton demonstrated this with particular reference to teaching in his Year 9 class. In his interview, he stated: "I wanted to look as if I knew what I was doing thus avoiding the whole thing of this teacher has no idea so let's run amok!"

Working in practically based settings with a range of diverse materials and equipment meant that the beginning teachers' levels of competence very quickly became apparent to colleagues. The findings identified that once colleagues deemed that the beginning teachers could competently and safely perform their teaching role and that it aligned to some degree with their own practices, identity became externally validated, and the beginning teachers became accepted as colleagues.

As a result, they were then encouraged to take increasing ownership in regard to lesson content and pedagogy. The visibility of beginning teachers' capabilities was also highlighted through the collaborative nature of teaching Design and Technology education in shared workspaces. This is in contrast to the majority of other subjects which are taught primarily behind closed doors within individual classrooms, where limited opportunities are provided for colleagues to critique, evaluate, or to provide immediate advice, support, or encouragement to those who are commencing their teaching career. Positive feedback and responses from colleagues affirmed aspects of the beginning teacher's classroom practice and, in so doing, imbued them with confidence and enthusiasm for their teaching roles. As a consequence, any initial self-doubts and tensions that the beginning teachers had predicted were soon dissipated.

Professional identity, in this early stage of transition, appeared to be primarily shaped by how the beginning teachers believed they were being perceived by others. As argued by Fetherston (1993), "the new teacher is constantly on the stage and urgently needs to develop a performing self with whom he or she can live comfortably" (p. 95). While the demands of beginning to teach and its inherent responsibilities entailed a continual analysis of and reflection on beliefs and practices, the data revealed that this analysis was strongly influenced by the responses and feedback received from colleagues and students. Developing an identity with which one comfortably could live was, at this stage, developing an identity that others, that is, colleagues and students, viewed as being acceptable. For the pre-service teachers in this study, becoming a teacher was a matter of acquiring and then redefining an identity that was socially legitimated (Coldron and Smith 1999).

At 6 months. After 6 months of teaching, the narratives that initially spoke of uncertainty and self-doubt were replaced with narratives that echoed a sense of growing confidence as the beginning teachers became more familiar in the knowledge associated with the structure and culture of schools, that is, the daily routines and expectations, and with finding a voice in acting on their beliefs in regard to teaching. Earlier, the beginning teachers had been focused almost exclusively on developing their ability to integrate their subject content knowledge into their classroom practice, developing their pedagogical approach to teaching, and, most significantly, being accepted by their teaching colleagues and, in some instances, by their students. The beginning teachers were now able to look beyond their classrooms and were beginning to consolidate a personal knowledge of self as teacher, not only based on the feedback and acceptance of others, but on how they wanted to be defined by others and by themselves as teachers.

For example, Peter stated:

> Originally it was the weight of the worrying about the expectations of others that was the biggest thing to shape my identity. This has only changed this term. I have got to the point now where my biggest thing is my expectation of myself and the critique of myself. I often say "Oh, it is past the point of where I ask myself: am I doing what I am expected to do'? I am getting positive reinforcement from other staff and now it's me saying, 'Hey, you need to take a different direction here'. For example, if the kids are not engaged, I ask myself 'what are you doing?" It is now more about me and my expectations of what I want to do and what

> I want to achieve. So, that is something that has changed. I don't really care too much about what other people think now because I know that, by what they are saying, I am doing an OK job. (Peter, interview 2)

After 6 months of teaching, some of the beginning teachers appeared to have had the opportunity to bring individuality and uniqueness to their teaching. For example, Isaac stated that as he became more experienced, he believed that his professional identity became: "... more closely aligned to who I am, to what I have done in a previous life, and to who I want to be as a teacher" (Isaac, interview 2).

Isaac further stated that, to a large extent, he felt that he now shaped his identity rather than relying on his colleagues to provide guidance and acceptance. During the interview, Isaac discussed the connectedness between the skills and knowledge that he had brought to teaching from his past work and his life experiences and his recently developed teaching skills in shaping his professional identity. After what appeared to be an initial and brief stage of validation, the beginning teachers were able to assume ownership in what and how they taught to participate in ongoing change and, in some schools, to initiate change.

For example, Isaac stated:

> I have been able to shape some aspects of my teaching, like the Year 12 D&T class projects. When I first started, I implemented existing projects because it was easier and sort of expected that's what I would do. Some of the teachers are aware that I can bring new ideas that create interest and increase our student numbers so most teachers will go with the projects I have put forward. (Isaac, interview 2)

After 6 months, the majority of beginning teachers in this study evidenced a capacity to negotiate a professional identity and began to consolidate a personal knowledge of self as teacher (Sachs 2005). However, they continued to be confronted with ongoing and new challenges and tensions associated with beginning to teach. These challenges and tensions were focused primarily on realizing and acknowledging the complexity and diversity of the teaching role. These roles were indirectly associated with classroom teaching such as teacher as counselor, teacher as administrator, and more generally "just knowing and learning how the school systems run" (Peter, interview 2). The majority of the beginning teachers looked forward to experiencing a full year of teaching and to being able to say: "OK, I have now seen how a whole year runs."

After 1 year. After a year of teaching, the beginning teachers continued to view that their professional Identity as something that was dynamic and ever-changing. This was evidenced by Aaron: "I would say I am still working towards the sort of teacher I want to be. I am still a learner; my identity as a teacher is still evolving. You learn every day in school and you learn from your experiences" (Aaron, final e-journal entry).

Before they commenced teaching, the beginning teachers had predicted that the most significant influence in shaping their professional identities would be associated with school-based experiences and interactions with others. Participants identified that it would be the dialogue and responses of others coupled with an acceptance of their teaching practice that would serve to affirm their professional identities. Before they commenced teaching, there was a degree of apprehension in how participants felt they would be supported and their practice affirmed within the school context.

However, the findings revealed that these original fears of being subjected to “the powerful socialising forces of the school culture” (Flores and Day 2006, p. 221) were unfounded. After 1 year of teaching, all participants, albeit to varying degrees, continued to feel supported by their colleagues and students. The beginning teachers were encouraged to undertake new ways of teaching and to introduce new ideas and projects. The degree of freedom and ability to teach in ways that they wanted to was greater than they had originally anticipated. After a year of teaching, it became very clear that, through interacting positively with colleagues in and beyond the Design and Technology faculty and with students, the beginning teachers became identified with and identified themselves as being someone who was accepted within their school community.

Findings suggest that the main reason for this acceptance related initially to the alignment and visibility of subject content and pedagogical knowledge. More specifically, it was the recognition of sameness between aspects of beginning teachers’ subject content and pedagogical knowledge and that of their more experienced Design and Technology teaching colleagues that facilitated this recognition.

Case Study Conclusions. This case study aimed to examine the predicted and actual influences that served to shape the professional identity of beginning Design and Technology teachers as they commenced teaching in Australian secondary schools. The findings of this case study served to reinforce that it was the interplay between the beginning teachers’ personal histories (both work and life), the school culture, and, more specifically, the support and acceptance by colleagues and students within that culture that emerged as the strongest mediating factors in shaping participants’ professional identity. The pre-service teachers had initially identified each of these aspects before they commenced teaching, and the significance of each aspect continued to be highlighted as the study progressed. While the beginning teachers in this study acknowledged that they were continuing on their journey to be effective teachers, they also acknowledged that generally the transition process had not been as traumatic, isolating, or as tension filled as they had initially predicted. The point of difference in this study from those explored earlier in the introduction of this chapter was the short duration of time that it took for the beginning teachers to feel that their practice was validated and that they were recognized as equals by colleagues. The recognition of sameness was associated with the subject content knowledge, including the technical knowledge and skills that the beginning teachers brought to their educational settings. Being recognized as a teacher by their colleagues and by those in positions of leadership became an essential aspect of the legitimization of identity (Gee 2001). The beginning teachers’ understanding of subject content knowledge and competence in delivery soon became visible and apparent to colleagues as they worked collaboratively in practically based settings with a range of diverse materials and equipment.

Similarly, the ways in which the beginning teachers teaching ideas and pedagogical approaches were accepted and, in some cases, welcomed were also not predicted from the existing research. This study revealed that beginning teachers, after a period of time, were able to make choices in regard to the existing traditions, characteristics, and dispositions, and, in so doing, they were able to professionally locate themselves while informing others of who they were (Coldron and Smith 1999). Throughout the study it became evident that collaborative support and input of experienced colleagues are vital for the successful transition of beginning teachers into their school sites. Surrounding beginning teachers with a professional culture (Ingersoll and Strong 2011; Short and MacGregor 2015) that supports their personal and professional growth and well-being appeared to be, as predicted, a significant factor in shaping professional identity throughout the first year of teaching.

Case Study Postscript. In contrast to the Australian statistics which state that 25–40% of beginning teachers resign in their first 3–5 years of teaching (Berliner 2001; Ewing and Smith 2003), all ten participants of this collective case study are continuing to teach in Design and Technology education. The majority are teaching in the same school in which they commenced their teaching career 5 years ago. Four participants have moved into leadership roles as faculty coordinators. Many of the participants have continued to push the boundaries of what it means to be a teacher of Design and Technology. For example, Damien has shared his expertise in the area of advanced manufacturing with teachers internationally, and Evan has become an Australian representative for the technology schools of America.

Chapter Summary

Effective Design and Technology teachers are ones who feel confident that the content of their programs is of value and they have developed the skills to effectively engage students in its study. To develop this confidence, teachers need to know the content of their subject and how they can assist learners in developing design and making skills, so they can apply this knowledge to solve every day technical problems. The knowledge of Design and Technology is extensive, as it is for all teachers of applied subject areas. Besides mastering vast bodies of knowledge and planning for its delivery through effective instruction, Design and Technology teachers need to also develop confidence within themselves and see themselves as effective teachers. This is the essence of developing a professional identity for a Design and Technology teacher. This identity is influenced by the interactions that teachers have within the school environment that they teach. Welcoming teachers who assist as mentors to other teachers contribute greatly to the development of an individual teacher’s professional identity. The responsiveness of students to the teacher’s instruction is another factor that contributes to the melding of such an identity. Administrative leadership within schools also aids in one’s professional development identity. In addition, what the school and local community values of Design and Technology as a school subject also contribute to the development of the teacher’s professional identity. Understanding the importance of the concept of nurturing a professional identity can help all who influence teachers' success do a better job at enabling Design and Technology teachers to succeed at their craft.

Cross-References

- ► Community of Practice: Pedagogical Strategies for Linking communities of Practice to the Classroom
- ► Visions of the Technology Education Profession by Technology Teacher Educators

References

Alsup, J. (2006). *Teacher identity discourses: Negotiating personal and professional spaces*. Mahwah: L Erlbaum Associates.

Atkinson, S. (2011). The relationship between the time spent studying subject knowledge and the attitude of trainee teachers to the subject they will teach. In D. Fazarro (Ed.), Ohio: Bowling Green State University. *The Journal of Technology Studies*, *37*(1),17–30.

Atkinson, S. (2012). What constitutes good learning in technology education: How can we ensure that technology education graduates can provide it? In H. Middleton (Ed.), *Proceedings of the 7th biannual international conference on technology education* (Vol. 1, pp. 1–12). Brisbane: Griffith University.

Australian Curriculum Assessment and Reporting Authority (ACARA). (2016). STEM connections project report Australian Curriculum Assessment and Reporting Authority, Sydney.

Australian Curriculum and Reporting Authority (ACARA). (2012). *The shape of the Australian Curriculum*. Melbourne: Australia Government Publishing Service.

Australian Education Council (AEC). (1994a). *A statement on technology for Australian schools*. Carlton: Curriculum Corporation.

Australian Education Council (AEC). (1994b). *Technology – A curriculum profile for Australian schools*. Carlton: Curriculum Corporation.

Barlow, J. (2002). *Technology teacher education: Is it time to do a Maslow? International conference on technology education research conference proceedings*. Brisbane: Griffith University.

Barlow, J. (2012). Some thoughts on the diseconomy of the NSW technology education curriculum. In H. Middleton (Ed.), *Proceedings of the 7th biennial international conference on technology education, explorations of best practice in technology, design and engineering education* (Vol. 1, pp. 33–41). Brisbane: Griffith University.

Beauchamp, C., & Thomas, L. (2009). Understanding teacher identity: An overview of issues in the literature and implications for teacher education. *Cambridge Journal of Education, 39*(2), 175–189.

Beauchamp, C., & Thomas, L. (2011). Understanding new teachers' professional identities through metaphor. *Teaching and Teacher Education, 27*, 762–769.

Berliner, D. C. (2001). Learning about and learning from expert teachers. *International Journal of Educational Research, 35*(4), 463–482.

Beijaard, D., Meijer, P. C., & Verloop, N. (2004). Reconsidering research on teachers' professional identity. *Teaching and Teacher Education, 20*(2), 107–128.

Britzman, D. P. (1991). *Practice makes practice: A critical study of learning to teach*. Albany: State University of New York Press.

Britzman, D. P. (1999). Thoughts awaiting thinkers: Group psychology and educational life. *International Journal of Leadership in Education: Theory and Practice, 2*(4), 313–335.

Bullough, R. (2005). The quest for identity in teaching and teacher education. In G. Hoban (Ed.), *The missing links in teacher education design* (pp. 237–258). Dordrecht: Springer.
Carter, M., & Franci, R. (2010). Mentoring and beginning teachers' workplace learning. *Asia-Pacific Journal of Teacher Education, 20*(3), 249–262.
Clandinin, D. J. (1993). Teacher education as narrative inquiry. In D. J. Clandinin, A. Davis, P. Hogan, & B. Kennard (Eds.), *Learning to teach, learning to learn: Stories of collaboration in teacher education*. New York: NY Teachers College Press.
Clandinin, D. J., & Connelly, F. (1998). Stories to live by: Narrative understandings of school reform. *Curriculum Inquiry, 28*, 149–164.
Clandinin, D. J., & Connelly, F. (2000). *Narrative inquiry: Experience and story in qualitative research*. San Francisco: Jossey-Bass.
Clandinin, D. J. (2007). *Handbook of narrative inquiry: Mapping a methodology*. London: Sage.
Cohen, J. (2008). 'That's not treating you as a professional': Teachers constructing complex professional identities through talk. *Teachers and Teaching: Theory and Practice, 14*(2), 79–93.
Coldron, J., & Smith, R. (1999). Active location in teachers' construction of their professional identities. *Journal of Curriculum Studies, 31*(6), 711–726.
Connelly, M., & Clandinin, J. (1999). *Shaping a professional identity: Stories of educational practice*. New York: Teachers College Press.
Creswell, J. W. (2013). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. (4th ed.) California: Sage.
DECD (2010) Workforce DATA. https://www.decd.sa.gov.au/sites/g/files/net691/f/workforce_data_2010.pdf
Department of Education Training and Employment (DETE). (2001). South Australian curriculum standards and accountability framework (SACSA). http://www.sacsa.sa.edu.au. Accessed 3 May 2012.
Erikson, E. (1968). *Identity, youth and crisis* (1st ed.). New York: WW Norton & Company.
Erikson, E. (1980). *Identity and the life cycle* (Vol. 1). New York: WW Norton & Company.
Ewing, R., & Smith, D. (2003). Retaining quality early career teachers in the profession. *English Teaching Practice and Critiques, 2*(1), 15–32.
Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record, 103*(6), 1013–1055.
Fernandez, F. (2000). Leadership in an era of change: Breaking down the barriers of the culture of teaching. In C. Day, A. Fernandez, T. E. Hauge, & J. Moller (Eds.), *The life and work of teachers. International perspectives in changing times*. London: Falmer Press.
Fetherston, T. (1993). Learning from the first years of classroom teaching: The journey in and the journey out. *Teachers College Record, 95*(1), 92–112.
Flores, M. A., & Day, C. (2006). Contexts which shape and reshape new teachers' identities: A multi-perspective study. *Teaching and Teacher Education, 22*(2), 219–232.
Foucault, M. (1990). The history of sexuality: The use of pleasure (Vol. 2). Random House Digital, Inc.
Furlong, C. (2013). The teacher I wish to be: Exploring the influence of life histories on student teacher identities. *European Journal of Teacher Education, 36*(1), 68–83.
Furlong, J., & Maynard, T. (1995). *The growth of professional knowledge, mentoring student teachers*. New York: Routledge.
Gee, J. P. (2001). Social linguistics: Ideology in discourses. *Journal of Adolescent & Adult Literacy, 44*(8), 714–725.
Groundwater-Smith, S., Mitchell, J. M., & Mockler, N. (2007). *Learning in the middle years: More than a transition*. Boston: Thomson Learning.
Ingersoll, R., & Strong, M. (2011). The impact of induction and mentoring programs for beginning teachers: A critical review of the research. *Review of Educational Research, 81*(2), 201–233.
Johnson, B., Down, B., Le Cornu, R., Peters, J., Sullivan, A., Pearce, J., & Hunter, J. (2012). *Early career teachers: Stories of resilience*. Adelaide: Australian Research Council.

Lamote, C., & Engels, N. (2010). The development of student teachers' professional identity. *European Journal of Teacher Education, 33*(1), 3–18.

Lortie, D. (1975). *Schoolteacher: A sociological study*. Chicago: University of Chicago Press.

MacGregor, D. (2002). Understanding design in primary design and technology. In H. Middleton & M. Pavlova (Eds.), *Proceedings of the 2nd international conference on technology education research*. Brisbane: Griffith University.

MacGregor, D. (2012). The value of mentoring: a strategy for beginning design and technology teacher retention. In H. Middleton (Ed.), *Explorations of best practice in technology, design and engineering education* (Vol. 2, pp. 25–31).

MacGregor, D. (2013). Transforming identities: The process of becoming a design and technology teacher. In H. Middleton & L. Baartman (Eds.), *Transfers, transitions and transformations of learning*. Rotterdam: Sense Publishers.

Mayer, D. (2006). The changing face of the Australian teaching profession: New generations and new ways of working and learning. *Asia-Pacific Journal of Teacher Education, 34*(1), 57–71.

Merriam, S. (1988). *Qualitative research and case study applications in education* (2nd ed.). San Francisco: Jossey-Bass.

Middleton, H. (2006). Changing practice and changing lenses: The evolution of ways of researching technology education. In M. J. De Vries & I. Mottier (Eds.), *International handbook of technology education: The state of the art. International technology education studies* (pp. 53–64). Amsterdam: Sense Publishers.

O'Connor, K., Scanlon, L. (2005). What I do is who I am: Knowledge, skills and teachers' professional identities. Australian Association for Research in Education annual conference, University of Melbourne, Melbourne.

Pietsch, M., & Williamson, J. (2010). Getting the pieces together: Negotiating the transition from pre-service to in-service teacher. *Asia-Pacific Journal of Teacher Education, 38*(4), 331–344.

Reynolds, C. (1996). Cultural scripts for teachers: Identities and their relation to workplace landscapes. In M. Kompf, W. Boak, W. Bond, & D. Dworet (Eds.), *Changing research and practice; teacher's professionalism, identities and knowledge*. London: Falmer Press.

Richardson, P. W., & Watt, H. M. (2006). Who chooses teaching and why? Profiling characteristics and motivations across three Australian universities. *Asia-Pacific Journal of Teacher Education, 34*(1), 27–56.

Sachs, J. (2005). Teacher education and the development of professional identity: Learning to be a teacher. In P. Denicolo & M. Kompf (Eds.), *Connecting policy and practice: Challenges for teaching and learning in schools and universities*. Oxford: Routledge.

Schwartz, S. (2001). The evolution of Eriksonian and neo-Eriksonian identity theory and research: A review and integration. *Identity, 1*(1), 7–57.

Short, T., & MacGregor, D. (2015). Mentoring for beginning teachers in Australia. In W. Slater (Ed.), *Mentoring: Perspectives, strategies and impacts on school performance*. New York: Nova.

Sloan, K. (2006). *Teacher identity and agency in school worlds: Beyond the all-good/all-bad discourse on accountability-explicit curriculum policies*. Oxford: Blackwell.

Smith, R. (2007). Developing professional identities and knowledge: Becoming primary teachers. *Teachers and Teaching: Theory and Practice, 13*(4), 377–397.

Smith, S. (2003). Change of pre-service teachers' perceptions of technology and technology education through their university study and its implications for the implementation of the new technology syllabus. Honours dissertation, Griffith University.

Soreide, G. E. (2006). Narrative construction of teacher identity: Positioning and negotiation. *Teachers and Teaching: Theory and Practice, 12*(5), 527–547.

Staples, R. (2003). Shaping the profession's image. In G. Martin, M. Middleton (Eds.), *Initiatives in technology education: comparative perspectives*. Proceedings of the American-Australian technology education forum, Brisbane.

Watson, C. (2006). Narratives of practice and the construction of identity in teaching. *Teachers and Teaching: Theory and Practice, 12*(5), 509–526.

Wenger, E. (1998). *Communities of practice: Learning, meaning and identity*. Cambridge: Cambridge University Press.

Yin, R. (2003). *Case study research: Design and method* (3rd ed.). Thousand Oaks: Sage Publications.

Zembylas, M. (2003). Emotions and teacher identity: A post-structural perspective. *Teachers and Teaching: Theory and Practice, 9*(3), 213–238.

Zuga, K. (1991). Technology teacher education curriculum courses. *Journal of Technology Education, 2*(2), 60–72.

48 Pedagogical Content Knowledge for Technology Education

Michael A. de Miranda

Abstract

This chapter presents varied research reports and methodological approaches to studying teacher pedagogical content knowledge (PCK). The ability of a teacher to fluidly transform this knowledge requires that he or she develops PCK skills, so rich forms of instruction that are pedagogically powerful can be provided. This is the essence of PCK. The author presents a model for the analysis of PCK in engineering and technology education. Additionally, several PCK studies are analyzed to unpack the varied complexities and methodological challenges that researchers have encountered when designing and conducting PCK research. A result of this review of PCK research in engineering and technology education, along with PCK research from associated fields, highlights important questions about the need for a conceptual framework and PCK taxonomy that can help guide and inform future PCK research approaches in engineering and technology.

Keywords

Teacher content knowledge • PCK • Assessing PCK • Engineering and technology PCK research

Contents

M.A. de Miranda (✉)
Claude H. Everett, Jr. Endowed Chair in Science and Engineering, Texas A&M University, College Station, Texas, USA
e-mail: demiranda@tamu.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_47

Introduction

Instead of focusing on what content to teach students, pedagogical content knowledge (PCK) focuses on the strategies employed in teaching and those strategies that bring about the best learning experience for every learner. Pedagogical content knowledge involves the teacher knowing how to fluidly take advantage of different teaching approaches that make a learning experience most suitable for the learners. This includes being flexible and adjusting instruction to account for various learning styles, abilities, interests, and learning contexts. Knowing how to best teach a concept so that the learners will receive the best learning experience speaks to the essence of PCK. The different teaching approaches employed will vary from teacher to teacher and from differing educational contexts, but they invariably revolve around similar principles for each approach.

The notion of pedagogical content knowledge was first introduced to the field of education by Lee Shulman in 1986 and a group of research colleagues collaborating on the *Knowledge Growth in Teaching (KGT)* project. The focus of the project was to study a broader perspective model for understanding teaching and learning (Shulman and Grossman 1988). The KGT project studied how novice teachers gained new understandings of their content and how these new understandings interacted with their teaching. The researchers of the KGT project described PCK as the intersection of three knowledge bases coming together to inform teacher practice: subject matter knowledge, pedagogical knowledge, and knowledge of context. Subject matter content knowledge is described as knowledge that is unique to teachers and separates, for example, an engineering and technology teacher from an engineer or biologist. Along the same lines, Cochran et al. (1991) differentiated between a teacher and a content specialist in the following manner:

> Teachers differ from biologists, historians, writers, or educational researchers, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. For example, experienced science teachers' knowledge of science is structured from a teaching perspective and is used as a basis for helping students to understand specific concepts. A scientist's knowledge, on the other hand, is structured from a research perspective and is used as a basis for the construction of new knowledge in the field. (p. 5)

Geddis et al. (1993) described pedagogical content knowledge as a set of attributes that helped someone transfer the knowledge of content to others. According to Shulman (1987), it includes "most useful forms of representation of these ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others" (p. 9).

In addition, Shulman (1987) suggests that PCK is made up of the attributes a teacher possesses that help her/him guide students toward an understanding of specific domain content like those within engineering and technology, in a manner that is meaningful. Shulman argued that PCK included "an understanding of how particular topics, problems, or issues are organized, presented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8). In light of what engineering and technology education teachers should know and be able to do, Shulman argued that pedagogical content knowledge was the best knowledge base of teaching and suggests:

> The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students. (p. 15)

Therefore, the intersection of scientific, technology, engineering, and mathematics content knowledge required to engage in the practical and analytical aspects of technological literacy and engineering design within the engineering and technology education classroom will wholly depend on the ability of teachers to transform this knowledge into adaptive grade-level appropriate instruction. The quality and effectiveness of the instruction teachers deliver within engineering and technology classrooms covaries with teacher content knowledge, knowledge of pedagogical practice, and contexts. Figure 1 helps to capture the complex relationship between content knowledge, knowledge of teaching, context, and their interaction in the engineering and technology education instructional settings.

Figure 1 helps to conceptualize the complex relationship between teachers' content knowledge in engineering and technology education in addition to knowledge required to infuse engineering and technological concepts into classroom instruction. Of particular complexity within this model is when content-specific knowledge and pedagogical strategies are situated within a context. Engineering, technology, and design are most often situated in social, environmental, or complex problem-oriented systems and contexts. This critical center intersection shown in Fig. 1, labeled pedagogical content knowledge in engineering and technology, is the most intriguing. It represents the quintessence of teaching in an engineering and technology education classroom. Further adding complexity to the model is the dynamic nature of each segment represented in the model. In actual teaching, the model segment positions and interactions are constantly changing as the content, context, and instructional decisions made by the teacher evolve. Each of the

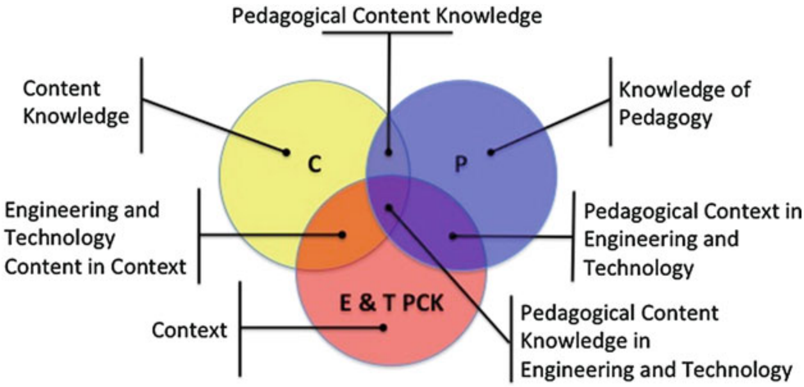


Fig. 1 Relationship of dynamic covariates that inform engineering and technology teacher PCK

variables presented in Fig. 1, combined with preservice and in-service teachers' general knowledge of pedagogy, helps to contribute to a specialized form of PCK in engineering and technology education. In addition, the specialized knowledge of engineering and technology is often highly contextualized in the form of authentic application to design problems that are context bound.

Interest in PCK as an epistemological perspective for research on the preparation of preservice engineering and technology teachers and as a knowledge base for infusing engineering and technology principles, content, and methods in the study of engineering and technology continues. This interest provides opportunity for our field to learn from more mature fields in research on PCK teaching. In the following subsections, examples of PCK research and their methodologies will be presented in order to seed thought and discussion on similar research that can be translated to the improvement of our understanding of teaching for better education in engineering and technology education.

Review of Research and Methodological Approaches

Study 1. Literature Review Method

Research-focused studies that attempt to characterize and measure PCK in its unified form have been rather elusive; however, recent studies that have incrementally advanced our knowledge and understanding of the fundamental elements of PCK have been fruitful. For example, the first study in this review conducted by Rohaan et al. (2009) worked to first critically characterize elements of PCK through a systematic literature review method that helped inform research progress toward scale development to measure PCK in primary technology education teachers.

Rohaan et al. (2009) utilized literature from studies focused on primary and often secondary teaching of technology education, with some literature derived from studies of science teaching. From the literature, the authors were able to extract and categorize six critical elements that emerged from the systematic review on PCK into three domains: subject matter knowledge, pedagogical content knowledge, and attitude.

Within the first domain, subject matter knowledge, the authors found that domain-specific knowledge of technology often outlined in standards and content guides for the study of technology formed the first element of teacher subject matter knowledge. The second element that formed teacher subject matter knowledge was teacher's concept of technology. This second element that reportedly formed teacher subject matter knowledge was quite intriguing. The authors reported that often teachers within the same school held different perceptions of technology and that a lot of teachers thought of technology exclusively in a school context, reportedly model-making. The authors offered that a teacher's narrow perception of what technology is or how it relates to their life may inhibit student's understanding of technology leading to students considering technology as irrelevant or disconnected from real life or contributing to the formation of misconceptions of technology. Another finding was that some of the teachers, who used science to explain technology, appeared to be confused about the general concepts of science and technology.

For the second domain, pedagogical content knowledge, the authors reported finding that the literature suggests that an important element that helps form a teacher's pedagogical content knowledge is a teachers' knowledge of student's general concept of technology and specific conceptions related to technology. The second element that helps to form a teacher's pedagogical content knowledge is knowledge of different pedagogical approaches and teaching strategies that are effective in technology education. The third element, teachers' knowledge of the nature and purpose of technology education, was reported to play an essential role in teaching technology education, meaning what teachers found to be important was often what is taught. Teacher's knowledge of the nature and purpose of technology was closely linked to their understanding of subject matter knowledge.

The final domain, derived from the systematic literature review study, was teacher attitude. The authors reported that teacher's attitude toward technology and confidence in teaching technology form important traits with respect to pupils' attitude toward technology. These findings are consonant with the research findings on teacher efficacy, which like pedagogical content knowledge is another elusive construct to capture (Gibson and Dembo 1984; Tschannen-Moran and Hoy 2001).

The work of Rohaan et al. (2009) helps to demonstrate that in research on PCK in engineering and technology education, a thorough and sophisticated literature review is the foundation and inspiration for substantial, useful research. The authors demonstrated the complex nature of disciplined inquiry using a systematic literature review methodology that demands such thorough and critical analysis. Such scholarship is a foundational prerequisite for advancing the methodological sophistication and for improving the usefulness of educational research on PCK in engineering and technology education (Boote and Beile 2005).

Advancing a Diverse Methodological Base

Pedagogical content knowledge is found to be a crucial part of the knowledge base for research on teaching and very important in advancing a base of knowledge for the teaching of engineering and technology education. While continued studies work to define, categorize, and bring about a more robust understanding of the complexities that surround the teaching of engineering and technology education, ample research movement is being made in working to test and refine methodologies to measure pedagogical content knowledge in engineering and technology education. In this subsection, several research studies will be presented that attempt to advance our methodological toolbox in engineering and technology education.

Study 2. Construct Measurement Method

Rohaan et al. (2012) assert that common methods used to investigate teachers' pedagogical content knowledge are often complicated and time and labor intensive. In their study to analyze and measure teachers' PCK in primary technology education, the authors used a combination of four existing scales to collectively measure teacher subject matter knowledge, pedagogical content knowledge in teaching technology, teacher self-efficacy in teaching, and an attitudes scale. This methodological approach attempted to measure the characteristic of teacher PCK in teaching technology extracted from their earlier literature review. The results indicated that on average, primary school teachers had poor to mediocre levels of pedagogical content knowledge in technology education. In addition, these authors reported teachers scoring high on technology subject matter knowledge, moderately confident in teaching technology (efficacy score), and held a more positive than negative attitude toward technology.

The 2012 Rohaan, Taconis, and Jochems study exemplifies the difficulty in measuring the central aspects that make up pedagogical content knowledge. Furthermore, the study uncovers the lack of specific scales or measures directly designed for the teaching of technology. Adapting scales from other fields or purposes injects sources of error and content and context validity when done in engineering and technology education. When research is moved from the realm of conceptual theorizing to the measurement sciences, the relative infancy of research on the study of PCK in teaching technology is exposed. Lee Cronbach (1975), writing in *American Psychologist* titled *The Two Disciplines of Scientific Psychology,* warned that as researchers tend to each and every 1st, 2nd, 3rd, and 4th order interaction, they enter a *Hall of Mirrors* that extends to infinity.

Study 3. Topical Content Knowledge Measurement Approach

Attempting to avoid the *Hall of Mirrors* warning leveled at educational researchers and working to unpack the complexities of just subject matter content, Fantz et al. (2011) adopted a methodological approach that investigated how teachers' educational training (subject matter background) influences their design and conceptualization of engineering content in teacher-created design briefs. Taking the teacher subject matter knowledge measurement approach toward a more focused measure of teacher topical content knowledge, the authors situated their study to advance the understanding of how engineering and technology teacher educational backgrounds influence their ability to design classroom interventions, in this case design brief content that infuses engineering design principles.

The underlying distinction between technology education and engineering lies with their perspective of the design process. Hailey et al. (2005) developed a comparison table of the design processes between the two teaching fields. Table 1 displays the side-by-side comparison between an engineering design process and a technology education design process as presented in their manuscript.

To better understand the difference between traditionally trained technology teachers (collegiate major field to study technology education) and engineering-trained technology teachers' (collegiate major field to study engineering) conceptualization of design instruction, the content and instructional methods presented in their design briefs were examined. One efficient way to accomplish this task is by collecting artifacts that demonstrate typical teacher-prepared design briefs from both groups. The study used a document analysis quasi-statistical methodology to help unpack and characterize teacher conceptualizations of design problems and processes. The comparison of design briefs was evaluated using a rubric that was created around the eleven-step engineering design process as defined by Eide et al. (1997) and shown in Table 1. In the rubric each component of the process was detailed with four levels of attainment. The top score of a 3 for a component of the process demonstrated complete integration of that component into the design

Table 1 Design process comparison

Engineering design process (Eide et al. 2002)	Technology education design process (ITEA 2000)
1. Identify the need	1. Defining the problem
2. Define the problem	2. Brainstorming
3. Search for solutions	3. Researching and generating ideas
4. Identify constraints	4. Identifying criteria
5. Specify evaluation criteria	5. Specifying constraints
6. Generate alternate solutions	6. Exploring possibilities
7. Engineering analysis	7. Select an approach
8. Optimization	8. Develop a design proposal
9. Decision	9. Building a prototype or model
10. Design specifications	10. Testing and evaluating the design
11. Communication	11. Refining the design
	12. Make it – create it
	13. Communicating results

process. On the other hand, a score of 0 indicated either a lack of use of that component or inadequate integration into the design process.

An independent sample t-test between engineering-trained ($n = 12$) and technology-trained ($n = 12$) teacher-generated design briefs/problems was performed for each of the ten engineering design steps. The results indicated that in the design steps common to engineering and technology design, Table 1 rows 1–4, 6, and 10, when compared at the alpha level of 0.01, the tests produced a statistically significant difference favoring engineering trained teachers for the engineering design step 10, communication.

When the design steps unique to the engineering design process, rows 5 and 7–9, were analyzed, significant differences were found favoring engineering-trained teachers. Although these results might appear to be expected, they represented important knowledge distinctions between the two groups and were helpful in understanding teacher topical content knowledge. If engineering design is an important knowledge component for technology education content, this study showed that engineering-trained teachers are more likely to include these concepts as outcome expectations in their design briefs.

In this study the authors focused on measuring the topical content knowledge of two groups of teachers, differing in their degree preparation to teach engineering design in technology education classrooms. The research approach tried to unpack a single subject matter knowledge area, in this case the engineering design process, and attempted to understand if educational training and background as a variable influenced the teacher-created design brief content. The study highlights a document analytical methodology using an evaluation rubric to yield data that can be subjected to classical means comparison analytical methods. The results of this study suggest that topical content knowledge does affect how teachers design and conceptualize instruction in the teaching of engineering design, critical building blocks for the understanding of engineering, and technology teacher PCK.

Study 4. Content Representation (CoRe) Approach to Articulate Teachers' PCK.

In a turn to science education, a study conducted by Williams et al. (2016) describes an effort to use teacher content representations (CoRes) as a way to articulate teachers' PCK in technology education. CoRes attempt to unpack a holistic overview of expert teachers' PCK related to the teaching of a particular topic. The CoRes contain sets of key ideas and a set of pedagogical questions/prompts which unpack each key idea from the teacher's perspective. Earlier research conducted by the authors used the CoRe matrix tool as a planning instrument to develop early career secondary teachers' PCK and was designed to examine whether such a tool, co-designed by an early career teacher, together with expert content and pedagogy specialists, can enhance the PCK of the early career science and technology secondary teachers. The technology education researchers discovered that unlike science concepts, concepts taught in technology education are often embedded within project-based learning. Second, the researchers found that the content area or topic that a CoRe refers to is relatively unproblematic in science education. The authors assert that science has a well-established epistemology, leading to an established organization of knowledge into accepted topics of inquiry that easily lend themselves to common teacher representations of the content, concepts, and how they can be taught. The authors argue that technology education has a shorter history as a field of study and no commonly agreed-upon epistemology related to the nature of knowledge in the study of technology and how that knowledge can inform how it might be taught.

In addressing the main research question in this study (What are the effective components of a CoRe for technology education teachers?), the researchers found that teachers recommended changes to the CoRe template from unpacking teacher conceptions of *Big Ideas* originating from teaching the nature of science, but rather to reflecting the technology teacher's CoRe related to student abilities and/or understandings of technological concepts embedded within a project or task. Williams et al. (2016) found that the changes were not major, yet they are more accurately related to the practical nature of technological activity. The CoRe planning matrix was restructured to provide a project focus, ideas were expanded to include abilities, and the pedagogical questions were modified to address both abilities and understandings. The consensus of the research team was that these changes would make it more suitable for technology teachers to use in the development of their PCK. This study highlights a fundamental difference between the nature of scientific and technological knowledge, and it confirms that methods used to study teacher PCK cannot be universally transferred between fields of study. This research contributes to the ongoing debate about the nature of knowledge in technology and the way knowledge informs teaching practice.

Study 5. Combined Knowledge Measurement Approach

In a turn to mathematics education, Hill et al. (2008) report their efforts to conceptualize and develop measures of teachers' combined knowledge of content and students by writing, piloting, and analyzing results from multiple-choice items. Not unlike engineering and technology education, the authors argue that gaps in pedagogical content knowledge studies in mathematics education research stem from a twofold problem. First, the field lacks studies that demonstrate that teachers possess this knowledge (PCK) apart from knowledge of the content itself. Second, the field has not developed, validated, and published measures to assess the many programs designed to improve teacher knowledge in this domain and to understand how this knowledge relates to student achievement.

This research attempted to first conceptualize, develop, and test measures of teachers' knowledge of content and that of students (KCS). The researchers did so in a methodological framework that ultimately attempted to connect all three pieces of this work, tying the conceptualization directly to the specification of measurement items and tying results from field tests back to strengths and weaknesses of the initial conceptualization. This work might also be informative for the field of engineering and technology education, such as measuring teachers' ability to design effective instruction and measuring teachers' skills in motivating students to learn about technology. Finally, a parallel to this work can be drawn to engineering and technology research previously reviewed in that this work represents an important precursor to designing and implementing large-scale studies that assess whether teachers' knowledge of engineering and technology and students contribute to student learning.

This study advances our methodological toolbox by introducing taxonomy as an intermediate basis from which to design measurement items to achieve the research objectives. The authors built upon their conceptualization of pedagogical content knowledge in mathematics education similar to Fig. 1 in this chapter. The taxonomy of mathematical content was derived from a domain map extracted and built from the researcher's conceptualization of mathematics teacher's PCK. The researchers then created specific items to reflect the domains of teacher knowledge in the taxonomy. The researchers then adopted classical test theory methods to refine their measures. A distinct refinement this study adds to the research literature on PCK is that the researchers were very intent in understanding the discriminant power of their measure to differentiate between measuring teacher content knowledge and a clear statistical signal from the data that indicated measurement of PCK.

This study highlights how a taxonomy of mathematical content can help build precision into the construction and testing of items within a measure. Second, methodological lessons can be learned that can help inform research efforts in engineering and technology education, and third, this research helps us to realize that not unlike other content areas, research on teacher PCK within the domain of engineering and technology education remains understudied.

Taxonomies and Conceptual Frameworks: Requisites for Guiding PCK Research in Engineering and Technology Education

Explicit taxonomies are available in the science education literature, and there are two frameworks in the technology education literature that can help guide the field of engineering and technology education in understanding the PCK required to deliver meaningful engineering and technology content (Lewis and Zuga 2005; McCormack and Yager 1989; Neale and Smith 1989). Neale and Smith (1989) constructed a configurations checklist, or taxonomy, for evaluating science educator teaching performance. The features of this checklist included lesson segments, content, teacher role, student role, activities/materials, and management. The checklist pertained to conceptual change in teaching of science. A teaching performance was rated for each feature of the checklist in terms of high vs. low implementation. McCormack and Yager's (1989) taxonomy of teaching and learning science incorporated five categories or domains of science education. The taxonomy was designed to help students become scientifically literate. The five hierarchical domains were organized by importance: (a) knowing and understanding (scientific information), (b) exploring and discovering (scientific processes), (c) imagining and creating (creative), (d) feeling and valuing (attitudinal), and (e) using and applying (application and connections).

In technology education, Lewis and Zuga (2005), in *A Conceptual Framework of Ideas and Issues in Technology Education,* raised the question of domain knowledge and teacher competence required for technology teachers to teach technology and design. The authors question the amount of domain-specific knowledge necessary to effectively teach a domain and further argue that a technology teacher also needs some agreed-upon competence level in engineering, mathematics, and science. These discussions raise serious questions regarding the state of technology education teacher preparation programs to prepare teachers to infuse engineering and design concepts into the technology education classroom and adequately represent this content in a valid and reliable manner.

More recently, Rossouw et al. (2011) in their publication titled *Concepts and Contexts in Engineering and Technology Education: An International and Interdisciplinary Delphi Study* asserted that one of the issues in the development of engineering and technology education is the search for a sound conceptual basis for the curriculum. This search has become relevant, as the nature of technology education has changed. It has gradually evolved from focusing on skills to focusing on technological literacy. The authors raised the question, what is a realistic image of engineering and technology? The studies related to PCK reviewed earlier in this chapter point to this question needing to be resolved within a field as a prerequisite for progress. Rossouw, Hacker, and de Vries point to a major accomplishment in the development of the *Standards for Technological Literacy, Content for the Study of Technology* (ITEA 2000) in the USA. While within these standards are many concepts and competencies in the form of student grade-level benchmarks related to engineering and technology, these authors argue that the competencies defined within the standards are still quite broad. Therefore, the Rossouw, Hacker, and de Vries effort attempted to identify a set of overarching, unifying concepts and contexts that cut across the technological domains in an effort to gain insight into the holistic nature of engineering and technology.

Their research design used a Delphi study methodology with groups of experts invited to rank both concepts and contexts. The results were followed by a panel of experts meeting with the purpose of turning the Delphi consensus outcomes into a framework for curriculum development. The panel developed a single list of contexts the authors characterized as “umbrella contexts” addressing personal, societal, and global concerns. The list included food, shelter, water, energy, mobility, production, health, security, and communication. For concepts, the panel developed five main concepts of designing, systems, modeling, resources, and values, each with accompanying sub-concepts that helped reduce abstraction.

A taxonomy of hierarchical domains in the study of engineering and technology education could serve as a catalyst for helping teachers negotiate the inherent overlap between general technological content for the study of technology, STEM content, specific engineering principles, and design. The development of an explicit teaching and learning taxonomy for the study of engineering and technology in a K-12 setting would alleviate the diffusion of curriculum claiming to teach engineering among other subjects like integrated STEM while providing clear guidance for curriculum development and tools to understand what teachers know or need to know to become effective teachers (Veal and MaKinster 1999). Conversation and efforts could turn to more significant work on *how to teach* and developing teacher PCK, rather than expend resources on *what to teach*.

Critical Considerations for PCK and the Training for Preservice Technology Teachers

Science and mathematics education and indeed PCK research have important messages for the teaching and learning of engineering and technology education. Commenting on criteria used for evaluation of teaching in the 1980s, Shulman (1986) asked "Where did the subject matter go? What happened to the content?" Of course those in engineering and technology education should attempt to advance educational theory in the same way that any other field does "pure research." But surely advances in theory of a school subject have only one purpose – to reflect back on, and improve, the practice within the field. The time is right in engineering and technology education to think through what we know about student learning, in conjunction with analysis of what it means to understand particular concepts in technology and engineering, to generate useful pedagogical practices specifically tailored for each concept, and then to assess, through research, the effectiveness of these practices. This would correspond with the notion of "applied PCK research" in the engineering and technology teacher preparation field.

Perhaps a more productive path to travel is to examine more critically the concept of PCK and what it means or could mean to the preparation of future technology education teachers. While *content knowledge* refers to one's understanding of the subject matter, and *pedagogical knowledge* refers to one's understanding of teaching and learning processes independent of subject matter, *pedagogical content knowledge* refers to knowledge about the teaching and learning of particular subject matter, taking into account its particular learning demands.

Each technology teacher has a unique knowledge of specific domains spanning multiple content areas identified with the study of technology (ITEA 2000). As technology teacher educators, we can never hope to transmit to the preservice technology teacher a duplicate of this knowledge. However, we can work toward developing a prospective technology teacher's knowledge, skills, and pedagogical dispositions that are the building blocks of PCK into powerful forms of teaching engineering and technology content. Certainly the reorganization of a teacher's knowledge structure into PCK will depend upon the context and nature of the subject matter. As more cross-cutting content, such as engineering design, science, and mathematics, is incorporated into the engineering and technology education curriculum, teachers will need to become comfortable with incorporating and making content border crossings in their instruction. To improve teacher preparation, faculty will need to know both subject matter from engineering and technology and be able to integrate mathematics and science content not only for itself but also in terms of its teachability and student learnability.

References

Boote, D. N., & Beile, P. (2005). Scholars before researchers: On the centrality of the dissertation literature review in research preparation. *Educational Researcher, 34*(6), 3–15.

Cochran, K. F., King, R. A., & DeRuiter, J. A. (1991). Pedagogical content knowledge: A tentative model for teacher preparation. East Lansing: National Centre for research on Teacher Learning. ERIC Document Reproduction Service No. ED. 1991; 340683.

Cronbach, L. J. (1975). The two disciplines of scientific psychology. *American Psychologist, 30*(2), 116–127.

Eide, A. R., Jenison, R. D., Mashaw, L. H., & Northrup, L. L. (2002). *Introduction to engineering design and problem solving* (2nd ed.). Boston: McGraw-Hill.

Fantz, T. D., De Miranda, M. A., & Siller, T. J. (2011). Knowing what engineering and technology teachers need to know: An analysis of pre-service teachers engineering design problems. *International Journal of Technology and Design Education, 21*(3), 307–320.

Geddis, A. N., Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education, 77*(6), 575–591.

Gibson, S., & Dembo, M. H. (1984). Teacher efficacy: A construct validation. *Journal of Educational Psychology, 76*(4), 569.

Hailey, C. E., Erekson, T., Becker, K., & Thomas, M. (2005). National center for engineering and technology education: The overall impact of the NCETE is to strengthen the nation's capacity to deliver effective engineering and technology education in the K-12 schools. *The Technology Teacher, 64*(5), 23–26.

Hill, H. C., Ball, D. L., & Schilling, S. G. (2008). Unpacking pedagogical content knowledge: Conceptualizing and measuring teachers' topic-specific knowledge of students. *Journal for Research in Mathematics Education, 39*(4), 372–400.

Lewis, T., & Zuga, K. F. (2005). *A conceptual framework of ideas and issues in technology education*. Technology Teacher In-service Education and National Science Foundation: Arlington.

McCormack, A. J., & Yager, R. E. (1989). A new taxonomy of science education. *The Science Teacher, 56*(2), 47–48.

Neale, D., & Smith, D. (1989). Configurations checklist for evaluating a teaching performance. *Teaching and Teacher Education, 5*(1), 1–20.

Rohaan, E. J., Taconis, R., & Jochems, W. M. (2009). Measuring teachers' pedagogical content knowledge in primary technology education. *Research in Science & Technological. Education, 27*(3), 327–338.

Rohaan, E. J., Taconis, R., & Jochems, W. M. (2012). Analysing teacher knowledge for technology education in primary schools. *International Journal of Technology and Design Education, 22*(3), 271–280.

Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–424.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–23.

Shulman, L., & Grossman, P. (1988). *The intern teacher casebook*. San Francisco: Far West Laboratory for Educational Research and Development.

Technology for All Americans Project, International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston: International Technology Education Association.

Tschannen-Moran, M., & Hoy, A. W. (2001). Teacher efficacy: Capturing an elusive construct. *Teaching and Teacher Education, 17*(7), 783–805.

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical content knowledge taxonomies. Electronic Journal of Science Education. *3*(4). http://ejse.southwestern.edu/article/view/7615/5382/. Accessed 19 Jul 2016.

Williams, J., Lockley, J., & Mangan, J. (2016). Technology teacher's use of a CoRe to develop their PCK. Utrecht, Netherlands: 2016 PATT Conference; 2016. https://hubl.hu.nl/session/conference-program-papers. Accessed 9 Jul 2016.

Visions of the Technology Education Profession by Technology Teacher Educators

49

John Ritz and Gene Martin

Abstract

As the technology education school subject has evolved, its evolution has quickened in the latter parts of the twentieth and the early years of the twenty-first century. This chapter reports the visions of the future of technology teacher education as reported by United States' university lead professors, recent graduates, and currently enrolled Ph.D. students who are preparing to become technology education teacher educators. Information reported in this chapter was collected from the research literature and through three author conducted research studies. It was found that the focus of the curriculum continues to evolve to better prepare teachers and learners to engage with technology. Findings show the content focus of the technology teacher preparation curriculum in the United States to be influenced by knowledge of technological literacy, technological systems, and engineering design. However, STEM integration is a major new program strategy identified for future instructional design and delivery as seen by new doctoral graduates. As these new Ph.D.s engage in practice, they bring with them new ideas regarding the content and delivery of technology education. Beliefs about the future for teacher preparation, their professional development, and journals for reporting ideas and research are identified. In addition, information about their beliefs of the future of the profession and its relationships with other STEM professions are reported. Since member involvement guides the future of professions, it was found important to involve all groups, seasoned and new, in the planning of the future of technology education and its professions.

J. Ritz (✉)
Old Dominion University, Norfolk, VA, USA
e-mail: jritz@odu.edu

G. Martin
Texas State University, San Marcos, TX, USA
e-mail: gm01@txstate.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_51

Keywords
Professions • Technology Teacher Educators • Curriculum • Future • Visions

Contents

Introduction

Governments make decisions about the schooling of children, and as societies change, decisions are made that place importance of subjects that all students should study. Throughout time, countries have emphasized the study of native languages, mathematics, history, and science. In many developed countries, there is often a major emphasis on subjects needed to prepare students to study at the university.

Economics has had an influence in determining which additional subjects and what emphasis should be included in the curriculum in addition to basic studies. To stay competitive in the world economic market, career and technical education (TVET – technical vocational education and training) has become attractive for governments to support. TVET provides technical training and skills needed to build a competitive workforce that is capable of producing goods and services for the world market. Many countries are losing their trained technicians due to retirements, and fewer students are entering technical training programs while in the formal schooling system (Ritz and Martin 2013).

STEM studies and their related occupations are also receiving increased interest and support from business/industry and government (Ritz and Fan 2015). These interests are self-serving for these groups, since specific STEM studies provide the skilled workers that companies seek to hire such as scientists, technologists, and engineers. These STEM educated learners will be called upon to create and produce the products that will keep economies stable or even growing in positive directions.

With the economic connections that can be made to schooling, some governments support the study of general technological studies in primary and secondary schooling. Since the nineteenth century, teachers have been prepared to help students understand and develop skills in the use of technology. As with most school subjects, the content and practices have changed to meet the needs of society.

Once a course of study used to develop basic skills in industrial practices, technology education has transitioned from the twentieth century industrial practices to align with the needs of the twenty-first century (Ritz and Bevins 2016). Development of computer skills and the design and modeling of products are some of the strategic outcomes of today's technology education programs. Engineering design and STEM integration are instructional and content focuses and are often used for designing technology education programs today.

Professional development of the current teaching force and the recruitment and development of new teachers are important functions of technology teacher education programs today. Professional organizations are providing a platform for networking and discussing the trends in program content and teacher preparation practices. Although additional technology education teachers are needed, their method of preparation varies as many candidates who seek to become technology education teachers do this after they have initially entered the workforce (Freedman and Goggin 2008). Discussions continue in the professional literature and at conferences on how best to prepare technology education teachers.

Professional Discourse

Participation in professional organizations and professional meetings has been viewed as one way for teacher educators and government officials to discuss methods that are used to prepare technology teachers, teachers who will educate future generations to understand, use, and evaluate new technologies (ITEEA 2007). Technology has been taught in schools since the latter half of the 1800s. At its early inception, technology education and its predecessors (crafts, manual skills, manual arts – learning by doing) had philosophers who bolstered how the hands-on study of technology could help children develop and also prepare industrial workers for the future (Martin 1979).

In many countries, this school subject divided into two tracks during the mid-twentieth century. Depending upon the country, the beliefs of its educators, and governmental decisions, determinations have been made as to whether the technology program had a vocational or general education focus. While both tracks are important to education and society today, one track focuses on the development of future skilled workers and the other focuses on the general belief of technological literacy for all. At times it is difficult to differentiate the separation of tracks because the projects students design and make and the laboratories in which technology is taught may look very similar. The focus of this analysis will be on a general education technological literacy track.

Although business/industry, and at times government, has looked at the school study of technology education for career selection exploration and preparation, most subject specialty researcher and leader dialog today is focused on technological literacy for all citizens. This base of professional researchers/leaders gives presentations, conducts and publishes research, and espouses philosophical beliefs concerning pupil's benefits from a general study of technology. Practicing professionals gather information from others in their own country and from those outside their country. New knowledge is taken and implemented or expanded upon to make changes in their technology education programs.

Technology Education Professionalism

Professions join people together who are interested in the same or similar topics. Through professional meetings and organizations, members (professionals) are provided a forum to share ideas. Key participants within organizations are practicing members, users, government officials, and universities (Burrage et al. 1990). Many form together because of their shared interest in topics and often partake in professional meetings to learn and to further develop professionally. Others join to build additional legitimacy of their beliefs (Muzio and Kirkpatrick 2011). Today, our profession seeks legitimacy of technological literacy education in primary and secondary schooling.

Through graduate education and professional affiliations, those interested in technology education can earn credentials and gain knowledge to serve as university professors of technology education. Continuing the profession relies on those who know this subject, have the skills to deliver instruction in the subject, and have the political aptitude to protect and grow this school subject within our schools. An important component of technology education is keeping its content up-to-date so its legitimacy is seen for including it in a twenty-first century school curriculum. Unfortunately, as governments and local education agencies have evolved, barriers have been posed that threaten technology education as a school subject (e.g., back to basics movement, standards reform, STEM fundamentals – mathematics and science enhancements, reduced funding) (Ritz 2011).

To provide further context for visions of technology education by teacher educators, the authors report on three recent research studies on this topic. These studies were undertaken in the United States to better understand how change impacts the practices of delivering technology education and the beliefs about technology education by current and future teacher educators.

Study 1 – Technology Education Teacher Preparation Curriculum Study.

For the most part, technology education is a required course at the middle school level (grades 6–8) in the United States. At the secondary level (grades 9–12), it is an elective course in most states. As a school subject, it is highly selected as an elective by many students. Rarely is technology education a formalized study at the primary level. The United States has technology education teacher preparation programs in many states with approximately 40 of these programs located at universities throughout the country. This number has decreased from approximately 300 in the 1970s (Rogers 2015). Changes found in university curriculum outcomes, university funding, and college student selection of this major have negatively impacted higher education technology programs.

Survey research was undertaken by Ritz in November 2015 using program leaders from United States colleges/universities that prepare technology education teachers. This population was selected from those teacher education programs that were affiliate members of the International Technology and Engineering Educators Association (ITEEA 2015). ITEEA's listing identifies 31 affiliate members out of the approximate 40 United States' programs. These affiliated member institutions were invited to participate in the Ritz study.

For this study, 28 lead teacher educators accepted invitations to participate. A total of 100% of the lead teacher educators completed a survey seeking information on their teacher education curriculum. Participants were asked to rate their program related to its inclusion of the following content foci: arts and crafts, American industry, world of manufacturing and construction, Maryland plan, career education, general study of technology, technological systems, design technology, engineering design, and STEM education. These foci were selected because research had been undertaken to develop each of these content foci from the late 1800s through 2015. The study provided a narrative description of each of the foci selected by the researcher. These study descriptions were described as follows:

Arts and Crafts. These types of curriculum activities were the basis for the early years of the development of our school subject. Teachers designed craft products and students replicated these to develop tool and material skills. Curriculum efforts such as Sloyd and manual arts contributed in this approach to the curriculum.

American Industry. This is an approach to education that studies the elements of industry used in industrial enterprises. It is applicable to manufacturing and enterprise courses where concepts such as materials, processes, finance, procurement, and personnel are studied and integrated through enterprising activities.

World of Manufacturing and Construction. This is an approach to teaching industrial technologies where students study the systems of manufacturing and construction within school studies. Knowledge is taught and incorporated into activities that include research, development, and the production of goods and structures.

Maryland Plan. It is an instructional and curriculum approach for middle school technology education. This program was designed to include historical and contemporary studies of industry and technology and had students develop models of artifacts, operate mass production companies, and research and experiment with technological products.

Career Education. This is an introduction to career studies within the general education curriculum. Legislative Acts followed that supported career exploration through the study of technology education.

The General Study of Technology. Curriculum designs for the study of technology are based on the philosophies of researchers such as Warner, Olson, and DeVore. It is the basis of ITEEA's *Standards for Technological Literacy* (2000, 2005, 2007). Systems of technology are studied and the impacts of technology on individuals, society, and the environment are emphasized.

Technological Systems. These studies have proposed that the systems of technology are major structural components of technology education. Systems such as biotechnology, information and communication, construction, energy and power, manufacturing, medical, and transportation are some of the systems suggested by researchers to use to structure programs.

Design Technology. Originally a British approach to the study and application of the design cycle to the study of technology, this approach has evolved into many approaches for solving technological problems. It is also referred to as technological design and design thinking.

Engineering Design. It is a curriculum and instructional approach to technology education where students define and construct solutions to open-ended design problems. Testing and analysis are used in solution refinements.

STEM Education. A curriculum approach designed to strengthen student knowledge by increasing attention to the application of mathematics and science through hands-on technology and engineering activities. The aim is to enhance students' knowledge and increase their selection and preparation for STEM careers.

Respondents were asked to use their professional judgments to indicate the impact that each research-based curriculum movement had on their current teacher preparation program. The selections they could choose to rate each movement included (a) no or little impact on the "current" curriculum, (b) concepts are reviewed within a course, (c) content is a major component of a current course, or (d) concepts are integrated into the overall teacher preparation curriculum.

The research-based curriculum movements found to be most influential on the current United States teacher preparation curriculum were The General Study of Technology ($M = 3.54$), Engineering Design ($M = 3.46$), and Technological Systems ($M = 3.43$) (The mean is based on a 4-point scale). This study by Ritz documented that the curriculum for teacher education has continued to morph as research reports are reviewed and integrated into practice. This is a very positive finding. Teacher educators in the United States continue to try to better grasp STEM and STEM integration at this time ($M = 3.00$). Currently the study of STEM is undertaken within one course. As research continues on this educational reform practice, one must wait to see if it has increasing influences on teacher preparation and teaching practices. The findings of this particular study show that the older curriculum foci are being practiced less in the United States. See Table 1 for a summary of this study's findings.

Although this study illustrates the current curriculum for the preparation of technology teachers in the United States, it also represents the views of emerging teacher educators (i.e., those recently prepared in the past 5 years or those currently in preparation). The next study show what recent graduates believe about the technology education profession.

Study 2 – Technology Teacher Educators Beliefs, Recent Graduates

Ritz and Martin (2013) reported on a national study they had conducted in the United States in November 2012 by identifying several possibly alarming factors related to the health, vitality, and possibly the future of the technology and engineering education profession. Moye (2009) identified that there had been a significant decline in the number of practicing technology education classroom teachers. For example, between 1995 and 2009 there was a 35.4% decline ($N = 9658$) in the number of classroom teachers. Ritz and Martin (2013) identified other examples that may have contributed to the health, vitality, and future of the profession including (a) the economic downturn of the first decade of the twenty-first century, (b) the value(s) professionals place on belonging to and participating in professional organizations, and (c) the societal impacts associated with 9/11. It is important to note the factors that Ritz and Martin identified were not limited to just the technology and

Table 1 Impacts of curriculum research on teacher professional development

Curriculum Research Movement	Med.	Mean
Arts and crafts	2.00	1.68
American industry	2.00	1.92
World of manufacturing and construction	2.00	2.32
Maryland plan	2.00	2.32
Career education	2.00	2.43
The general study of technology	4.00	3.54
Technological systems	4.00	3.43
Design technology	3.00	3.00
Engineering design	4.00	3.46
STEM education	3.00	3.32

Note: For statistical purposes 1 was rated no or little impact on the "current" curriculum, 2 was rated as concepts are reviewed within a course, 3 was rated content is a major component of a current course, or 4 was rated concepts are integrated into the overall teacher preparation curriculum

engineering profession, as other teacher-related professions and professional organizations also experienced the same or similar factors.

With the preceding information serving as foundational information, Ritz and Martin (2013) thought it was appropriate to look to the future of the technology and engineering profession (what technology education is being referred in the United States) by examining recent doctoral graduates' perceptions of their profession. They surmised that if these perceptions were identified and then critically examined through a national survey study, then they would be able to communicate to the greater profession of technology and engineering educators a portrait of the profession's future as seen through the lens of recent doctoral students. Specifically, they examined factors within the following four themes:

1. What should be the focus of content taught in a formalized K-12 technology and engineering education program?
2. What should be the focus on instructional strategies in a formalized K-12 technology and engineering education program?
3. What are the characteristics of these graduate students' planned professional involvement?
4. What does the future of their profession look like?

The sample for the Ritz and Martin (2013) study was a group ($N = 34$) of new doctoral graduates (78.8% male; 21.2% female) who had been awarded their terminal degrees (Ph.D. or Ed.D.) within the 5-year period immediately preceding commencing of their study and who had been nominated to participate by their professors. The participants were graduates of one of seven doctoral-degree granting institutions in the United States or had been awarded their doctoral degrees under the auspices of a university who was a member of the National Center for Engineering and Technology Education consortium. Finally, some of the graduates had participated in the International Technology and Engineering Educators Association's Twenty-first Century Leadership Academy Program (Havice and Hill 2012).

Ritz and Martin (2013) noted that they had designed and administered through Survey Monkey™ a 12-question, two-part survey. When one examines the findings of the Ritz and Martin national study, it is clear that they found some general agreement and lack of agreement among the participants. These "agreements" should provide a foundation to initiate discussions among technology and engineering educators at all levels of the profession or even extend existing discussions and debates among these educators.

Where might the profession focus its discussions now and in the immediate future? If the Ritz and Martin (2013) study is taken into consideration, they would encourage the profession to follow the recommendations of recent doctoral graduates, while strongly considering the following:

1. When instructed to identify what should be the focus of content taught in a formalized K-12 technology and engineering education program, there is general agreement among the participants that the focus should be on technological literacy, STEM integration, and engineering design. Each one of these three foci received a recommendation from more than 50% of the participants. Ritz and Martin (2013) noted that the recommendation of the recent doctoral graduates is aligned with and supported by the work of Bybee (2013), ITEEA (2000, 2005, 2007), and Wicklein (2006).
2. Ritz and Martin (2013) noted that the focus of instructional strategies is important to offering a quality technology and engineering education program. The study's participants appeared to believe that also. More than 50% of the participants thought that project-based, design-based, and contextual were important instructional strategies.
3. Ritz and Martin (2013) found that the primary audience for a technology and engineering education program continues to remain unclear in the profession, even among their study's participants. Their findings are supported by the work of ITEEA (2000) and Ritz (2011). In the Ritz and Martin (2013) study, no one particular audience (e.g., elementary school, middle school, high school) received as much as 30% of the recommendations from the participants.
4. How important is readership to maintaining the health and vitality of a profession? Ritz and Martin (2013) found that the *Technology and Engineering Teacher* and the *Journal of Technology Education* were the only two journals regularly read by more than 75% of the study's participants. The other journals (*Children's Technology and Engineering, Prism Magazine*, and *Journal of Technology Studies*) were regularly read by less than 25% of the participants.

Ritz and Martin (2013) found a number of other factors that directly impact the health and vitality of the technology and engineering profession. For example, their study revealed that there is no agreement among the study's participants on the pathways (e.g., 4-year campus program, 5-year campus program with industry/engineering major, license add-on) that individuals will follow to become certified teachers. In addition, the Ritz and Martin study of recent doctoral students' perceptions found the following:

1. Future teachers will receive their training through on campus courses (55% of the respondents) and through hybrid systems (76% of the respondents) involving both on campus and "other" delivery systems such as distance learning.
2. National professional associations (64% of the respondents) and teacher education institutions (70% of the respondents) will continue to be major players in professional development programs and activities. These findings are also supported by the work of Devier (2013), Karseth and Nerland (2007), and Leahy (2002).
3. The long-term viability of professional associations depends on its membership and participation of its members (Martin 2007; Reeve 2013). Participants in the Ritz and Martin study viewed their future professional memberships as being focused on ITEEA (75% of the respondents), American Society for Engineering Education (ASEE) (69% of the respondents), STEM associations (56% of the respondents), and the Council on Technology and Engineering Teacher Education (50% of the respondents).
4. Participants plan to attend professional conferences as part of their commitment to supporting their profession. For example, the conferences of ITEEA (79% of the respondents), ASEE (62% of the respondents), and state-level conferences (57% of the participants) were most often identified by the participants.
5. The *Journal for Technology Education* (86%) and the *Technology and Engineering Teacher* (73%) were most often identified by the participants as journals they would seek to publish manuscripts.

What did Ritz and Martin (2013) learn from their study? They believe their data clearly supports the need to further a discussion at the state- and national-level about what future initiatives should be undertaken by the profession's leadership and its professional associations. Furthermore, since the participants in the study represent the future of the profession, these participants should be engaged in further discussions with the profession's current leadership.

Study 3 – Technology Teacher Educators in Preparation Beliefs

In a somewhat parallel study, Martin et al. (2014) focused on currently enrolled technology and engineering education doctoral students' perceptions of their profession, as compared to those who graduated over the previous 5-year period. They noted that they had selected this particular student population for their study because as new and emerging leaders, they would have a strong influence on the future of the technology and engineering education profession. The leadership challenges-facing students were also supported by the work of Ehrenberg et al. (2007). Throughout their study, Martin et al. (2014) referred to this population of students as scholars, since a doctoral education is designed to help develop new scholars for a profession (Walker et al. 2008).

In the Martin et al. (2014) study, the researchers captured the doctoral students' perceptions related to the following four themes: (a) focus of content taught in a formalized K-12 technology and engineering education program, (b) methodologies used to prepare future teachers of this program, (c) their planned professional involvement, and (d) future forecasting. The researchers then developed four research questions that addressed the four themes.

Martin et al. (2014) chose the survey research method to capture the perceptions of these scholars. The researchers first contacted lead professors at five USA-based universities and requested that they nominate doctoral students who are currently pursuing their degree in technology and engineering education. This purposeful sample ($N = 34$) became the population for the study and they were invited to participate in an electronically delivered survey in October 2013. The 12-question survey with five additional demographic questions was sent to the 34 participants. This study had a 100% response rate. The participants ($n = 18$ males; $n = 16$ females) all identified the United States as their home country. In addition, 44.1% indicated that their professional area of interest is secondary education and 41.2% indicated that they are currently classroom teachers.

Martin et al. (2014) found that the participants see technological literacy ($n = 21$), design technology/engineering design ($n = 23$), and STEM integration ($n = 27$) as the content focus of a formalized K-12 technology and engineering education program. Since the participants could select all that apply, the n values do not discriminate one response from another. In a closely related question, the participants were instructed to identify the focus of instructional strategies in this type of program. Of the five choices provided on the instrument, the top three choices were project-based ($n = 24$), design-based ($n = 28$), and contextual learning ($n = 23$). Finally, the participants were instructed to identify the primary audience for a technology and engineering education program, and they were provided six audiences to select one primary audience. Martin et al. noted that it remains unclear as to who should be the primary audience as 58.8% ($n = 20$) believe the primary audience is inclusive of elementary school, middle school, high school, and postsecondary school. Finally, it is clear that these scholars regularly read the *Technology and Engineering Teacher* and the *Journal of Technology Education*. It is also clear that they foresee other journals (e.g., *Journal of Engineering Education*, *PRISM*, *Journal of Technology Studies*) playing a lesser role in their regularly read list of journals.

In the second part of the Martin et al.'s (2014) study, 8 of the 12 survey items focused on three of the four original research questions. For example, when instructed to identify the characteristic of preparing future classroom teachers, 44.1% ($n = 15$) thought they would be prepared with a discipline degree accompanied with a teaching diploma that would take 4 to 5 years to complete. The second highest response rate was a combination of a university-school-based program ($n = 13$; 38.3%). Once the characteristic is identified, Martin et al. believed it was important to identify where this preparation will occur. Interestingly, 93.8% ($n = 30$) believe that future teachers will be prepared by using blended methods of instructional delivery (e.g., campus and distance learning delivery modes). The data also supported that "brick and mortar" university classrooms ($n = 15$; 46.9%) will continue to serve an important role in preparing future teachers.

Martin et al. (2014) reported that with the declining number of technology and engineering education teacher preparation programs in the United States, identifying service providers for professional development of practicing classroom teachers is a concern. Ultimately, the question is "Who will provide professional development activities in the future?" The participants identified teacher education institutions ($n = 26$; 78.8%), professional associations ($n = 23$; 69.7%), and distance learning providers ($n = 18$; 54.5%) as the leading providers.

Commitment to one's profession has always been a concern in professional circles. Martin et al. (2014) explored the topic of commitment through a series of four questions. For example, when instructed to select which associations they planned to participate in and be members of in 2025, the International Technology and Engineering Educators Association ($n = 30$; 90.9%) led all associations followed by STEM associations ($n = 21$; 63.6%) and the American Society for Engineering Education ($n = 20$; 60.6%). Another perspective on commitment relates to which conferences will participants regularly attend. When instructed to address conference attendance, the participants selected the International Technology and Engineering Educators Association most frequently ($n = 26$; 81.3%) followed by national/regional/state level conferences ($n = 20$; 62.5%). Another level of commitment may be found in scholarly journals the participants plan to publish manuscripts. Martin et al. reported that it is clear the participants plan to publish in traditional United States-based journals: *Technology and Engineering Teacher* ($n = 27$; 84.4%) and the *Journal of Technology Education* ($n = 27$; 84.4%). Finally, the participants were instructed to indicate whether they planned to contribute professionally to technology and engineering education organizations. Martin et al. reported that 88.2% ($n = 30$) planned to be actively involved in professional organizations.

In their last survey question, Martin et al. (2014) reported that the participants believe that the technology and engineering education profession will be integrated into a STEM organization ($n = 30$; 88.2%) by the year 2025. Overwhelming, they do not believe the "stand alone" technology education profession will exist in 2025.

What did Martin et al. (2014) learn from their study? First, efforts to bring engineering design and STEM principles into the technology and engineering curriculum are reshaping the content focus. Second, depending on how rapidly the reshaping occurs may influence how rapidly the teacher preparation programs are transformed. Finally, the professional commitment of our new and emerging leaders is high as they plan to participate in conferences, publish in journals, and be members of professional organizations.

Summary

Teacher educators in the United States play a most important role in the development and implementation of technology education at the primary, middle, high school, and university levels. Often these professionals undertake research to determine what contemporary content and principles to include in the curriculum, to better understand the impacts that studying technology has on learners, to identify contributions technological study has on the overall development of learners, and to determine how best to transfer this knowledge to learners. These faculty members have continually investigated new content and practices. Research shows that the content studied is evolving in the United States. Current technology teacher education programs have focused their curriculums to deliver content on the general study of technological knowledge, technological systems, and engineering design principles. Future teacher educators will continue to see curriculum content evolving with engineering design and STEM integration becoming more prominent in supporting the delivery of general technological concepts.

Designing hands-on projects that integrate design-based learning principles that reinforce technological concepts in a contextual situation are what future teacher educators in the United States foresee occurring in technology education classes. They strongly believe that these programs should aid by contributing to learner development at the primary, middle, high school, and university levels.

Although the common practice for preparing technology education teachers in the United States is a 4-year program attended at a university campus, future teacher educators believe many will seek this preparation at the postgraduate level after receiving technical preparation through another major. This education will be received through hybrid systems where some of the knowledge and practices will occur on campus or in community schools and be supported with other learning opportunities occurring with the assistance of distance learning technologies. These teachers will receive professional development provided by university faculty and professional organizations. Much of this development will be received at conferences or received via distance learning.

These future teacher educators believe that the International Technology and Engineering Educators Association and American Society for Engineering Education will provide their professional development. They will read the *Technology and Engineering Educator*, *Journal for Technology Education*, and *PRISM* magazine. However, they will mainly publish in the *Technology and Engineering Educator* and *Journal of Technology Education*. Although these future teacher educators believe STEM integration and engineering design will be important components of future curriculum, they are not planning to publish in publications that represent these content specialties.

As a closing thought, will the technology education community be represented by our current professional organizations or will it be integrated into other STEM education organizations or engineering professions? Different groups of United State' professionals believe differently about our future. The newest generation of university faculty members believes the study of technology will remain important, but there is uncertainty of how and where this content will be housed within professional organizations 10 years from now.

Cross-References

► Design in Technology Education: Current State of Affairs
► Engineering and Technology Concepts: Key Ideas That Students Should Understand

► Philosophy of Technology and Engineering
► Philosophy of Technology: Themes and Topics

References

Burrage, M., Jaraush, K., & Siegrist, H. (1990). An actor based framework for the study of professionalism. In M. Barrage & R. Torstendahl (Eds.), *The professional in theory and history.* London: Routledge.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. National Science Teachers Association: Arlington.

Devier, D. H. (2013). Fostering a professional culture in technology education. In D. L. Gilberti & D. L. Rouch (Eds.), *Advancing professionalism in technology education*. New York: Glencoe McGraw-Hill.

Ehrenberg, R. G., Jakubson, G. H., Groen, J. A., So, E., & Price, J. (2007). Inside the black box of doctoral education: What program characteristics influence doctoral students' attrition and graduation probabilities? *Educational Evaluation and Policy Analysis, 29*(2), 134–150.

Freedman, M., & Goggin, J. (2008). 50 plus. *Community College Journal, 78*(6), 34–38.

Havice, W., & Hill R. Foundation for technology and engineering education, International Technology and Engineering Educators Association, and Council on Technology Teacher Education 21st Century Leadership Academy [Internet]. 2012. Available from: http://www.iteea.org/Membership/21CenturyLeaders/LeadershipAcademyApplication2014.pdf

International Technology and Engineering Educator Association (ITEEA). ITEEA directory of institutional and educational members. 2015. Available from: http://www.iteea.org

International Technology and Engineering Educators Association (ITEEA). Standards for technological literacy: Content for the study of technology. 2000, 2005, 2007. Available from: http://iteea.org

Karseth, B., & Nerland, M. (2007). Building professionalism in a knowledge society: Examining discourse of knowledge in four professional associations. *Journal of Education and Work, 20*, 335–355.

Leahy, M. J. (2002). Professionalism in rehabilitation counseling: A retrospective view. *Journal of Rehabilitation Administration, 26*, 99–109.

Martin, G. E. (Ed.). (1979). *Industrial arts education: Retrospect, prospect*. Bloomington: American Council on Industrial Arts Education.

Martin, B. A closer look at three association super-trends. *Journal of Association Leadership* 2007. Available from http://www.asaecenter.org/PublicationsResources/JALArticleDetail.cfm?itemnumber=25246

Martin, G., Ritz, J., & Kosloski, M. (2014). Technology and engineering education doctoral students' perceptions of their profession. *Journal of Technology Studies, 40*(2), 82–94.

Moye, J. J. (2009). Technology education teacher supply and demand – A critical situation. *The Technology Teacher, 69*(1), 30–36.

Muzio, D., & Kirkpatrick, I. (2011). Introduction: Professions and organizations – A conceptual framework. *Current Sociology, 59*(4), 389–405.

Reeve, E. M. (2013). Professional associations, organizations & other growth opportunities. In D. L. Gilberti & D. L. Rouch (Eds.), *Advancing professionalism in technology education*. New York: Glencoe McGraw-Hill.

Ritz, J. M. (2011). A focus on technological literacy in higher education. *The Journal of Technology Studies, 37*(1), 31–40.

Ritz, J., & Bevins, P. S. Exploration of 21st century skills that might be delivered through technology education. PATT 2016, Utrecht. Available from: https://hubl.hu.nl/session/conference-program-papers

Ritz, J., & Fan, S. (2015). STEM and technology education: International state-of-the-art. *International Journal of Technology and Design Education, 25*, 429–451.

Ritz, J., & Martin, G. (2013). Perceptions of new doctoral graduates on the future of the profession. *Journal of Technology Studies, 39*(2), 65–78.

Rogers, G. (2015). *Editor. Technology & engineering teacher education directory, 2015–2016. 54th ed. Tinley Park, IL: Council on Technology and Engineering Teacher Education*. Tinley Park: Goodheart-Wilcox Publisher.

Walker, G. E., Golde, C. M., Jones, L., Bueschel, A. C., & Hutchings, P. (2008). *The formation of scholars: Rethinking doctoral education for the twenty-first century*. San Francisco: Jossey-Bass.

Wicklein, R. C. (2006). Five good reasons for engineering design as the focus for technology education. *The Technology Teacher, 65*(7), 25–29.

Part VI

Assessment

Assessment in Technology Education: Section Introduction

50

Kay Stables

Abstract

This chapter summarizes the five chapters featured in part "Assessment" in the Handbook of Technology Education.

Assessment has been inextricably linked to learning throughout human history – whether implicitly through examples in ancient scriptures, or explicitly, for example, through the written tests introduced in China over 2000 years ago as entry requirements for civil servants. Throughout history there has been a consistent dichotomy concerning the nature of the link; is the assessment supporting the learner's development (assessment for learning or formative assessment) or is the assessment aiming to categorize or grade the learner by what they know or don't know (assessment of learning or summative assessment). Technology education has not been exempt from the conflicts between these two positions, with high-stakes assessment such as external, "exit" assessments being seen, often at a political level, as an attainment priority, against in-the-minute assessment through interactions between teachers and learners in everyday classrooms as a priority for learning and achievement. Much has been written on these two dimensions and their impact on learning and achievement.

Both positions present teachers with challenges, the biggest of which can be juggling between the two, managing two different systems at once, meeting the learning needs of the learners in their classrooms while attending to the requirements of external stakeholders. But in reality, do these two positions create a dichotomy or would assessment practices be more accurately and usefully be positioned on a continuum? Are there understandings and skills within effective assessment practices that transcend the dichotomy? These questions open up a debate too large to enter into here, but the chapters in this section each provide insights that could

K. Stables (✉)
Goldsmiths, University of London, London, UK
e-mail: K.Stables@gold.ac.uk

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_73

usefully be explored in this light. While there is emphasis within chapters on particular modes of assessment, each chapter provides insights into an aspect of assessment that has both broad and specific relevance, covering issues of how assessment judgments are made; how comparative judgment can support both immediate and broader shared understandings of assessment; the potential of assessment portfolios; approaches to assessing creativity; and how teachers' self-efficacy in assessment practices can be developed.

In his chapter ▶ "Making Assessment Judgments: Policy, Practice, and Research" (Chap. 51), Richard Kimbell focuses on the processes by which assessment decisions are made, whether summative or formative, and the place of judgment in this. He begins by looking fundamentally at how humans make judgments, providing an account of Kahneman's research on how we make decisions based on "system 1" (intuitive and speedy) and "system 2" (effortful mental activity) thinking. He explores these in relation to expertise and trust, considering the impact the two types have on the assessment judgments teachers make. Providing examples that illustrate how, when looking at portfolios of project work, teachers use system 1 to identify the overall quality of work and then system 2 to rationalize what contributes to the quality perceived, he critiques approaches to atomized assessment schemes and the policies that generate these. An alternative is presented, drawing on historic research that created a model of a choreographed assessment portfolio assessed by holistic judgment and recent research that developed this further to create digital portfolios where the holistic judgments were made by comparative judgment. Emphasizing the potential of comparative judgment from validity, reliability, and manageability perspectives, he makes the case for a radical shift to mainstream use of comparative judgment in assessment systems and the contribution it could make from high-stakes summative assessment to teacher and peer formative assessment.

Niall Seery and Donal Canty, in ▶ Chap. 52, "Assessment and Learning: The Proximal and Distal Effects of Comparative Judgment," provide an account that explores comparative judgment further. Starting by distinguishing between assessment for and assessment of learning and highlighting the latter as being more directly linked to a learner, they pinpoint the priority of making assessment for learning effective, appropriate, and proximal to the learner. In noting the blurred boundaries of knowledge and skill in technology education and critiquing traditional assessment practices, they focus on authentic assessment practices and the proximal nature of such approaches placing learners at the center. Like Richard Kimbell, they point to the inappropriateness of approaches that attempt to "measure" learning through specific criteria that lack fit with assessing designerly thinking. They too identify holistic assessment as a more appropriate way to capture the overall quality of the "sum of the parts" rather than the parts in isolation and forefront the importance of judgment in the process. They then turn to a detailed account of comparative judgment in the context of assessment for learning, where multiple judges, both teachers and learners, contribute to the process. Highlighting the opportunity this creates for drawing on a community of practice in making and sharing judgments, they indicate how this supports validity, ipsative assessment, and metacognitive development. In addition to the positive proximal effect on learning, they explain the dual value of the approach in providing a distal, long-term effect within a community of practitioners, for example, in how comparative judgment enables building a shared construct of capability.

In Kay Stables' chapter ▶ "Use of Portfolios for Assessment in Design and Technology Education" (Chap. 53), she provides an overview of assessment portfolios, illustrating the many ways these have been described and the differences that can be discerned, from the underpinning educational paradigms to the purposes they are designed to achieve and the formats they can take. She contends that portfolios are a tool, and like all tools, the impact they have depends on the contexts and ways in which they are used. Turning to the specific ways in which assessment portfolios have developed within technology education, she provides a brief account of the history of their introduction in England, the catalyst for which was a shift away from assessing the outcomes of practical work in the craft-based subjects that were the provenance of the school subject of design and technology to the processes involved in designing and making. She explores ways they can be used to capture evidence of learning for assessment. Critiquing an "after the event" presentation style portfolio that is produced to match a set of externally set criteria, she makes the case for an assessment portfolio that is a working portfolio, capturing evidence of the thought and action as it takes place. Drawing on research that illustrates how a working portfolio can be created to capture evidence in real time as a project progresses, she illustrates how learning and development can be supported in tandem with assessment. Describing the potential for e-portfolios, she illustrates how making a range of digital tools available throughout an activity enhances both learning and assessment through supporting different learning styles. She also outlines the possibilities further enhanced through web-based portfolios, such as creating opportunities for comparative judgment processes, as described in earlier chapters.

In Remke Klapwjik's ▶ "Formative Assessment of Creativity" (Chap. 54), she focuses directly on formative assessment of creativity in technology education. Starting by providing a focus on the nature of creativity, she provides a backcloth of understanding of creativity and situates this in the context of technology education assessment, pinpointing both challenges and opportunities. Identifying the challenge of making judgments about creativity that go beyond personal opinion, or reaction to something new, she draws from literature to illustrate how initial reactions can be negative and dismissive to what later become recognized a highly creative work and uses this to underscore the importance of looking beyond the known and the objective. She then shifts this thinking to the context of assessing creativity in technology education. Making a case against fixed, preset standards, she calls for creating learning communities that develop shared criteria for assessment of creativity and sees formative assessment as a good match for this approach. Drawing on research by Wiliam, she identifies strategies for formative assessment that have been used by a team at Delft University of Technology to create a model for formative assessment of creativity with young children in the context of design and technology called "design in the picture." Using Rhodes' model that identifies four focuses for assessment, products, processes, person, and press (the latter she translates as context), she illustrates classroom approaches for each, showing how the model, which includes strategies such as "make productive mistakes," "make ideas tangible," "think in all directions," and "develop empathy," creates a scaffold both for developing and assessing creativity. In doing this, she also highlights how the approach links to related research on creativity and assessment.

In the final chapter on assessment, Eva Hartell places her attention directly on the teacher. In ► Chap. 55, "Teachers' Self-Efficacy in Assessment in Technology Education," she focuses on an important and less well-understood aspect of assessment – how teachers develop and maintain self-belief in their capability to effectively manage assessment practices in their classrooms and workshops. Drawing on the work of Bandura, she provides an overview of self-efficacy theory and outlines qualities of high self-efficacy, such as seeing challenges as something to be mastered, making effort to complete a task, and perceiving personal control over situations. These are set against a picture of low self-efficacy, such as tend to see tasks as more complex than they really are, giving up more easily, and perceiving a personal lack of influence. She also describes the concept of collective efficacy, showing how this relates to the whole school, including senior management and the differential impact of collective efficacy on individual teachers. She then turns to formative assessment and technology education, highlighting such aspects as the need for sufficient time for both teachers and learners to undertake, complete, and reflect on activities. For teachers, this means, for example, having sufficient time to plan for assessment, including time to do this collaboratively, and time and space to experiment and discuss with colleagues, something which research indicates is rare. She also highlights positive examples from research, such as the value of increasing teachers' subject knowledge, including hands-on experience and constructive alignment between subject knowledge and pedagogy. She draws a direct link between this and key strategies for formative assessment. In conclusion, she posits ideas for future research on self-efficacy. This includes researching alternatives to assessment rubrics to increase shared understandings, further exploration of possibilities afforded by digital technologies that provide rich evidence of learning and opportunities for shared assessment activities, and research that increases understandings of teachers' assessment practices, such as using think-aloud protocols. Within all of these, she calls for greater collaboration within the international technology education community.

None of the five chapters included in this section provide a broad overview of assessment in technology education. Rather, each takes a specific aspect and explores it in great depth. Taken together, the chapters provide a collective wealth of insights, all presented as ways to improve assessment practices, thereby also improve practice and shared understandings of learning and teaching in technology education.

Making Assessment Judgments: Policy, Practice, and Research

51

Richard Kimbell

Abstract

The focus of this chapter is on the *judgment process* that underpins any assessment. Whatever form the assessment takes (grades/numbers/ranks) and for whatever motive it is being pursued (summative, formative, diagnostic, or evaluative), teachers will exercise that judgment process. So how do we make the decision that *this piece* is worth an A and *that piece* only a D?

There are some particular challenges when assessing technological capability, and these are shaped both by prevailing policy and by traditions of practice. Both have focused on the coursework portfolio that is essentially a storyline demonstrating learners' journey through a technological task. The portfolio is a complex artifact and has been the target of considerable research.

In this chapter, I will show how our understanding of the judgment process has interacted with the evolution of policy and with the development of portfolio practice. Interestingly, from positions of great divergence, there emerges a common theme that has the potential to take us forward into a richer future.

Keywords

Teacher judgment • Performance assessment • Holistic assessment • Process portfolios • Comparative judgment

Contents

R. Kimbell (✉)
Goldsmiths, University of London, London, UK
e-mail: r.kimbell@gold.ac.uk

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_52

Assessment as a Cognitive Process

William James was an American philosopher and psychologist operating in the early twentieth century; a colleague of John Dewey and Emile Durkheim. He gave birth to the dual-processing theory of judgment … essentially that there are two very different kinds of thinking: associative and true reasoning. He argued that *associative* reasoning was principally reproductive, in the sense of reusing past experience to make a judgment. But when confronted by new problems, then *true reasoning* is called into action. Daniel Kahneman has significantly extended the dual-processing theory and has characterized James' two kinds of decision-making as "system 1" and "system 2."

> * system 1 operates automatically and quickly, with little or no sense of voluntary control.
> * system 2 allocates attention to the effortful mental activities that demand it, including complex computations … [and is] often associated with … agency, choice and concentration. (Kahneman 2011, p. 21)

We would all recognize system 2. It is the kind of thinking that we all understand as thinking in an everyday sense, involving concentration, the allocation of mental and other resources to work out a solution that we check as it emerges. But system 1 is not like that at all. It is intuitive and is (mostly) beyond our control. I have exemplified it elsewhere in the following passage.

> When driving a car, you don't look for the gear lever because you just 'know' where it is and your proprioceptive muscle memory does the work for you. You scan the road ahead – adjust your direction – slow down – signal – turn – accelerate …. all completely automatically. Those who have tried programming a computer-controlled buggy to do this job will know how complex it is.
>
> But we do it all without (system 2) thinking. We are in automatic pilot – below the level of conscious attention. Until something goes wrong. Then we rapidly engage another kind of thought as we try to compute our way out of the problem. Interestingly – as we engage this deliberate (system 2) form of thought – the world appears to go into slow-motion, indicating the phenomenally fast processing speed that we are generating to tackle the difficulty. (Kimbell 2013, p. 87)

Kahneman describes his two kinds of thinking in the context of *skilled* behavior. To use my example above, learner drivers definitely ***do*** have to think deliberately about what they are doing, and this makes their driving appear clumsy and uncoordinated. As we develop more skill, the auto-pilot phenomenon progressively smooths our behavior, and gradually we lose conscious awareness of those separate considered actions. They blend into a coherent (system 1) performance.

The relative scale of these two cognitive characters is worth a moment's reflection. A hundred years ago, Freud made the point that our conscious (type 2) thought is massively outweighed by the scale of our unconscious processing. He refers to conscious thought as the above-the-water tip of the mental iceberg, while, below the surface, there is limitless unconscious activity buzzing away. Wilson (2002) has more recently reconfigured that iceberg metaphor. In *Strangers to Ourselves*, he suggests that our conscious, deliberate thinking is a really tiny proportion of our whole mental activity, better thought of as a snowball sitting on top of Freud's iceberg.

It is a salutary thought that whatever cognitive processes are going on as we make an assessment judgment, we can be sure that the vast majority of it will be unconscious or perhaps we should say preconscious.

At the heart of Kahneman's account of decision-making is what he calls "associative memory."

> system 1 . . . is constructed by associations that link ideas, events, actions and outcomes that occur with some regularity. . . .. As these links are formed . . . the pattern of associated ideas comes to represent . . . our expectations of the future. (Kahneman 2011, p. 71)

Our experience shows us how this applies in an examining context. We see endless scripts, many of them with the same weaknesses or the same strengths. We form intuitive mental links that create patterns that in turn lead to expectations. Brooks (2012) takes this a step further, citing the work of Suto and Greatorex at Cambridge Assessment, the overarching entity that manages the university's three examination boards and its research activities.

> This theory distinguishes 'quick and associative' System 1 judgements from 'slow and rule-governed' System 2 judgements (Suto and Greatorex 2008, p. 215). Judgments made using System 1 are 'intuitive', 'automatic, effortless, skilled actions, comprising opaque thought processes, which occur in parallel and so rapidly that they can be difficult to elucidate' whereas System 2 judgments involve 'slow, serial, controlled and effortful rule applications, of which the thinker is self-aware.' (Brooks 2012, pp. 65–66)

Suto and Greatorex worked with examiners using a "think-aloud" protocol and found convincing evidence for both of Kahneman's judgment-making types. However, most interestingly, they saw evidence of examiners transferring the cognitive load involved in assessment judgments from system 2 (slow and deliberate) to system 1 (quick and associative).

> The two systems are thought to be concurrently active, enabling subjects to switch between them according to the cognitive demands of the task in hand. . .. Another important feature of the dual-processing theory is that 'complex cognitive operations may migrate from System 2 to System 1' as individuals gain experience. (Suto and Greatorex 2008, p. 215)

In other words, as teachers/examiners become skilled in their assessments, they no longer have to look for the gear lever. As their expertise develops, they progressively move from type 2 to type 1 processing.

There is an important qualifier to introduce at this point. Kahneman is NOT saying that fast, intuitive, type 1 judgments are always inevitably correct. Indeed, he is skeptical about it and argues that in some situations, the bias that individuals bring to judgments can make them seriously unreliable. He devotes a chapter of *Thinking Fast and Slow* to discussing the conditions in which we can trust expert intuition (see ▶ Chap. 22, "Teaching and Learning Technology in Different Domains: Tradition and Future Developments", pp. 234–244). Since *associative memory* is the key mechanism at work with system 1, it is essential that the decision-making setting meets two conditions.

> If the environment is sufficiently regular and if the judge has had a chance to learn its regularities, the associative machinery will recognise situations and generate quick and accurate predictions and decisions. You can trust someone's intuition if these conditions are met. (Kahneman 2011, p. 243)

In the Suto and Greatorex research – indeed in most school-based assessment – it is not difficult to see that the conditions can be met. The *regularity of the environment* concerns the regularity of the work being assessed – and examiners will be marking the same examinations papers (or portfolios) where conditions have been regularized by the nature of the examination. The *opportunity for assessors to learn the regularities of student performance* speaks to the need for assessors to experience a training program that enables them to see and discuss types and qualities of performance. In such settings, the migration of judgment from system 2 to system 1 that Suto and Greatorex observed seems both reasonable and inevitable.

But there remain some real problems implicit in this expert view of assessment. And they are *policy* problems. The more expert we become, and the more we are able to operate with intuitive (type 1) processing, the less transparent the process appears. We are in effect saying "Trust me – I know this one deserves many more marks than that one."

There are at least three problems with this position.

First, we live in a world that is increasingly distrustful of experts. We no longer accept the teachers' word just because they are a teacher – we want to see the evidence that their judgment is appropriate. Even a visit to the doctor (whose word was once law) may be followed by a bit of google browsing to look up the symptoms and check what the doctor has said. So the articulation of criteria of judgment can be seen as a double-edged sword in the battle for acceptability in the assessment world. On the one hand, the criteria are helpful learning tools for the inexperienced, and on the other, they are helpful public relations tools to show others that we value this . . . and that . . . and that our marking reflects these concerns in a very objective sense. If a parent were to question a teachers' judgment that a piece of work was poor – then the teacher might be expected to say (e.g.,) there is no evidence in the work of X . . . or Y . . . or Z. If these three qualities (X, Y, and Z) exist as critical criteria of performance, then the teacher can easily justify her judgment. It gets more difficult if the judgment relies solely on the expert intuitive judgment of the teacher.

Second – how do we *become* expert? Driver training initially involves breaking down the driving task into discrete elements to draw attention to them and make them the focus of thought and practice. Initially it is helpful to break down complex tasks into a set of units – and in the assessment world, these have become "criteria" to inform the judgment. We are in effect saying "look for **this** quality . . . and also **that** one . . . and then maybe also **that other** one." Again, this approach seems common sense and helpful, and we can even begin to value them differently; the first quality is most important (most marks) and the third one is least important (fewer marks). If we break the assessment task into enough pieces, then by adding up the individual marks we have allocated, we can expect to get a fair and proper judgment of the whole. Scarily however, once teachers become more expert at judgments, Kahneman's type 1 processing increasingly kicks in and gives us answers without all the prior reasoning. To be an expert (having seen thousands of such pieces of work) is to be able to make quality judgments intuitively. In the case study below (see Fig. 1), I illustrate how one group of teachers responded to this challenge.

A third rationale supporting the articulation of criteria has impinged into this assessment debate. And it concerns the learner. Surely, if we want learners to get better at doing something, we should spell out for them what is involved so that they can be self-aware (meta-cognitive) about their own learning. The driving metaphor works even better for the learner than for the novice teacher. Tell me what is involved so I can think about it . . . practice it . . . and get better at it. So, criteria of judgment that were traditionally applied at the ***end*** of a learning process have increasingly morphed into learning objectives or intended learning outcomes that are explicitly articulated at the ***beginning*** of the learning process to help learners to understand and develop their performance.

These three sensible rationales for the atomization of the assessment process have informed educational assessments throughout the world. As just two examples

> The West Australia 'Engineering Studies' y11 syllabus has 'grade descriptions' that cover 3 pages with tightly packed prose, amounting to 1,248 words. (Government of West Australia School Curriculum and Standards Authority 2015, pp. 27–29)

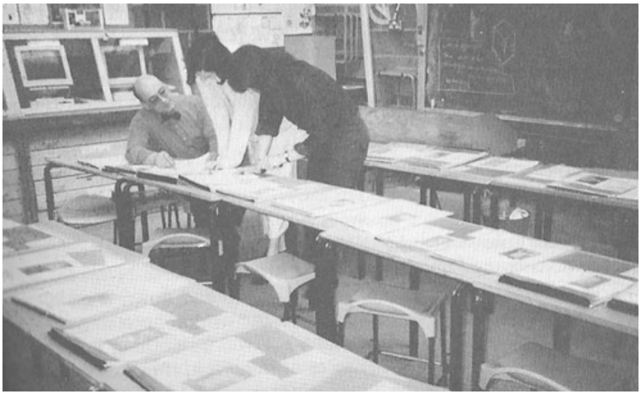


Fig. 1 Teachers assessing a group of portfolios

> The New York State 'Teacher Certificate Examination' in Mathematics identifies 7 competencies each with numerous 'performance indicators' amounting to 2,175 words (New York State Education Department 2015)

Inevitably, England and Wales was not immune to this atomizing tendency, and in the original National Curriculum (NC) document (DES 1990), capability in all subjects was articulated into many explicit "Statements of Attainment" (SoA) that were intended to be guides for learners as well as assessment guides for teachers. There were approximately 150 in technology. The assessment process was then a matter of deciding which SoA had been met by a learner and which had not. Decisions at that level were then amalgamated through an intricate set of rules that produced a "score" or "level" for the learner. Managing this assessment (150 SoA $\times$ 30 children in a class) proved so massively burdensome that (after 2 years of heartache) teachers and schools refused to have anything more to do with it and launched a national boycott of the tests. In the end, the Minister responsible for the shambles was sacked, and the whole process redesigned. The associated policy chaos dominated life in schools for the first half of the 1990s throughout England and Wales, cost multiple millions of Sterling, and wasted thousands of hours of teacher time.

> Bowing to overwhelming pressure, Mr Patten announced yesterday that National Curriculum testing is to be radically reduced from next year . . . action would be taken to reduce the workload of teachers . . . (Daily Telegraph 1993)

In the midst of this 1990s mayhem, Wiliam (1992) was cautioning against succumbing to the pressure to criterion reference all assessments, especially those involving complex skills and performances that are irreducible and cannot be itemized because "the whole is greater than the sum of parts." Later, Wiliam notes that teachers involved in the General Certificate of Secondary Education (GCSE) English qualification – assessed entirely by coursework – "quite quickly internalized notions of "levelness," so that in the vast majority of cases different teachers would agree that a particular portfolio of work merited, say, a D." (Wiliam 1996, p. 297)

Wiliam was articulating exactly what Kahneman would have said if he had been asked about the assessment of student performance. And the evident failings of the massively bureaucratic process of NC assessment would have been very predictable for him. It was a deeply "type 2" process. By focusing relentlessly on the 150 isolated bits of knowledge and skill, the process deliberately prevented teachers from becoming fast "type 1" experts in their judgments.

But teachers' *practice* has a way of mediating policy, and the extreme madness of those England/Wales assessments encouraged teachers to develop all kinds of practical "work-arounds." I suggested above that "To be an expert (having seen thousands of such pieces of work) is to be able to make quality judgements intuitively," and in the case below, I illustrate how one group of teachers responded.

This photograph (Fig. 1) shows three teachers assessing two class sets (about 50) of complex design portfolios. Initially, they made a set of intuitive judgments and laid out the portfolios in quality order. The best on the front row (top-left) then the rest over three more rows of tables to the weakest (bottom-right). This process brought their type 1 expertise to the fore, and after about 15 min, they were confident that ***this*** was the best one and ***that*** was a bit weaker and so on down the rows. But then (because they had to) they undertook the detailed, type 2, blow-by-blow process of filling in the assessment forms for each case. This took many hours.

> Did they shuffle this one up a bit and that one down a bit in the light of all that box-ticking? No they didn't. They did have initial disagreements and discrepancies – with a better one apparently missing out on some of the Statements – and a poorer one getting them. But that just forced them to go back and change their box-ticking for the 1st one. In short – the teachers trusted their judgement about the work MORE than they trusted the ticked boxes. The ticked boxes didn't *generate* the result (as was supposed to happen with NC assessment), rather the result – decided at the outset by holistic judgement – then informed the box-ticking. (Kimbell 2012 p. 154)

When interviewed, the teachers claimed that "the assessment" was what they did as they completed the detailed assessment forms. But in fact it was the process of laying out the portfolios in quality order that was the REAL assessment. And it used classic "type 1" processing.

The Problem of Assessing "Process"

While Kahneman's work concerns decision-making in general, the assessment of capability in technology raises a particular difficulty. Technology curricula typically emerged from "craft" or "applied science" programs in the 1960s and 70s (see Penfold 1988), and these traditionally involved the assessment of *propositional knowledge* and/or *tool skill.*

The first significant research project to tackle this deeply embedded norm was led by John Eggleston whose project team at Keele University (1969–1974) was increasingly recognizing "design & make" projects as the core activity of the emerging technological subject. The more Eggleston's team got to grips with designing as a means of teaching and learning, the more they began to wrestle with the problem of assessing students' ability to undertake a ***process***. Obviously this involves both **knowing** about stuff and being **skilled** with other stuff – but maybe there is more to it than just the sum of the two parts, and Eggleston waded into this tricky new territory (Schools Council 1975).

It soon became evident – to Eggleston's team and to many teachers who tried to use the approach (including myself as a young teacher in 1971) – that assessing ***processes*** is FAR more subtle and complex than assessing knowledge and skills. Traditional assessments of knowledge and skill were of the "right/wrong" variety; they know it (e.g., carbon % in tool steel) or not; they can do it (e.g., file flat) or not. But design processes are not like that. What is "idea development" or "investigation"? What do they look like? *Idea development* might involve sketches (or not) –

and *investigation* might involve interviews (or not). There are many ways to do these things, and often the objective evidence (e.g., a model) only makes sense if you see it with the eyes of the learner and what s-/he is thinking about at the time (see NWSEB 1970). So you have to get inside the learners' head and ***infer*** meaning in relation to the objective evidence. In the end, the assessment requirement centered on story-telling. I would say to my students "Tell your design development story (in a portfolio) so that the examiner can see where you have been and what you have done." "Being good" at designing had morphed into "being a good storyteller" about designing. This was radically different from anything previously imagined for assessment.

Ten years after the publication of the Keele research, Goldsmiths won a research contract for a project to assess the performance of the nations' 15-year-old students in design & technology (for a full account, see the final 1991 Assessment of Performance Unit [APU] report: Kimbell et al. 1991 or see Kimbell and Stables 2007, Chap. 5). In the interim between the end of the Keele research and start of our own at Goldsmiths, design & technology had become an established part of the curriculum, and the modus operandi typically involved students working through design & make projects and producing portfolios. Our brief from APU was to assess the performance of a randomly selected 2% sample of the nation's 15-year-old population (approximately 10,000) and then to *explain* the levels achieved by reference to a number of variables (gender/school type/curriculum experience, etc.). Recognizing the centrality of process portfolios to practice in design & technology, we did not create tests of knowledge and skills, but rather we developed a "fast portfolio" approach. The rules for APU assessments were created by earlier surveys in maths, science, English, and modern languages, and we were given 90 min slots within which to assess students. Much of our work centered on how to make real, open-ended design tasks (and portfolio responses) work within such a tight timeframe. We subsequently labeled these structured portfolios as "un-pickled" (Stables and Kimbell 2000; Kimbell and Stables 2007).

Having built the task bank – and run the 1988 survey – we then assessed how (and how well) learners had tackled the tasks. We recruited 120 teachers to become assessors for the 20,000 portfolios (each of 10,000 learners completed two portfolio activities in different contexts to establish a broader measure of their capability than could be expected from a single task).

Evolving an Assessment Protocol

There were many kinds of assessment involved in the APU research – some of them purely for research purposes as we struggled to articulate what design and technology capability looked like with this 15-year-old cohort. But the leading edges of the assessments made by our teacher/markers were of three kinds:

- Initially an holistic assessment on a 6 point scale (0–5)

- Then a set of process judgments to illuminate their performance (1–4 scale), e.g., for one of the tests
  - Grip on the issues in the task
  - Ability to think ahead and resource themselves
  - Grip on developing the product (for user and for manufacture)
  - Ability to appraise for value and consequence
- Finally a set of conceptual judgments concerning the kind and depth of knowledge being used (1–4 scale)
  - Materials
  - Energy systems
  - Aesthetics
  - People

From this process, each piece of work had an overall mark of quality (the holistic) and then two sets of marks that fingerprinted the *kind* of response that the learner had produced.

We were doing this marking in 1989, which was 22 years before Kahneman published *Thinking Fast and Slow*, but our approach had been evolving through many years of dissatisfaction with formal examination protocols and through many experimental forms and trials. The final form of our assessment placed initial emphasis on what Kahneman subsequently called system 1 thinking, allowing teachers to bring their expertise to the overall judgment – much as the teachers did as they laid portfolios out on rows of tables in Fig. 1 above. Subsequently, the assessment required markers to analyze *elements* of performance using rather more of what Kahneman calls system 2 processing.

Two pieces of APU data tell us a good deal about the efficacy of the contrasted approaches. The first deals with inter-rater *reliability*, the correlation between the judgments of the markers. This was a Spearman rank-order correlation. The second was *attitudinal* data, marker views about the assessment process (what they liked/disliked; what they felt confident/uncertain about) collected by questionnaire at the end of the marking.

> Of all the judgements markers made, they felt most confident and were most reliable when assessing holism (Kimbell et al. 1991)
>
> *Question*:
> Which judgements did you find easy/hard to assess? In what way and why?
> *Answer*:
> Easy – holistic characteristics – especially after I had worked through the scripts to build up a feeling/impression for the work.
> *Answer:*
> I liked the idea of the holistic mark on one hand – followed by a more detailed breakdown.
> (Kimbell et al. 1991, pp. 135–6)

The holistic overview mark had an inter-marker correlation coefficient of 0.75, which represents a high degree of reliability in the case of such qualitative and dominantly procedural performance assessments.

To Summarize So Far . . .

In the 1970s, the Keele research project established design processes as the heart of the assessment challenge. In the process, they established the centrality of storytelling ***process portfolios*** and sidelined the role of knowledge and skill testing.

In the 1980s, the Assessment of Performance in Design and Technology project evolved an approach to assessment based on short (90 min) design tasks resulting in structured portfolios. The assessment of them (20,000 of them) proved manageable and reliable and centered initially on ***holism*** and only thereafter moved to analyze and value the ***constituents*** that made up holism.

In the 1990s, teachers faced with an utterly unmanageable set of assessment requirements for the UK National Curriculum evolved a ***practice*** that made sense to them and that focused on holism. Having established their holistic overview of the quality of all the work, they then tackled the atomized detail that was required by the NC assessment regulations.

Teacher Judgment Supported by Computational Power: Project E-Scape

The story now moves into the new millennium and the world of digital portfolios. Project e-scape at Goldsmiths had established that it was possible for learners to create web portfolios direct from their work in school design workshops and studios (Kimbell et al. 2009). Using handheld technologies, learners could use sketch, text, photos, video, and voice files to build web portfolios that recorded and presented the whole story of their progress through a design challenge. At the end of the national trial of the approach, we had more than 350 such web portfolios, and we were tackling (once again) the problem of how to assess them. But the rules of the game had shifted to a quite astonishing degree, because now – for the first time – the portfolios were web based and hence shareable so all the examiners (wherever they were) could see the same pieces simultaneously. It was time to experiment with another radical change in the assessment process.

The approach centered on Thurstone's law of comparative judgment (Thurstone 1927) that established that it is far easier (and hence more reliable) to do assessment by comparison (Pollitt 2004; Laming 2004). As examples, it is easier to say (comparatively) which of two rooms is warmer than it is to say (absolutely) what the temperature is in each. And it is easier to say which of two bags is heavier than it is to say exactly how many kilograms is in each. So rather than trying to put numbers on the portfolios – we just compared them and ended up with a rank order. In association with a software development group, we created the "Adaptive Comparative Judgement" (ACJ) engine to manage the paired judgment process. Twenty-nine teachers and researchers undertook the comparisons. Their task was (first) to study portfolio A and understand what the learner had done and then (second) to study portfolio B and understand what the other learner had done on the same task. Then the judges had to make a judgment about which of the two portfolios was the more convincing piece of designing. That was it . . . the complete assessment process . . . just compare this to that and decide. Then do it with another pair, and another pair, and another pair. Each teacher/judge made more than 100 comparisons, and these individual comparisons combined to create a rank order of learners' performance. Analyzing the resulting data, Pollitt (a statistics consultant to awarding organizations worldwide) made the following observations.

> *Because every single judgement made can be compared to the outcome predicted (with the benefit of hindsight) from the final rank ordering, very detailed monitoring is possible of the consistency of the judgements made by each judge, and of each portfolio.*
>
> *The portfolios were measured with an uncertainty that is very small compared to the scale as a whole . . . The value obtained was 0.95, which is very high in GCSE terms.* (Pollitt A in Kimbell et al. 2009, p. 81)

In the 1980s, the APU team was pleased with the reliability statistic of 0.75 achieved by the APU teacher/markers, but with the ACJ engine helping the e-scape teacher/judges to achieve a reliability statistic of 0.95, the game has moved on to a whole new level. And remember that this was a holistic judgment – looking at the whole performance. Again the teacher/judges were asked for their reaction to the comparative judgment process.

> *Easier assessment; no need to calculate grades and points. Quicker to make assessments. Speed of judging.*
>
> *Portfolios displayed in this way have a huge advantage in that the big picture can be seen immediately. It's very easy to get a feel for the project.*

Moreover, many commented that the system was more fair since judges were not bound into the details of criteria but can (through the holistic judgment) reward qualities that are important but not prespecified.

> *GCSE marking relies heavily on a tick box assessment of a pupil's work. It can be frustrating when confronted with an excellent piece of designing and making that does not meet the exam board's criteria. Too often the linear pattern of coursework requires the assessor to jump back and forth to find the marks that a student deserves. The e-scape judging is so simple in comparison.*

Yet another source of enhanced fairness was seen to result from the accumulation of judgments from multiple judges.

> *The judging system feels to be fair; it doesn't rely on only one person assessing a single piece of work. It removes virtually all risk of bias. . .. It feels safe knowing that even if you make a mistake in one judgement it won't significantly make a difference to the outcome or grade awarded to the student as other judges will also assess the same project. Also knowing that the system automatically checks the consistency of the assessor's judgements again reinforces the feeling of fairness that this process brings.* (All teacher comments from Kimbell et al. 2009, pp. 69–71)

It is one thing to have good reliability statistics. It is a further thing to have supportive teacher comments about the ease and apparent fairness of the assessment process. But it is yet a further step to understand how it is that teachers are able to make these judgments. How can we explain their ability to do it?

It is helpful here to refer back to Wiliam and his argument to move beyond criterion-based judgment to *construct*-based judgment. He uses the case of English teachers judging coursework folders. The assessment is not objective in the sense that there are no objective criteria for the learners to satisfy, but the experience is that teachers can judge them reliably.

> To put it crudely, it is not necessary for the raters (or anybody else) to know what they are doing, only that they do it right. Because the assessment system relies on the existence of a construct (of what it means to be competent in a particular domain) being shared among a community of practitioners (Lave and Wenger 1991), I have proposed elsewhere that such assessments are best described as 'construct-referenced' (Wiliam 1994). The consistency of such assessments depends on what Polanyi M, (1958) called *connoisseurship*. (Wiliam 1998, p. 5)

Interestingly, Eisner (2002) has also used the term connoisseurship in the context of assessment. He defines it as the art of appreciation, though he is careful to make the distinction that appreciation does not exclusively mean to *like* something. Rather, it is consisting of "recognizing and appreciating the qualities of a particular," (p. 215). In complex portfolio assessment, I think it is even more than that. It is seeing the qualities in relation to each other and how they impact on the whole.

But, on the face of it, there remains something a bit unsatisfactory about the level of mystery surrounding Wiliam's "construct" and "connoisseurship." All our experience tells us that they exist and that teachers can indeed share them and make good judgments. But it would be good to know how it works.

And then, finally, along comes Kahneman (2011) and publishes *Thinking Fast and Slow* in which he explains the judgment process in terms of cognitive science. His system 2 thinking is rule bound and methodical, but it is his system 1 thinking that lies at the heart of the assessment capabilities that teachers were using to lay out portfolios in Fig. 1, and to make the holistic APU assessments, and to choose portfolio A or B for the e-scape assessments.

The cognitive process at work here is based on *associative memory.*

> The main function of system 1 is to maintain and update a model of your personal world, which represents what is normal in it. The model is constructed by associations that link ideas of circumstances, events, actions and outcomes that occur with some regularity. . . .. As these links are formed . . . the pattern of associated ideas comes to represent the structure and events of your life, and it determines your interpretation of the present as well as your expectations of the future. (Kahneman 2011, p. 71)

Years of experience (as teachers/markers/judges) make our system 1 process very good at doing this patterning. In the context of assessment, those teachers sorting portfolios have seen at least hundreds and probably thousands of them. They have common features . . . and these features are often associated with kinds of performance . . . and these in turn are often associated with what we call excellent or common place or poor performance. These associations (that occur with great regularity) form cognitive links and patterns. So when I next see (this or that) I do not even have to think about it, I can predict – intuitively – that it is a case of good/poor performance. Where something unusual arises and the patterns do not add up, then it is necessary consciously to reengage system 2 to focus on the difficulty and resolve the matter.

> Intuition is nothing more and nothing less than recognition. . .. We marvel at the story of the firefighter who has a sudden urge to escape a burning house just before it collapses because the firefighter knows the danger intuitively 'without knowing how he knows'. . .. The mystery of knowing without knowing is not a distinctive feature of intuition; it is the norm of mental life. (Kahneman 2011, p. 237)

A Future Assessment Landscape

Teachers report that the process of comparative judgment is simple to do and it produces very reliable assessments. In the qualitative, process-portfolio territory that we inhabit, it is more reliable than any of the conventional forms of assessment currently in use by examination bodies. There is a prima facie case for any certificated summative assessments to make use of it. Not the least benefit would be a dramatic reduction in the number (and cost) or appeals against inaccurately awarded grades. In the UK in 2014, 45,500 grades were changed on appeal (BBC News 2014).

Holistic judgment lies at the heart of the process, and it enables us to capitalize on two key reliability aids: first Kahneman's system 1 (fast and intuitive) judgment and second, comparative judgment methodology. As Pollitt proposed in his paper to the International Association for Educational Assessment, "Let's stop marking exams" (Pollitt 2004).

Moreover, recent research in Ireland (Seery et al. 2012) has illustrated an additional benefit implicit in the amalgamation of holism with comparative judgment. They adapted the approach for its formative, learning benefit. They used the holistic judgments of a group of 63 undergraduate engineering students – and the emerging rank – as a generator of discussion for articulating key qualities in students' and their peers' work.

> Holistic assessment enabled students to value a wide range of evidence that displayed their peers' capacity to be creative, to communicate, and to display their technological capability. In this context, the strength of comparative pairs assessment lies in its capacity to aggregate subjectivity, supporting diversity in designing. (Seery et al. 2012 p. 223)

The combined strength of the holistic with the comparative is a potent tool of meta-cognition. Through the comparative methodology, Kahneman's system 1 presents us with our own decision-making, and in a learning context, we must grapple with it and seek to explain it, if only to ourselves. By sharing that self-knowledge, we enrich our entire community of practice.

References

BBC News, 21 Oct 2014.

Brooks, V. (2012). Marking as judgment. *Research Papers in Education, 27*(1), 63–80.

Daily Telegraph, 12 May 1993.

DES. (1990). *Technology in the national curriculum.* Department of education and science. London: HMSO.

Eisner, E. W. (2002). *The educational imagination: On the design and evaluation of school programs* (3rd ed.). Upper Saddle River: Prentice-Hall.

Government of West Australia School Curriculum and Standards Authority. (2015). *Engineering studies Y11 syllabus and examinations*. Available at: http://wace1516.scsa.wa.edu.au/__data/assets/pdf_file/0015/11292/Engineering-Studies-Y11-Syllabus-ATAR-2016-GD_pdf.pdf#page=31

Kahneman, D. (2011). *Thinking, fast and slow.* London/New York/Toronto: Allen Lane/Penguin.

Kimbell, R. (2012). Understanding assessment: Its importance; its dangers; its potential. In P. J. Williams (Ed.), *Technology education for teachers*. Rotterdam/Boston/Taipei: Sense Publishers.

Kimbell, R. (2013). Transferring standards: Judging 'this-now', by reference to 'that-then'. In H. E. Middleton & L. K. S. Baatman (Eds.), *Transfer, transitions and transformations of learning*. Rotterdam: Sense Publishers.

Kimbell, R., & Stables, K. (2007). *Researching design learning*. Dordecht: Springer.

Kimbell, R., Stables, K., Wheeler, T., Wozniak, A., & Kelly, V. (1991). *The assessment of performance in design & technology.* London: School Examinations and Assessment Council/ Central Office of Information.

Kimbell, R., Wheeler, T., Stables, K., Shepard, T., Pollitt, A., Whitehouse, G., Martin, F., Lambert, D., & Davies, D. (2009). *E-scape portfolio assessment phase 3 report.* TERU: Goldsmiths University of London.

Laming, D. (2004). *Human judgment: The eye of the beholder.* London: Thomson.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

New York State Department of Education. (2015). *Teacher certificate examinations: Mathematics subject area test.* Available at http://www.nystce.nesinc.com/PDFs/NY_fld04_objs.pdf

NWSEB. (1970). *A course of studies in design*. North Western Secondary School Examinations Board Manchester: NWSEB.

Penfold, J. (1988). *Craft design & technology: Past, present and future*. Stoke on Trent: Trentham Books.

Polanyi, M. (1958). *Personal knowledge: Towards a post-critical philosophy.* London: Routledge & Kegan Paul Ltd.

Pollitt, A. (2004, September). "Let's stop marking exams". Paper given at the *IAEA Conference*, Philadelphia. Available at: http://www.cambridgeassessment.org.uk/research/confproceedingsetc/IAEA2004AP

Schools Council. (1975). *Education through design and craft*. London: Edward Arnold.

Seery, N., Canty, D., & Phelan, P. (2012). The validity and value of peer assessment using adaptive comparative judgement in design driven practical education. *International Journal of Technology and Design Education, 22*(2), 205–226.

Stables, K., & Kimbell, R. (2000). The unpickled portfolio; pioneering performance assessment in design & technology. In *D&T International Millennium Conference: Learning from experience; Modelling new futures*. Wellesbourne: Design and Technology Association.

Suto, I. & Greatorex, J. (2008, September). What goes through an examiner's mind? Using verbal protocols to gain insights into the GCSE marking process. Paper presented at BERA 2008, University of Glamorgan.

Thurstone, L.L. (1927). A law of comparative judgment. *Psychological Review*, *34*, 273–286. Reprinted as Chapter 3 in Thurstone, L. L. (1959). *The measurement of values*. Chicago: University of Chicago Press.

Wiliam, D. (1992). Some technical issues in assessment: A user's guide. *British Journal of Curriculum and Assessment, 2*, 11–20.

Wiliam, D. (1994). Assessing authentic tasks: Alternatives to mark-schemes. *Nordic Studies in Mathematics Education, 2*(1), 48–68.

Wiliam, D. (1996). Standards in examinations: A matter of trust? *The Curriculum Journal, 7*, 293–306.

Wiliam, D. (1998, July). *The validity of teachers' assessments*. Paper presented to Working Group 6 (Research on the Psychology of Mathematics Teacher Development) of the 22nd annual conference of the International Group for the Psychology of Mathematics Education, Stellenbosch.

Wilson, T. (2002). *Strangers to ourselves: Discovering the adaptive unconscious*. Boston: Harvard University Press.

Assessment and Learning: The Proximal and Distal Effects of Comparative Judgment 52

Niall Seery and Donal Canty

Abstract

The endeavor to support creative and innovative activities within the construct of testing, grading, and rewarding in a standardized, reliable, and equitable way is a significant challenge for every subject. Technology education supports the development of a critical and inquisitive disposition (Williams 2011), yet one can question the capacity to effectively and validly measure the capabilities that enact this disposition. This chapter highlights the importance of integrating professional judgment as a means of supporting a more effective assessment of the evidence and actions that allude to the characteristics of a technologically capable person. The chapter discusses the proximal and distal effects of using adaptive comparative judgment (ACJ) as a means of judging evidence of capability so as to demonstrate the validity of the assessment method while supporting the pragmatic requirements of formal education. The chapter also discusses critical aspects of the impact assessment practices have from the perspective of the teacher and the student. The chapter concludes by presenting ACJ as a central approach to effective assessment "as" learning.

Keywords

Assessment as learning • Professional judgment • Holistic assessment

---

N. Seery (✉)
Athlone Institute of Technology, Athlone, Ireland

Royal Institute of Technology, KTH, Stochlom, Sweden
e-mail: nseery@ait.ie

D. Canty
University of Limerick, Limerick, Ireland
e-mail: donal.canty@ul.ie

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_54

Contents

Introduction

The function of assessment is multifaceted. Its role varies from awarding, which includes defining standards, discriminating performance, and rewarding capability, to formative, which supports learning and discourse, defines targets, identifies misconceptions, and challenges norms, in addition to everything in between. The importance of assessment practices is highlighted by the discourse around defining the functions of assessment in response to a targeted agenda. Advocates for assessment "for" learning argue for its use as a diagnostic tool to support direct and meaningful feedback in a way that is a pedagogical feed-forward. Implementations and interpretations of assessment for learning have begun to push the boundaries of educational transactions to actively include the learner in the process of assessment (Sadler 2009; Black and Wiliam 1998; Yorke 2003; Orsmond et al. 2000). Critically, assessment "as" learning encourages self and peer appraisal as a self-regulatory act. Ultimately, assessment "of" learning is an expected outcome of assessment of what the learner knows or can do at the end of a learning activity, course, or curriculum. The capacity to monitor progress and determine standards is what governs much of assessment practices.

The approach to assessment will impact on what can be established about the learner's ability or what they know. Torrance and Pryor (2001) characterizes Convergent assessment as being concerned with finding out if the learner knows, understands, or can perform a predetermined task. As a method it entails detailed planning and is generally accomplished by closed or pseudo-open questioning and tasks (Torrance and Pryor 2001). In this method the interaction of the learner with the curriculum is seen from the perspective of the subject curriculum. The approach is theoretically behaviorist, derived from mastery-learning models.

Divergent assessment by comparison, emphasizes the learner's understanding rather than the predetermined agenda of the assessor or Awarding Body (Torrance and Pryor 2001). With this form of assessment, the important thing is to discover what the learner knows, understands, and can do (Torrance and Pryor 2001). It is characterized by careful framing of open questions, activities and tasks that are of more relevance to developing the learner. As a result it is difficult to predict what the learner will demonstrate as evidence of learning, therefore providing authentic insights into the learners' development and capability. The implication of this divergent approach is that a constructivist view of learning is adopted. As a result, assessment is seen as accomplished jointly by the teacher and the student and oriented more toward future development rather than measurement of past or current attainment (Torrance and Pryor 2001). Dow (2005) outlines that students learn best when they are actively engaged in formative, as opposed to summative, assessment. This approach provides feedback, giving indication of action to affect improvement, developing skills of appraisal and critical reflection. This suggests that for effective learning, we must employ effective and appropriate assessment.

So What Is It We Are Trying to Assess?

Throughout this handbook, multiple perspectives, approaches, and interpretations of technology education have been presented. The following section attempts to capture this complexity by way of framing a prequel to the discussion around assessment in practice. The nature of technology education, although variable within contexts, cultures, treatment, and emphasis, viewed at a macro level, presents common challenges associated with reliable and valid assessment.

In defining technology education from a content perspective, McGarr and Lynch (2015) highlight the nature of the subject as having blurred boundaries. Using Bernstein's (1975, 1990) framework to classify and frame the knowledge dimension of technology within the context of STEM Education, McGarr and Lynch (2015) highlight the weakly classified nature of technology education as it draws from the knowledge base of many other disciplines (e.g., ICT, chemistry, physics, mathematics, art, and design as well as the social sciences). This is supported by Kimbell and Perry's (2001, p.19) description of design and technology as a "restive and itinerant non-discipline." The framing of technology could be described as loose, with "no universally accepted order by which topics/areas are delivered or taught" (McGarr and Lynch 2015). Yet, there are recognizable practices, processes, outcomes, and outputs that are unique to technology and unquestionably of value to the learner, such as engagement with conceptual and thematic design tasks which require a synthesis of internal and external thinking and result in the creation of conceptual and physical innovations.

Kimbell and Stables (2007) capture the complexity of the concept of technology and present a useful working frame of reference that describes capability to include the combination of critique and speculation. Although this is conceptually broad, it acknowledges a philosophical direction that underpins a disposition of enquiry (William 2011) and innovation. The mantra of considering the world "as it could be" as opposed to "how it is" is the conceptual framework that must inform practice, pedagogy, curriculum, and assessment.

Although competencies and capability are variable with respect to developmental stage, culture, context, and curriculum, the processes of knowledge acquisition, application, and creation are central. True technological capability involves self-monitoring and an awareness of how and when to use particular skills and knowledge. Barlex and Trebell (2008) argue that competency develops with coherent thinking and not just as an accumulation of knowledge. This is operationalized through design-based activities, where the need to acquire relevant multidisciplinary knowledge, demonstrate capability, evolve problem solving skills, effectively communicate skills, and synthesize information and conceptions are critically important. Supporting this, Gibson's (2008) model of technological capability illustrates the connectedness between skills, values, and problem solving in the context of knowledge both within and beyond technology. Demonstrating capability manifests through an iterative dialectic (Kelly et al. 1987) supported by the disposition of enquiry. The emphasis on the creative relationship between designing and making allows for an amalgam of the speculative and critical. Kimbell (2011) describes this best by explaining that we work in a distinctively dynamic environment mandating the need to operate in an "intermediate zone of activity where hunch, half-knowledge and intuition are essential ingredients" (p.7). Learning through design, which Archer (1992, p.8) identifies as an "entirely different mental discipline," is at the core of technology activity. Having an epistemological position that supports a disposition of enquiry within the blurred boundaries of disciplinary knowledge where normal practice is iterative, it is not difficult to problematize assessment.

As a novice within this context of technology education, imagine all the questions you would ask if you were required to grade evidence of learning:

- Do we create knowledge or apply it?
- What is learning and is that what we are trying to measure?
- Where did the criteria come from?
- Why is that the criteria? Who decided?
- Why is it worth 3 marks?

Now couple with these questions the notions of discretion, value judgment, and inference, and you are faced with a very complex amalgam of competing yet arguably complementary elements of what is valuable in the learning/assessment activity. Therefore what we require are judgments that unite critical elements of evidence, to form an overall impression of the learners' ability.

Assessment: Limitations and Challenges

Current discourse on technology education recognizes the benefits of fostering diversity and creativity in student's responses to design tasks. It is recognized that students must be supported in a process that is unique and individual to each and every learner. Valuing such traits in educational terms is problematic if learning activities are rigidly aligned to assessment requirements that inadvertently predetermine the outcome of the activity to some extent. With the importance of designerly activity outlined as a key element of capability (Kimbell et al. 1991), the difficulty lies, not only in the inability of traditional criterion-referenced assessment to accurately measure the process but also in its ability to have a negative impact on the learning activity itself. This is especially true when "desired outcomes" become so high on schools'/teachers' agendas; they distort the learning process in an attempt to maximize the outcome. The proximal effect of how learners perceive and respond to assessment is a critical consideration for assessment practices. If an authentic measure of creative, diverse, individual, personalized, conceptual, and concrete outcomes is what we need, it becomes obvious that the student and their learning must become central to the assessment process with assessment almost taking on the role of an inspirational pedagogue driving and motivating both students and teachers.

Williams (2000) argues that the outcomes and solutions to design problems can often involve more variables than can be represented in a sequence or loop model of designerly activity. The problem is trying to "measure" evidence of thinking, like on a ruler, while encouraging diversity within a system predicated on standardization and weighted criteria. Therefore, for the most part, we rely on criteria. However, let's consider the perspective of the practicum – Who creates, weights, and determines the relevance of criteria that we use when assessing the performance of student we teach? Who makes the ruler? The origin of criteria may appear obvious, but what if the agenda of stakeholders is not shared? Kimbell (2010) highlights the conflict that may exist between curriculum policy and assessment policy, with the difficulties centering on standardization and testing. This questions the validity of what it is we are actually measuring. Students conforming and aligning their outputs to address given assessment criteria (regardless of meaning) only facilitates a "sorting" agenda of assessment. This assessment challenge is amplified within technological subjects as Kimbell et al. (1991) argue that the essence of the problem with design-based educational activities lies in the transformation of active capabilities into passive products. The transformation of the real-time learning struggle is often lost through the reporting of a "dead" secondhand PowerPoint account that is "neat nonsense" (Ive cited in Barlex 2007, p. 53) prettied up to gain marks.

Assessment criteria that over-define the stages and functions of design can render the objective futile due to the exploration, experience, and decision-making that are central to learning being removed. Therefore, the relationship between effective technology education and the limitations of assessment methods to capture critical domain-specific knowledge (if even we should advocate for a strong definition of this, [either absolute or relative]), designerly thinking and a disposition that is developed through iterative action and enquiry, calls for a significant rethink with regard to assessment practices.

An Alternative View: Holistic Judgment

Hager and Butler (1996) argued that innovations and initiatives in education such as problem-based learning, education for capability, and portfolio-based performance assessment are most suited to a judgmental model of assessment. Boud and Falchikov (2007) identify a fundamental problem with the dominant discourse in assessment being the positioning of the learners as passive subjects to be measured or classified by the assessment acts of others. Seeing the learner as a "passive subject" does not subscribe to the idea of capability being a critical and speculative disposition. Judgment in assessment, whether made analytically or holistically, needs reference to some form of criteria in order to be explained (Sadler 2005). Therefore, having criteria that align with the qualities of capability is critical for a valid assessment. However, Sadler (2009) describes many uses of criterion-referenced assessment as suboptimal, limiting both the teacher and student in the learning and assessment process. This is supported by Kimbell (2007) where the suitability of analytical criterion-referenced assessment is called into question when faced with diverse and creative work. Sadler (2009) further outlines two problems with traditional criterion-referenced assessment. The first is that the sum of the parts may not always reflect the intuitive or holistic mark of the teacher and the second is that there may be criteria missing from an assessment rubric that are important or set the particular work aside as exemplarily. The difficulty with these anomalies is that they are structural and cannot be addressed by making assessment rubrics more explicit or elaborate.

Holistic assessment on the other hand is the judgment of value of "the whole" rather than the sum of a set of individual components of a task or assessment. Kimbell et al. (1991) believe that due to the complex and integrated nature of design-based activities, a model of holistic assessment that takes account of learning processes and interactions is the most effective in assessing overall capability of students. The judgment of the work is based on the appraisal of qualities that relate to appropriate criteria (Kimbell et al. 1991; Sadler 2009). Kimbell et al. (2004) outline that criteria that are flexible or conceptual (like having, growing, and proving) are useful in supporting the authentic generation of evidence of learning. The flexibility in this approach allows the assessor to call on more evidence where necessary to make a value judgment rather than being bound by fixed and predetermined criteria (Hager and Butler 1996).

Sadler (2009) presents holistic judgment as an appropriate assessment for work with open and divergent responses using skilled judgment based on multiple criteria. Such responses are determined as demonstrating sophisticated cognitive abilities, integration of knowledge, complex problem solving, critical reasoning, original thinking, and innovation (Sadler 2009). The judgment cannot be reduced to a set of individual measurements to be reconstructed to arrive at the correct appraisal but rather is based on holistic recognition based on the intellectual processing of the relationship between qualities observed as a whole. These qualities must be internally processed by the judge, based on personally set (externally influenced) criteria and standards.

Adaptive Comparative Judgment (ACJ)

It is clear that measurement beyond the product outcomes of technology is critical for a valid assessment of capability. It has been presented that measuring such a complex iterative process requires a flexible model of assessment that can value a diverse range of evidence presented by students in response to the assessment task. In ▶ Chap. 51, "Making Assessment Judgments: Policy, Practice, and Research," Kimbell presents the capacity of teachers to assess capability in design and technology through holistic judgment. He presents the high level of reliability achieved with the ACJ engine in project e-scape concluding that collectively teachers operating within a "community of practice" (Lave and Wegner 1999) produce valid and reliable assessments of capability. If this community of practice holds the expertise to enact the curriculum, then it is logical that collectively this group holds the expertise to assess its outcomes. With this as a central premise to assessment, a number of challenges are presented. How can we capture the collective opinion of the community of practice on what capability actually is (without explicit predefined assessment rubrics) and how do we know if they reach a consensus? This chapter considers the use of comparative judgment as being an approach to assessment that can unlock the potential of the community of practice through the use of holistic judgment of students work. This produces the proximal effect of having more valid and reliable assessment of learning, without skewing the direction of the learning, while distally building the construct of capability by engaging the community of experts.

The comparative judgment approach presents solutions to some of the assessment issues previously outlined in this chapter. The system has three elements; a set of portfolios of work from the students that is a response to the assessment task, a community of judges or experts from the subject domain, and a "pairs engine," a software solution that dynamically selects pairs of portfolios and presents them to judges for adjudication on the quality of the work. The basis for the decision by the judge is derived from their holistic assessment of quality based on their personal construct of domain related capability. The uniqueness of this comparative judgment is that the judge does not have to score the work in terms of quality, giving it a 6 or a 9 out of 10; they simply have to make a binary decision on which portfolio is better in terms of capability (see ▶ Chap. 51, "Making Assessment Judgments: Policy, Practice, and Research" by Kimbell for a more detailed explanation). The process begins with a rough sorting mechanism to establish broad categories of quality. As the process evolves the system generates more information about each portfolio becoming adaptive, allowing the subsequent parings of work to refine the position of the portfolios on a rank order of capability as collectively determined by the group of judges.

To ascertain a high degree of construct and convergent face validity within an assessment process utilizing ACJ, "the pairs engine" has a number of outputs that are useful in terms of assessment, learning, and quality assurance. The first is the rank order of portfolios. This can then be analyzed and mapped to grade categories if desired or used as an indicator of progression, illustrating an ipsative development. The second is the reliability statistic, which is an indicator of the degree of consensus among the judges on the quality and order of the portfolios, which gives an insight into the collective consensus of the community of practice indicating whether a common view of capability is shared. Another statistical data output by the system is the degree of consensuality of the judges within the decision-making process. The ACJ system records how often and by how much each judge is at variance with the other judges in the group. A judge outside of acceptable parameters (set by the awarding authority) is a cause for concern but can now be identified and an appropriate intervention can be actioned. A similar set of statistics is generated for the portfolios that identify portfolios of work where there was a significant level of disagreement by the judges. Both of these statistics present the opportunity to analyze where there is and is not consensus providing opportunity for analysis, discussion, and intervention. The final significant aspect of the system is the potential for formative feedback to the learner. As part of the judging process, judges have the opportunity to record formative comments on the portfolios of work. One of the strengths of the process is that multiple judges giving a broad and potentially rich source of formative feedback will have assessed each portfolio. Considering these outputs, the focus of the following sections is to outline the impact and potential of ACJ in technology education.

Proximal and Distal Dynamics

Pedagogues, awarding bodies, students, and parents will consider the proximal and distal effects of assessment varyingly. Regardless, there are multiple positives that can be achieved by employing the ACJ method. In addition to the valid and highly reliable pragmatic outcomes, ACJ affords us an insight into the processes associated with the learning activity. Critically it is the teachers and students that will be most affected by using ACJ. The following section will look at the proximal and distal effect of ACJ from the perspective of both the learner and teacher. The proximal will focuses on the immediate impact on the teaching and learning transaction, with the distal examining the broader and potentially more long-term impacts of the approach.

O'Donovan et al. (2004) outline that there is both an explicit and tacit nature to the development of standards and criteria, and students must be exposed to both for effective learning and assessment. Orsmond et al. (2000) describe assessment as shaping every part of the student learning experience often defining what the student regards as important. The proximal effect for the learner is an interesting point for discussion. The move from detailed to more overarching criteria, made possible by operationalizing holistic judgment, has a liberating affect. The students' inability to align with specific weighted criteria forces a more authentic response to the learning task. The learner cannot produce the typical "secondhand" account of learning to meet criteria. Instead, the internalized process of what it means to be capable is central to the presented evidence of their learning. The work of Canty (2012) shows evidence of the proximal effects and perceptions that manifested within students who engaged with the ACJ process. Testimonials offered by students (offered throughout this section) highlight the liberation from strict and potentially oppressive criteria and the capacity of ACJ to assist students in crystallizing their constructs of capability and their conception of a standard.

> *It was great to get the opportunity to have such complete autonomy in a module, it was refreshing because often I find I feel that very particular things are being sought by*

assessment whereas here I was allowed to decide myself what I wanted to show – this would likely never be shown in a more strictly formed assessment approach.

Having completed the assessment I am more confident in my ability to think for myself and produce work to a fairly high level that is also creative and interesting.

I think the fact that we were given the freedom to use our imagination as much as possible enabled a lot of positivity amongst us as students, and for us as teachers it will allow our students to develop their own thoughts, goals and aspirations, through our guidance and link imagination and thought with a set of workshop skills and problem solving skills

Two significant areas where ACJ is effective with regard to assessment as learning are metacognitive development and ipsative development. Students begin to develop metacognitive skills (both regulatory and audit) when forced to present evidence of their capability. Having to decide what is of value requires the student to engage in self-directed meaningful critique of his or her own evidence of learning to establish what is of value. There are two levels of sophistication in the approach. Firstly, it requires the student to define for themselves their personal construct of capability through their experience in the learning task – Am I demonstrating capability? Questioning what is capability is the initial effect that ACJ instills. This then begins the critically constructive process of building a personal construct of what it means to be capable. Secondly, they are required to discriminate between the evidence they produced during the learning task and present what best represents their capability. This appraisal is significantly important in developing and refining their conception of capability.

As a result of the interplay between construct identification, refinement, and evidence, there is a significant increase in diversity of outcome and output. The personal interpretation, solutions, and conceptions are colored by the iterative dialectic that talks to the students' unique experiences, knowledge, and skills. Sadler (1987) describes academic standards as being "essentially in unarticulated form inside the heads of assessors, and are normally transferred expert to novice by joint participation in evaluative activity." ACJ as a construct-building tool provides a powerful means of engaging the learner in a sophisticated discussion around what it means to be capable. Usually this discussion is avoided by virtue of acknowledging the assessment criteria that will ultimately be used to award a grade. Demonstrating that you are capable in response to overarching criteria is a very different challenge. The use of overarching criteria is only made possible by the holistic judgment that is operationalized by ACJ.

For the learner, there is a significant leap of faith when being asked to work in the risky environment that values creative and innovative endeavor. Will my work be valued? What if it is not what they are looking for? But this is actually what I have done and learned so surely this is what has to be measured! For effective assessment students must play their part. Students must be inducted into the assessment process to develop an understanding of its nature and purpose. This requires the development of skills of appraisal and judgment that will help the student in reflecting and establishing value on their own work and the work of others. Inducting students into the assessment process needs careful planning and support to ensure that it is meaningful and beneficial.

Students engaged in the ACJ method of assessment understand that they must create, discriminate, and present evidence of their capability, confident in the knowledge that the "expert" will recognize it when they see it and that there will be enough "experts" to represent the collective wisdom of that discipline area. This is a significant shift in the way students interact with assessment and is a direct result of the assessment method.

> *I thought that by thinking outside the box too much in my design, the concept would be lost on people. Therefore I kept the theme stark but simply communicated. If I was doing the project again and was aware of the high level of creativity in the class group, I would increase the level of abstract creativity in my project.*
>
> *one assessor may not value or appreciate my work and may have different beliefs in what should be presented, a larger group allows for a better understanding*

Furthermore, the proximal effect for the teacher is also apparent when considering the empirical evidence (Seery et al. 2012; Canty et al. 2012). As learners can be successful in different ways, it is therefore difficult to identify all critical criterions and assign associated weightings that are appropriate to the divergent response that is representative of creative and designerly learning endeavors. For the teacher, the capacity to relax constraints (predetermined criteria) in favor of professional judgment enables them to respond to individual interpretation and evidence of learning that demonstrates capability. This more reflexive approach to assessing capability can respond to the creation of new knowledge and skills and the application to unique solutions, mediated by need. In addition the ACJ binary judgment approach provides a unique capacity to be flexible with the application and weighting of criteria. This is not to say that the teacher is "making it up as they go" but rather tailoring the value judgments in response to the evidence of learning. This change in the process of assessment significantly changes that nature of how we identify evidence that is of value. For example, how do you grade the exceptionally well-executed solution verses the more innovative?

Engaging the student in a peer judging process has the additional distal effect in further impacting on the evolving capability construct. This exposure to peer work makes visible a breadth of interpretations and responses often only visible to one assessor and usually at the summative stage. The significance of this formative approach is not surprising as the student can quickly position their performance relative to another's work. The process of sharing peer solutions/responses to the same task exposes them to a breadth of interpretations, conceptions, and approaches that they may not have considered or in fact may not have been invited to consider. The work of Canty (2012) in particular highlights that the use of ACJ as an integrated learning tool was arguably more critical than the actual learning task itself. This integration of ACJ involved a capacity to critique outcomes relative to the educational task and associated quality of evidence.

> *. . .we were given the freedom to go down whatever design route we wanted using the skills that we had learnt. But, in my own case I let myself be blinkered by one idea and missed out*

on a chance to be really creative, this was illustrated to me when I viewed everybody else's projects I felt that I'd sold myself short. This was an invaluable lesson for me personally

This assessment activity gave me great confidence and motivation for other modules. I felt under pressure in the course until I found that I was more than capable in the area of design and making from this module. It was my kick-start.

Over time the ACJ process exposes students to all levels of evidence, and the determination of quality and the ability to appraise it simultaneously develops through an iterative comparison of self and peer work.

In addition to ACJ impacting educational transactions for students, there is significant potential for a similar positive impact to be experienced by the teacher. From the teacher's perspective, the ACJ approach integrates two key pedagogical characteristics highlighted by Torrance and Pryor (2001): proximally, it provides direct feedback to the teacher during the judging session as a reflective catalyst and distally provides the opportunity for shared construction and comprehension of assessment criteria.

The nature, quality, and alignment of the professional judgment of the teacher can be considered from two perspectives: the personal construct of capability as determined by the act of judging evidence at an individual judge/teacher level (proximal and distal) and the consensual position held by the profession, determined by their level of agreement when judging (distal).

Exercising Judgment

The role of the teacher is critical regardless of the assessment agenda. Broadfoot (1996) highlights the dominance of the social role and purpose of assessment (sorting – using predefined, usually mandated criteria) and its variance with its educational function. This dual role highlights significant challenges for the teacher, as they are required to serve two masters that require two very different practices. For a teacher to make judgments about the quality or standard of work, they must have a reasonable idea or feel for the standards they intend to apply (Sadler 2005). Enhancing this capacity is generally associated with the development of experience of a teacher through social dialogue and exposure to the broad-ranging endeavors of the community of practice. The commitment to innovation and designerly thinking is the kernel of the contention when it comes to assessment in technology education. To further complicate the process, Sadler (1987) and O'Donovan et al. (2004) argue that despite best efforts, the articulation of standards in assessment are difficult to capture, often fuzzy in nature, open to interpretation and context. Therefore, the ability to appraise qualities and evidence of technological capability is predicated on having a clear personal construct of what is of value.

The capacity to classify or categorize a disposition is problematic, yet we are all confident that we will recognize evidence of it once we see it! This is the empowerment that ACJ unlocks through the process of holistic binary judgment.

Grading students' work is the quickest way of externalizing your own expertise. The act of determining a grade that is subject to further moderations can result in confidence building or vulnerability for the teacher. The professional development that comes with experience is critical in enabling confident judgment. It is the experience of articulating, exercising, and appraising evidence of learning that supports the novice teacher in developing a sense of qualities and standard. The ACJ method provides assessors with the opportunity to assess their own conception of value in comparison to their peers and exposes them to a broad range of qualities and levels of attainment. Although the ACJ model of assessment focuses on individual teachers making independent decisions on students work, the strength of the system is in the aggregation of the independent decisions to converge on a consensus. Therefore, teachers' professional judgments contribute as a part of the overall decision, which will help form the collective agreement on a measure of the quality of student work. Therefore, evolving constructs of value and quality are shaped through experience, reference, and exposure to the collective wisdom of the community of practitioners.

A significant advantage of the ACJ method is its capacity to harness the collective professional responsibility of teachers. Involving a group (school, regional, or national) of teachers in the assessment of a pool of work helps ensure the validity and reliability of the assessment while protecting teachers from external pressures (social as highlighted by Broadfoot 1996). Individual teachers being exposed to potential litigation or difficult moral and ethical dilemmas may impact not only on the nature of teaching and learning but also the reliability of assessment decisions. Using ACJ to address assessment on a systems level can protect the capacity of teachers to make professional judgments on students' work and be supported by the collective view of that work. As ACJ equitably considers all judgments; therefore, teachers are reassured that their involvement in assessment is of value.

Concluding Comments

Providing a model of assessment that can exercise and utilize the holistic judgment of teachers while supporting discourse and the community of practice would therefore appear to present a potential solution to the assessment challenges of contemporary technology education. Stables (2008, p.16) asked, when discussing the progression of future design research, "Do we build walls unintentionally and carelessly in all the wrong places?" and this question is also valid in the case of assessment. Meaningfully integrating assessment as part of a learning activity is full of challenges. Care is needed to ensure that our solutions to address these challenges support the nuanced nature of design-based activity. Supporting the teacher and learner grappling with the intrusion of assessment and helping them to establish its purpose and place is important. The role that ACJ can play in this process has multiple possibilities in both the development and measurement of student capablility.

References

Archer, L. B. (1992). The nature of research into design and design education. In B. Archer, K. Baynes, & P. H. Roberts (Eds.), *The nature of research into design and technology education* (pp. 7–13). Loughborough: Department of Design and Technology, Loughborough University of Technology.

Barlex, D. (2007). Assessing capability in design and technology: The case for a minimally invasive approach. *Design and Technology: An International Journal, 12*(2), 49–56.

Barlex, D., & Trebell, D. (2008). Design without make: Challenging the conventional approach to teaching and learning in a design and technology classroom. *International Journal of Design and Technology Education, 18*(2), 119–138.

Bernstein, B. (1975). *Class, codes and control: Towards a theory of educational transmission* (Vol. III). London: Routledge.

Bernstein, B. (1990). *The structuring of pedagogic discourse: Class codes and control* (Vol. IV). London: Routledge.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education, 5*(1), 7–74.

Boud, D., & Falchikov, N. (2007). *Rethinking assessment in higher education: Learning for the longer term*. London: Routledge.

Broadfoot, P. (1996). *Education, assessment and society: A sociological analysis*. London: Open University Press.

Canty, D. (2012). *The impact of holistic assessment using adaptive comparative judgment of student learning*, PhD Thesis, University of Limerick, Ireland.

Canty, D., Seery, N., & Phelan, P. (2012). Democratic consensus on student defined assessment criteria as a catalyst for learning in technology teacher education. Paper presented at the 26th Pupils' Attitudes towards Technology (PATT) Conference, Stockholm, Sweden.

Dow, W. (2005). Developing inclusive communities of learners in technology education: Practical craft skills – Facilitator or hindrance. *International Journal of Technology and Design Education, 15*(1), 5–17.

Gibson, K. (2008). Technology and technological knowledge: A challenge for school curricula. *Teachers and Teaching: Theory and Practice, 14*(1), 3–15.

Hager, P., & Butler, J. (1996). Two models of educational assessment. *Assessment and Evaluation in Higher Education, 21*(4), 367–378.

Kelly, A. V., Kimbell, R., Patterson, V. J., Saxton, J., & Stables, K. (1987). *Design and technology: A framework for assessment*. London: HMSO.

Kimbell, R. (2007). E-assessment in project e-scape. *Design and Technology Education: An International Journal, 12*(2), 66–76.

Kimbell, R. (2010). The transient and the timeless: Surviving a lifetime of policy and practice in assessment. *Design and Technology: An international Journal, 15*(3), 18–27.

Kimbell, R. (2011). Wrong. . .. But right enough. *Design and Technology Education an International Journal, 16*(2), 6–7.

Kimbell, R., & Perry, D. (2001). *Design and technology in a knowledge economy.* London: Engineering Council.

Kimbell, R., & Stables, K. (2007). *Researching design learning: Issues and findings from two decades of research and development*. Rotterdam: Springer.

Kimbell, R., Stables, K., Wheeler, T., Wosniak, A., & Kelly, V. (1991). *The assessment of performance in design and technology.* London: School Examinations and Assessment Council/Central Office of Information.

Kimbell, R., Stables, K., Wheeler, T., Miller, S., Bain, J., & Wright, R. (2004). *Assessing design innovation*. London: Department of Education and Skills.

Lave, J., & Wegner, E. (1999). Learning and pedagogy in communities of practice. In B. Leach & J. Moon (Eds.), *Learners and pedagogy* (pp. 21–33). London: Open University Press.

McGarr, O., & Lynch, R. (2015). Monopolising the STEM agenda in second-level schools: Exploring power relations and subject subcultures. *International Journal of Technology and Design Education*, [online]. Available: doi:10.1007/s10798-015-9333-0.

O'Donovan, B., Price, M., & Rust, C. (2004). Know what I mean? Enhancing student understanding of assessment standards and criteria. *Teaching in Higher Education, 9*(3), 325–335.

Orsmond, P., Merry, S., & Reiling, K. (2000). The use of student derived marking criteria in peer and self-assessment. *Assessment & Evaluation in Higher Education, 25*(1), 23–38.

Sadler, D. R. (1987). Specifying and promulgating achievement standards. *Oxford Review of Education, 13*(2), 191–209.

Sadler, D. R. (2005). Interpretations of criteria-based assessment and grading in higher education. *Assessment & Evaluation in Higher Education, 30*(2), 175–194.

Sadler, D. R. (2009). Transforming holistic assessment and grading into a vehicle for complex learning. In G. Joughin (Ed.), *Assessment, learning and judgement in higher education* (pp. 45–63). Rotterdam: Sense Publishers.

Seery, N., Canty, D., & Phelan, P. (2012). The validity and value of peer assessment using adaptive comparative judgement in design driven practical education. *International Journal of Technology and Design Education, 22*(2), 205–226.

Stables, K. (2008). Designing matters; designing minds: The importance of nurturing the designerly in young people. *Design and Technology Education: An International Journal, 13*(3), 8–18.

Torrance, H., & Pryor, J. (2001). Developing formative assessment in the classroom: Using action research to explore and modify theory. *British Educational Research Journal, 27*(5), 615–631.

Williams, P. J. (2000). Design: The only methodology of technology? *Journal of Technology Education, 11*(2), 48–60.

Williams, P. J. (2011). Dispositions as explicit learning goals for engineering and technology education. In M. Barak & M. Hacker (Eds.), *Fostering human development through Engineering and technology education* (pp. 89–102). Rotterdam: Sense Publishers.

Yorke, M. (2003). Formative assessment in higher education: Moves towards theory and the enhancement of pedagogic practice. *Higher Education, 45*(4), 477–501.

Use of Portfolios for Assessment in Design and Technology Education 53

Kay Stables

Abstract

This chapter explores the use of portfolios in assessment, starting with a general overview of the nature of assessment portfolios, then moving on to their use within technology education for developing and assessing capability. I start by considering their early use in public examinations in England and reasons why they were introduced. From this I explore issues presented by using portfolios, their potential and their problems. I draw on a range of research and development projects, mainly from within technology education, then present a case study of portfolio development from research at Goldsmiths, University of London, and use this as a basis for exemplifying the potential of digital portfolios. Finally, I provide hopeful but cautious guidance, drawing from the success stories, the findings, and the concerns raised through the chapter.

Keywords

Assessment • Portfolios • e-Portfolios • Design processes

Contents

K. Stables (✉)
Goldsmiths, University of London, London, UK
e-mail: K.Stables@gold.ac.uk

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_53

Introduction

Assessment portfolios have become an increasingly common feature of learning and teaching in recent years. A question here might be why? What was wrong with existing assessment systems that made people start looking for an alternative? Davies and Le Mahieu offer a positive answer to this by identifying how portfolio assessment adds value, making visible development over time, allowing greater engagement and effort, supporting "deeper performance," allowing learners to choose what to include, revealing their "dispositions towards learning" and providing opportunities for a learner to engage with and reflect on what they have done (Davies and Le Mahieu 2003, p. 148).

The development of e-portfolios is more recent but has emerged for similar reasons. Both "paper based" and digital forms are tools for capturing a range of evidence of learning forming a basis for assessment. Butler (2006) provides a straightforward description of a portfolio as "a collection of evidence that is gathered together to show a person's learning journey over time and to demonstrate their abilities" (Butler 2006, p. 2). But beyond this quite neutral and somewhat limited description are multiple views of what a portfolio is, what a portfolio is for, and what views of education, learning, and assessment underpin a portfolio. Their use has become ubiquitous in school and tertiary education, including in areas of professional education such as teacher education. Definitions abound.

From a learning and assessment perspective, the paradigm underpinning the creation and use of a portfolio is important to consider. Barrett identifies two clear distinctions – positivist approaches, "assessment tools to document the attainment of standards" and those within a constructivist model as "stories of deep learning" (Barrett 2004, para 2). Elton (2007) adds to this a nuance of interpretivist approaches in which each learner is being judged as an individual, often through ipsative assessment. Elton suggests that in an interpretivist model credibility and transferability are more appropriate than the reliability and validity that is required in positivist assessment where "all students are judged against a common yard stick" (Elton 2007, p. 6)

Other approaches to categorizing portfolios relate to their purpose. Mason et al. (2004) identify a range of purposes – assessment portfolios, presentation portfolios, learning portfolios, personal development portfolios, and working portfolios. Ridgway et al. (2004) pinpoint three purposes – a repository, a stimulus for reflection, and as a showcase. In an educational context, a classification around these three purposes is a common approach and link to a further distinction – a portfolio as a journey or as a container. Spendlove and Hopper (2006) suggest that within the Design and Technology community there are just these two perspectives – "that the portfolio is a developmental tool allowing for the development and refinement of ideas over time or that it is a 'repository' of and vehicle for the presentation of student's 'best work'." (Spendlove and Hopper 2006, p. 179). A more nuanced perspective comes from research conducted by Welch and Barlex (2004) who categorized teachers' responses into four purposes, the first (idea development) linking to the journey and the further three (a collection of ideas, record of what has been done, and evidence for assessment) linking more to the concept of container.

Barrett (2004) distinguishes between portfolios for summative assessment, which she describes as representing "a culture of compliance or a checklist of skills" and portfolios for formative assessment that she typifies as being within "a culture of lifelong learning/professional development" (Barrett 2004, para 6). Differences also exist in terms of the audience for a portfolio. Where the primary purpose is to support formative assessment, the audiences will be the learner themselves, their teacher and possibly other interested parties such as parents. With summative assessment, the primary audience is likely to be an examiner.

The challenge with all of the above perspectives is that they imply a simplicity that is rarely present. The context of use, the educational philosophy underpinning a portfolio, the pedagogic practices that surround it, all bring degrees of difference. The underpinning educational philosophy is a key aspect to consider – particularly the contrasting paradigms of positivism and constructivism, identified earlier. Barrett points out that the models are philosophically "at odds" with each other and that positivist approaches tend to be seen by learners as something "done to them" where constructivist approaches are more learner-centered. Paulson and Paulson (1994) provide a fascinating example of the contrasting impacts of these two stances, reporting on research whereby they developed a cognitive model for assessing portfolios that interlinked three axes – a process dimension (purpose, issues, standards, exhibits, judgments), stakeholder dimension (student, teacher, parent, agency), and history dimension (getting started, experiences, outcomes) that, when used in different contexts illustrated quite different approaches – one positivist and one constructivist. They capture these differences in the following description.

> The Atlanta project's clear focus is on student outcomes of instruction and the entire project is systematically designed to produce student outcomes that lend themselves to summarization across individuals and across groups. . . . The Wyoming project's focus was far more diverse. There were outcomes, but they were very generally defined – certainly not in terms that lend themselves to measurement as we usually think of it. Much of the approach was designed by students and teachers as they went along, guided less by a specific assessment design than a clear statement of philosophy regarding instruction and learning. . . . The contrast here is between two models of assessment: the one (represented by Atlanta) we call positivist, the other (represented by Wyoming) we call constructivist. (Paulson and Paulson 1994, p. 7)

This example illustrates the reality that a portfolio is a "tool." As with all tools, the impact, affordances, and constraints reside as much with the use of the tool as with the tool itself.

This initial exploration of portfolios opens up perspectives on portfolios. The following section draws on these perspectives, but within the specific context of Technology Education.

The Birth of "Portfolios" in Technology Education

The early use of portfolios in assessing design and technological capability coincided with recognition that the process, and not just the product, of design and technological activity was important. In England this happened around 1970. Portfolios, more commonly referred to as folders at that time, were seen as the place to look for evidence of process. Three initiatives exemplify this development. The first two link to examination courses for 16-year-olds. The first, in 1970, was a significant development in the, then, GCE Ordinary Level in Design and Technology for the London University Examination Board. Until that time examinations at this level had been of two types – a written test and a practical test. George Hicks, the Chief Examiner for course, identified a missing part in this system – that in which learners design and make something, documenting their thinking along the way. Kimbell (1997), reflecting back on this assessment innovation, recounted how

> a radically new form of examination had squeezed itself into the picture, and no one was quite sure whether it was to be treated as a 'theory' or a 'practical'. It involved writing and other kinds of 'desk-work', but it also required practical activity and the manipulation of tools and materials. . . . At a stroke [it] had welded theory to practice – lending legitimacy to the notion that it is right and proper to exercise thought and imagination into the world of products and manufacture. However, one of the lessons that candidates learned . . . was that in order to gain maximum marks it was necessary to make one's thinking very clear. . . . So the idea of design drawings – collected into a design portfolio – was a natural extension. (Kimbell 1997, p. 6)

At the same time a second examination qualification for 16-year-olds emerged. This was a Certificate in Secondary Education programme entitled "A course of study in Design" developed from the Design and Craft Education Project led by John Eggleston (Schools Council 1974). The assessment included a practical project accompanied by a project report that provided evidence of the process the learner had been through. The third was an examination course for 16-year-olds – the Oxford Advanced Level GCE entitled simply "Design." Assessing design projects was new and presented significant challenges that were highlighted in an "interim appraisal" after the first year of examination.

> The intention of the sponsors was to establish an A level course in which practical work within a design framework was used as a means of identifying intellectual ability and original thinking. It was essential to avoid 'soft option' and hence the standards of assessing are vital to success. Since the very nature of the course calls for just those qualities that are least easily identified, let alone assessed, this is no easy task. (Aylward 1971, p. 35)

The solution was to introduce a face to face meeting between the learner and the examiner.

> Finally the candidate is interviewed by the examiner as part of the assessment. Much of the judgment in this total assessment must be subjective and has to be taken on trust. At the same

> time, as with all public examinations, the examining board bears the responsibility of fixing standards and of awarding the final grades. (Aylward 1971, p. 35)

This use of external assessors enabled genuine discussion between learner and examiner focusing on their portfolio and outcome, adding to both reliability and validity of the assessments. This was further increased by an exhibition held at the end of the first year, sharing the work and the examination process, documenting the basis on which assessment judgments were made and identifying issues and challenges to be addressed in coming years. This event heralded another affordance of portfolios – the potential for sharing and discussing assessment amongst teachers and the professional development opportunities that this promotes – a matter to be returned to. A further matter to be returned to is the impact of assessments that were explicitly linked to "stages" in a design process that shifted attention from the outcome of a design project to the process of its development but which ultimately led to the problem of assessment criteria representing a linear design process.

Potential and Issues Arising from the Use of Assessment Portfolios

These early developments raised awareness of the value of focusing on processes – of Design and Technology and of learning more generally. They highlighted the potential for a portfolio to become a tool for reflection – and reflection that is made tangible in some way. They allowed a level of insight into a learner that had not previously been visible to a teacher or to an examiner. The tangible nature of what was documented also afforded opportunities for other teachers to be included. Barrett (2004) stresses the importance of reflection as part of a process of "deep learning" and suggests three dimensions.

> What? (The Past) What have I collected about my life/work/learning? (my artifacts)
>
> So What? (The Present) What do those artifacts show about what I have learned? (my current reflections on my knowledge, skills and dispositions)
>
> Now What? (The Future) What direction do I want to take in the future? (my future learning goals). (Barrett 2004, para 21)

For Barrett, a reflective portfolio of this nature becomes a story of learning – and others have also seen the value of the concept of "portfolio as story." In Design and Technology Martin (2007), for example, suggests that an electronic portfolio that enables storytelling in a digital form is particularly valuable because of the range and types of evidence, including those made possible through the use of digital tools. The study followed different cohorts of preservice student teachers. What became apparent was that when later cohorts were not restricted in any way in terms of the software used or the size of the portfolio, the story of a project that was documented better reflected the journey that was taken.

Product or Process

But, while portfolios can capture the story of a process, the very physicality of a portfolio means that it also becomes a product in its own right. This duality has historically presented problems – especially if collecting and presenting the process overshadows the authenticity of the process itself, sometimes resulting in a beautifully produced portfolio that shows only superficial evidence of thinking and learning.

In Martin's study, the assessment criteria emphasized the students' process and encouraged risk taking and the students largely felt that the digital nature of the portfolio allowed them to spend less time on making the portfolio "pretty" allowing more time for development. Investing time in making a portfolio "pretty" rather than focusing on the quality of the thinking and development of a project, what Mike Ive, former Chief inspector of Design and Technology in England, called "neat nonsense" (2001) has become a major issue in portfolio assessment. The driver for this has been the quantity and type of evidence deemed necessary – a factor that has side-lined constructivist approaches, as was illustrated above in the work of Paulson and Paulson (1994). Spendlove and Hopper (2006) suggest that this has stifled critical reflection, denied the opportunity for a portfolio to be a "liberating tool" that supports learners in exploring the creative potential of ideas in a design challenge and diminished possibilities for creative dialogue. They conclude that "the portfolio has become ritualistic and a product in itself." Spendlove and Hopper 2006, p. 180). Like Martin, they worked with preservice Design and Technology students and found that the repository view of a portfolio existed in many of their students' minds, along with those of the teachers in schools where students were undertaking placements. Also like Martin they saw electronic portfolios as an opportunity to explore a different model through students undertaking design projects that aimed at breaking the cycle of a redundant model whilst also facilitating good design practice. Encouraging a reflective and speculative process, utilizing a wide range of multimedia tools, and requiring students to create "electronic snapshots" for peer review that "filtered" their ideas, designing was put at the core of the students' projects. The approach encouraged risk taking, reflection, and critical thinking.

Both Martin's and Spendlove and Hopper's case studies had a common finding in that in both studies students broke free of a linear model of process and the approach taken within the portfolios assisted this. In both case studies, the students were supported to manage their projects, but were not directed by a prescriptive process. In the words of one student in Martin's study, "you can make links between specific parts of the design processs which makes it more like a true design process (i.e., not a linear process)" (Martin 2007, p. 59). Evidence of this shift is particularly useful as the straitjacket of a linear, prescriptive model of designing has been a major challenge within portfolio assessment, dating back to the early 1970s. The straitjacket is created when assessment criteria and atomistic mark schemes are attached to the requirements for evidence, placing overemphasis on creating evidence that will result in a high mark.

A study conducted by Doppelt (2009) also explored the opportunity of introducing an alternative model of portfolio assessment that placed significant focus on process. The study was undertaken with 16- to 18-year-olds who were engaged in a mechatronics course within the context of a design-based learning project. Portfolios were used for the students' graduation projects and the research that was undertaken focused on both the implementation of a creative development process, documented through a portfolio, and utilizing a model of creative thinking skills to assess the portfolios. Through a creative development process, learners were encouraged to systematically reflect to "develop awareness of their internal thinking processes and learn to direct their own thinking and document it" (p. 62). Focusing on reflection removed the need for learners to "slavishly" follow a linear design process. Interestingly all of the 128 learners involved in the study showed high levels of achievement overall, although this was far more evident in relation to the creative thinking skills in the development and evaluation of the product or system at the center of their project than they evidenced in learning, thinking, and problem-solving activities. Doppelt considered that the ability to reveal these differences through the portfolio and associated pedagogy highlighted areas where more focus is needed in learning and teaching.

Evidence: The Goods and the Bads

In the three studies outlined above, there has been emphasis on encouraging learners to document processes in ways that show a trajectory of thought and action through a development process. However, there is a genuine concern with the way in which portfolios can be overloaded with documentation that has little direct relevance to the project being undertaken, but that may contribute to the learner achieving a higher grade. At the heart of both positions is the need for evidence. What separates out the two positions is the nature of the evidence seen as necessary and the purposes that it serves – development and learning or meeting preset assessment criteria. This links back to the earlier discussion about the purpose of the assessment in question. Where assessment is summative, particularly in relation to external or "high stakes" testing, the evidence is created in response to meeting a particular set of standards. Where it is formative it is more likely to be diagnostic, revealing what a learner has or hasn't understood, can or cannot do, and indicating where emphasis in learning and teaching is now needed.

Whether the purpose is ostensibly formative or summative there is a clear danger that, where portfolios are concerned, evidence generation can become a major activity, often creating "after the event" rather than "in the moment" evidence. Teachers will joke about assessing a portfolio by weighing it, but in reality creating evidence can become burdensome, both for the creator and the assessor. It can also become displacement activity, taking valuable time away from development and learning, or simply a misguided assumption that the more evidence and the more beautifully it is presented, the higher the mark will be. This issue has been reported repeatedly in England through school inspection reports from the Office for

Standards in Education (e.g., Ofsted 2002, 2004, 2011) where it has been linked to superficial and superfluous work, wasted time, and even gender issues, identifying it as a demotivational aspect for boys. However, recent reports have found evidence that using e-portfolios can overcome this issue.

> Over the last three years, the technology to use electronic portfolios has developed so that students' achievement can be recorded in different ways, through use of voice recording, digital photography and video footage in addition to writing. Such developments are at an early stage and were relatively uncommon .... However, the examples observed suggest that the opportunity to use them more widely, supported by appropriate training for staff, could help to overcome a common problem in capturing student's achievement more fully. (Ofsted 2011, p. 33)

The following example from an inspection report in one school underscores the value.

> Students record their work as it develops, taking photographs on mobile phones or digital cameras to download later into computer-based portfolios. Brief annotations alongside the photographs enable students to explain when and why they made decisions to amend their work. This approach minimises paperwork and places the focus securely on designing and making high-quality original products. (Ofsted 2011, p. 51)

The push for more and more evidence has a clear link to perceptions of reliability in assessment processes which in turn links to increasing focus on teacher accountability, and a nervousness that portfolio assessment is inherently subjective and can't be trusted. A number of strategies aim to increase reliability in portfolio assessment, such as the use of rubrics, benchmarked "exemplar" portfolios, and assessment moderation sessions where teachers collectively assess work to develop shared understandings. These are all undeniably constructive and useful strategies. But it is equally valuable to consider the viewpoint of Elton (2007), shared earlier in this chapter, for whom an interpretivist stance would suggest that reliability is the wrong lens and that credibility and transferability would be more appropriate to support the development of an individual learner.

The focus on evidence, how much, how presented, and so on, begs another question – what purpose is the evidence serving. Between a teacher and learner it can be a point for dialogue, confirming, or not, understandings, providing the basis for next steps. Collecting this together in a portfolio provides opportunities to look both backward and forward on a learning journey. For high stakes assessment it may be that all that is needed is a score to create a rank to award a grade. If the latter is what is needed then recent research (Pollitt 2004, 2012) would suggest that judging rather than marking the evidence is more appropriate and holistic judgment, linked to a system of making comparisons of pairs of portfolios is all that is required to award grades. This approach is explored in more detail in Richard Kimbell's chapter in this book. The approach is also one that has its own "added value" in increased reliability in grading and potential to open up more democratic approaches to portfolio assessment – something explored later in this chapter.

Collecting or Curating?

A further issue that arises in relation to evidence in portfolio assessment is that of manageability – the very nature of a portfolio, holding considerable amounts of documentation of learning raises the question of organization, access, and storage. Where a portfolio is seen as a repository for evidence then systems of indexing, or digital tagging are possible. Where a portfolio is a story of learning this management issue can become an opportunity for learners to become curators of their own learning. The value of learners being at the center of making decisions about what should be included in their portfolio is highlighted by Davies and Le Mahieu (2003), suggesting, for example, how it helps learners organize their thinking in advance of discussing their work, kindling ownership, and responsibility while adding authenticity and validity in assessment processes. They also suggest that it increases learner motivation. Removing them from the decision making has the opposite effect.

In a study by Hardy et al. (2012), working with preservice teachers on a design project that was documented through an e-portfolio, the authors found that some valued the reflection that was prompted by documenting their project. However, others didn't recognize the portfolio they had created as a place where they had evidenced their learning, even when the analysis of the portfolios indicated that they had. This is exemplified by a student who felt that the portfolio had taught her to upload photos, but nothing about manufacturing processes, but whose portfolio provided a thoughtful and detailed refection on her making and the authors could see evidence of the learner "constructing knowledge [that] would lead to the student determining their own priorities in their learning" (p. 207).

An issue that arose in this study was the limitations or challenges of the digital tools available to them. This is a finding frequently repeated in relation to digital portfolios, reported within this chapter and elsewhere (Martin 2007; Stables et al. 2015; Williams 2013b). But while digital portfolios bring challenges, they also open up welcome opportunities.

Going Digital

While paper based and digital portfolios have the same goal of documenting evidence of learning over time, digital portfolios have an added dimension through the range of tools with which evidence can be captured. However, despite the tools being utilized, approaches to creating digital portfolios can be distinctly different, the most significant difference being whether they are created in real-time or as an "after the event" presentation. The latter is frequently evidenced through the use of powerpoint, falling into the category of a presentation portfolio. The former leans to an authenticity that makes learning visible within a task being tackled, adding validity to an assessment process through evidence that captures real-time performance, often literally through the voice of the learner. Lin and Dwyer (2006) suggest that traditional approaches to assessment are not always effective in capturing a learning process and that digital approaches have greater potential because of the multiple levels of assessment possible and the ways in which they can incorporate interactive multimedia tools. Such tools have benefits for learning itself as well as assessment of learning.

Williams (2013b) suggests that a shift to digital assessment emerged in Australia in line with a shift to high-stakes assessment in exit examinations for learners, in part because learning outcomes could not be easily captured in paper based systems. In a study exploring the use of digital assessment across a range of curriculum areas (Applied Information Technology, Engineering Studies, Italian Studies, Physical Education Studies), particularly focusing on ways of capturing evidence in authentic, performance contexts that could support reliable summative high stakes assessment, it was found that both learners and teachers were amenable, with learners generally preferring digital documenting to paper based. While they suggested frustration at some technical limitations, they explained that they could do their "best" work in this way, they could be more creative, and they could correct mistakes and change things more easily and document their process through a range of digital tools.

Such tools open up opportunities to understand and support different learning styles and increase ownership and student voice. They also offer more general opportunities to increase digital literacy, for both learners and teachers, even if at the outset the lack of skill may be a hindrance. Further possibilities emerge with web-based portfolios, potential spotted at an early stage by Sanders (2000) who foresaw possibilities for promoting and sharing achievements within and beyond the subject area. When comparing web-based portfolios with conventional ones he highlighted that "the Web allows us new options such as animation, navigation, digital audio/video, virtual reality, and interactivity" (p. 12).

As a way of exemplifying many of the affordances of digital portfolios, as well as drawing attention to some of their constraints, I will now turn to research on portfolio-based assessment that has been developed by a team at Goldsmiths, University of London.

From the "Unpickled" Portfolio to Project e-Scape

Portfolio-based assessment emerged as a research tool in a major study – The Assessment of Performance in Design and Technology. The study, commissioned by the UK Government's Education Department, required the research team to assess the design and technological capability of a 2% sample of 15-year-olds in England, Wales, and Northern Ireland – about 10,000 learners. The detail of this is reported elsewhere (Kimbell et al. 1991) but for the purpose of this chapter a significant development was what we came to call the "unpickled portfolio" (Stables and Kimbell 2000). A major challenge in the study was a constraint placed by the funders – that we had to assess capability largely through paper and pencil tests. This raised concerns about validity and thus reliability for the team. Dismissing standard paper-based test formats, we explored and developed an approach to scaffolding a design task that fast-forwarded learners into a design context (e.g., designing that addressed the challenges for elderly people, carrying shopping, preparing meals, etc.) and then engaged them in an assessment activity that was choreographed to enable a dynamic iteration between active and reflective modes of designing as they displayed their level of capability in designing to meet such challenges. The work was recorded in a unique, unfolding portfolio, designed to support the choreography of the subtasks. The whole “test” was completed within ninety minutes – hence the label of unpickled portfolio, distinguishing it from more typical long projects where evidence is created across time through learners being immersed in all the good pickling juices of learning and teaching.

This approach informed and underpinned our research and development work in assessment (Kimbell and Stables 2007) and in 2004 we had the opportunity to take the concept as the basis for the development of an e-portfolio – which gave birth to the e-scape project (e-solutions for creative assessment in portfolio environments, Kimbell et al. 2009). This project was undertaken in the context of high stakes assessment, exploring the potential of an e-portfolio for “controlled assessment” in Design and Technology GCSE – an external examination of 16-year-olds in England and Wales. Controlled assessment refers to a studio/workshop-based design and technology assessment, undertaken under timed conditions, with no teaching support.

While our approach has had much in common with other types of portfolio assessment, there is one significant difference. The approach fits clearly into “portfolio as journey” model. But while other portfolios of this type are largely curated, after the event, stories of learning and development, our approach has been to capture evidence in real time, the “trace-left-behind” as the designing and developing progresses. This creates a working portfolio, warts, and all. Going digital, working in collaboration with learning technology partners, has meant going web-based and this has enabled many opportunities, some mentioned in other projects above, some uniquely developed. The approach built directly from the “unpickled” structure – a design and technological activity scaffolded though iterating between action and reflection. The activities take place in studios and workshops, using all available and appropriate materials, tools, and components for a project, and documenting through handheld devices such as smart phones, tablets, and digital notepads. Learners are intermittently prompted, via the electronic device, to document progress: take photos of work in progress, add voice files explaining what is working, what isn’t, what next steps will be taken; share work with a “critical” friend and get their views on your progress; make a “walk-though” video showing how your model works; and so on. The documenting, whether text, drawing, photo, video, or mindmap, is instantly synchronized to a web portfolio, so that when the project is done, the portfolio is almost complete. A final prompt enables reviewing and annotating the portfolio with “hindsight” style comments.

The approach removes certain of the problems highlighted earlier in the chapter – there is no additional “burden” or time wasting in preparing the portfolio, there is no need to organize or curate the work – everything is documented in real time, but within a structure. The learner’s voice is literally present throughout – an aspect that has occasionally startled us by the level of confidence or honesty a learner displays.

We have had learners present a “rap” to explain their project, sing a song, or talk with absolute honesty about all the mistakes they have made.

Initial research was undertaken in England, within the subject of Design and Technology mainly with 15–18-year-olds, but also with learners as young as 9. Two smaller projects explored e-scape in science investigations and geography fieldtrips, showing its use across curricular areas and outside of formal classrooms, studios, and laboratories. The system has also been used with undergraduate students and primary learners and in other countries. For example, the portfolio software used in the latter stages of Williams’ study in Western Australia (2013a) was e-scape. The views learner’s expressed (outlined above) have been paralleled in other studies. One project, the Assessment in My Palm project, undertaken in Israel (Dagan and Stables 2013) explored using e-scape across a wide range of curriculum areas and for formative assessment. Learners responded well to the range of digital tools available to them and how the approach allowed teachers to better understand their work, as illustrated in the following comments.

> Learner 1 “I thought this was really interesting. Normally when I do projects I will write. When I write I use a very official language. When I was doing this project it was interesting because I would just speak and my teacher was seeing a video of me speaking about my work rather than writing very formally, that's very interesting. It gives me an idea of a different way to work and express myself.”

> Learner 2 “I think when we did this the teacher could tell more about what we were saying and also understand better what we were saying. It was more of a conversation rather than a report.”

A further dimension that emerged from this project was the value of learners with different learning styles being able to choose how they communicated their thinking. This was highlighted by special needs of teachers where learner motivation was high and using alternative tools to document their work improved learning and engendered feelings of self-worth through the success achieved.

The software, and in particular its web-based nature, also allowed for an alternative approach to assessment, based on holistic judgment and a system of adaptive comparative judgment mentioned earlier. This system is explained in more detail by Richard Kimbell’s chapter in this book, but, in brief, judgments are made about the overarching quality of capability based on systematically comparing the web-based portfolios against each other. The validity of the portfolios emerges through the real time, authentic evidence they provide. From a reliability point of view, the system produces a highly reliable ranking – extremely useful in high stakes assessment. From a manageability perspective, storage and access through the internet becomes extremely simple. But the approach also has value in two further ways, both of which were revealed by including learners in the judging process. What became clear was that the process of seeing a range of work from their peers, making judgments, and articulating their reasons for the judgments had a significant effect on their understanding of their own learning and development processes (Kimbell et al. 2009;

Seery et al. 2012). In addition, the potential is opened up for more democratic forms of assessment. Any number of stakeholders could potentially be involved from teachers to peers to parents to employers.

As Sanders suggested back in 2000, once a portfolio goes digital and web-based, any number of digitally based tools and resources can be incorporated. Our current research is exploring the potential of bringing Artificial Intelligence into a portfolio through an onscreen avatar that takes a coaching role with a learner, asking questions about the learner's project, and prompting the learner to think more deeply about what they are doing as they articulate their answers. The research is in an early stage, but indicates yet further potential for digital portfolios (Stables et al. 2016).

Conclusion: Considerations for Creating Portfolio-Based Assessments for the Future

At the time of writing this chapter, a pertinent scenario is being played out in the high stakes assessment arena of Design and Technology Education in England and Wales. The National Curriculum (5–14-year-olds) and the examination requirements for GCSE Design and Technology (the external examination taken typically by 16-year-olds) have gone through a "step change." Concerns expressed over a number of years about ritualized projects linked to portfolios structured around a linear process of designing, coupled with a perceived lack of challenge and relevance in projects has led to a major shift to iterative processes of designing and contextually based design challenges where learners have genuine ownership. This is reflected in the requirements placed on the Awarding Organizations who specify the requirements for the GCSE qualification and who are now faced with providing the structure and assessment scheme for a portfolio-based assessment that rises to these new challenges while maintaining reliability and validity. Initial models are emerging that represent a spectrum of approaches from the innovative, challenging, and risky to the minimally invasive. Over the next few years, we will see how this scenario plays out.

But guidance offered from the research drawn on in this chapter would suggest any person or organization creating assessment portfolios would be wise to:

- Be clear about the purpose of the assessment
- Be clear about the nature of the portfolio (paper/digital/on-line/curated/collected/choreographed)
- Be clear about the educational paradigm that the assessment is operating within and use this as a "health warning" on structures and systems as they are developed
- Be clear about the impact the approach to assessment may have on the learning that it aims to assess
- Explore and articulate the "added value" of all aspects of a proposed model
- Exploit the possibilities offered by new technologies
- Ensure that any evidence required is authentically drawn from the learning being assessed

- Consider a level of flexibility that places no undue challenges that distract from the authenticity of the learning being assessed
- Consider approaches that allow all learners to achieve their best

A wealth of evidence supports the potential for assessment portfolios, despite the challenges that come with new pedagogic and digital approaches. All systems of assessment in Technology Education, whether high stakes, summative assessment of learning, or ongoing assessment for learning, can now exploit their use to provide assessment that genuinely supports learning and teaching processes, optimizing the time teachers and learners spend together and maximizing the learning taking place.

References

Aylward, B. T. (1971). The Oxford 'A' level examination in design: An interim appraisal of an experimental approach. *Studies in Design Education Craft and Technology, 4*(1), 35–45.

Barrett, H. C. (2004). Electronic portfolios as digital stories of deep learning. Retrieved from http://electronicportfolios.org/digistory/epstory.html

Butler, P. (2006). A review of the literature on portfolios and electronic portfolios. Retrieved from https://akoaotearoa.ac.nz/download/ng/file/group-996/n2620-eportfolio-research-report.pdf

Dagan, O., & Stables, K. (2013). *Assessment in My Palm: Using dynamic, web based e-portfolios for formative and summative assessment*. Paper presented at the International Association for Educational Assessment: 39th Annual Conference, Tel Aviv.

Davies, A., & Le Mahieu, P. (2003). Assessment for learning: Reconsidering portfolios and research evidence. In M. Segers, F. Dochy, & E. Cascallar (Eds.), *Innovation and change in professional education: Optimising new modes of assessment: In search of Qualities and standards* (pp. 141–169). Dordrecht: Kluwer Academic Publishers.

Doppelt, Y. (2009). Assessing creative thinking in design-based learning. *International Journal of Technology and Design Education, 19*(1), 55–65.

Elton, L. (2007). Assessing creativity in an unhelpful climate. *Art, Design & Communication in Higher Education, 5*(2), 119–130.

Hardy, A., Tinney, J., & Davies, S. (2012). *Using e-portfolios to support trainee design and technology teachers in developing their subject knowledge*. Paper presented at the PATT 26: Technology Education in the 21st Century, Stockholm.

Ive, M. (2001). *Design & technology: Lessons from the past – issues for the future. An address to the National Conference of the Advisers and Inspectors of Design & Technology (NAAIDT)*. Paper presented at the NAAIDT Conference, Nottingham.

Kimbell, R. (1997). *Assessing technology: International trends in curriculum and assessment*. Buckingham: Open University Press.

Kimbell, R., & Stables, K. (2007). *Researching design learning: Issues and findings from two decades of research and development* (Hardback ed.). Berlin: Springer.

Kimbell, R., Stables, K., Wheeler, T., Wozniak, A., & Kelly, A. V. (1991). *The assessment of performance in design and technology*. London: SEAC/HMSO.

Kimbell, R., Wheeler, T., Stables, K., Shepard, T., Martin, F., Davies, D., …, Whitehouse, G. (2009). *e-Scape portfolio assessment: a research & development project for the Department of Children, Families and Schools, phase 3 report*. London: Goldsmiths, University of London.

Lin, H., & Dwyer, F. (2006). The fingertip effects of computer-based assessment in education. *TechTrends: Linking Research and Practice to Improve Learning, 50*(6), 27–31.

Martin, M. (2007). *Evaluating an approach for e-portfolio development*. Paper presented at The Design and Technology Association International Research Conference 2007, University of Wolverhampton, Telford Campus.

Mason, R., Peglar, C., & Weller, M. (2004). E-portfolios: An assessment tool for online courses. *British Journal of Educational Technology, 36*(6), 717–727.
Ofsted. (2002). *Secondary subject reports 2000/01: Design and technology*. London: Department for Education and Employment.
Ofsted. (2004). *Ofsted subject reports 2002/03: Design and technology in secondary schools*. London: Department for Education and Employment.
Ofsted. (2011). *Meeting technological challenges? Design and technology in schools 2007–2010*. London, UK: Ofsted.
Paulson, F. L., & Paulson, P. R. (1994). *Assessing portfolios using the Constructivist paradigm*. Paper presented at the American Educational Research Association, New Orleans.
Pollitt, A. (2004). *Let's stop marking exams*. Paper presented at the IAEA Conference, Philadelphia.
Pollitt, A. (2012). Comparative judgment for assessment. *International Journal of Technology and Design Education, 22*(2), 14.
Ridgway, J., McCusker, S., & Pead, D. (2004). *Literature of E-assessment: A NESTA Futurelab research report*.
Sanders, M. (2000). Web-based portfolios for technology education: A personal case study. *Journal of Technology Studies, 26*(1), 1–8.
Schools Council. (1974). *Design for today: Schools council design and craft education project*. London: Edward Arnold Ltd.
Seery, N., Canty, D., & Phelan, P. (2012). The validity and value of peer assessment using adaptive comparative judgement in design driven practical education. *International Journal of Technology and Design Education, 22*(2), 21.
Spendlove, D., & Hopper, M. (2006). Using 'electronic portfolios' to challenge current orthodoxies in the presentation of an initial teacher training design and technology activity. *International Journal of Technology and Design Education, 16*(2), 177–191.
Stables, K., Dagan, O., & Davies, D. (2015). Blended learning and assessment through dynamic digital portfolios: The e-scape approach. In S. Koç, X. Liu, & P. Wachira (Eds.), *Assessment in online and blended learning environments*. Charlotte: Information Age Publishing Inc.
Stables, K., & Kimbell, R. (2000). *The unpickled portfolio: Pioneering performance assessment in design and technology*. Paper presented at the D&T International Millennium Conference: Learning from Experience: Modelling New Futures, Institute of Education, University of London.
Stables, K., Kimbell, R., Wheeler, T., & Derrick, K. (2016). *Lighting the blue touch paper: Design talk that provokes learners to think more deeply and broadly about their project work*. Paper presented at the PATT 32: Technology Education for 21st Century Skills, Utrecht.
Welch, M., & Barlex, D. (2004). Paper presented at the DATA International Research Conference 2004: Creativity and Innovation, Loughborough University.
Williams, P. J. (2013a). Engineering studies. In P. J. Williams & P. Newhouse (Eds.), *Digital representations of student performance for assessment* (pp. 99–124). Rotterdam: Sense Publishers.
Williams, P. J. (2013b). Introduction and background. In P. J. Williams & P. Newhouse (Eds.), *Digital representations of student performance for assessment* (pp. 1–8). Rotterdam: Sense Publishers.

Formative Assessment of Creativity

54

Remke Marleen Klapwijk

Abstract

Policy makers and educators have emphasized the many promising features of technology education (TE) as a vehicle for the development of creativity. Design and technology are, in essence, manifestations of human creativity; educated designers display a high ability in seeing possibilities, discovering problems, branching out, and inventing (Facaoaru, 1985) skills everybody should master in the future.

It is, however, not easy for teachers and learners to know what creativity is and how to develop it. Assessment of creativity is particularly challenging because it is one of the areas of human affairs where we cannot write down rules for what makes something good. In addition, when products have a ground-breaking novelty, criteria to judge their relevance do not yet exist but have to be developed alongside.

Therefore, objective assessment – in the sense of using preset criteria – is not possible. To direct learning processes, teachers and students need ways to share personal perceptions of quality. This improves their understanding of creativity and to know where to go next. Formative assessment is most suitable for the assessment of creativity.

Formative assessment can focus on the (creative) processes, products, personal styles, and the context. For each angle, an overview of existing ways to assess creativity in various research traditions is given. The four angles will enrich each other and ideally TE teachers integrate them. Ways to formatively assess at the personal and context level are relevant but scarce.

R.M. Klapwijk (✉)
Delft University of Technology, Delft, The Netherlands
e-mail: r.m.klapwijk@tudelft.nl

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_55

Keywords
Creativity • Formative assessment • Values • Technology education • Design styles

Contents

Introduction

With the quest for twenty-first century skills and the growing need for creativity in many occupations, it is more important than ever that students learn to develop original solutions in technology education (TE). For students, these outcomes do not have to be new in the sense that they have never been thought of before, but they should create solutions that are new for them in order to develop skills for creativity such as divergent and convergent thinking (Howard-Jones 2002).

It is authentic solutions resulting from of the student"s imagination and collaboration we are looking for in TE classrooms. This type of creativity is called "little c" or everyday creativity and contrasted with "big" creativity (Kaufman and Beghetto 2009). Craft (2001 in Cremin et al. 2012, p.77) defines "little c creativity" as "purposive imaginative activity generating outcomes that are original and valuable in relation to the learner."

With the growth of interest in creativity, the assessment of creativity has become a priority. Among others, the Organisation for Economic Co-operation and Development (OECD) has focused on the development of a composite indicator for creativity (Saltelli and Villalba 2008). Although assessment of creativity has been one of the central topics in creativity research for a long time, hardly any progress has been made. Park et al. (2016) note: "Individual creativity research has not reached a meaningful consensus regarding the most valid and reliable method for assessing individual creativity" (p. 1).

Why is there hardly any progress in the assessment of creativity? The problem of a lack of consensus on creativity is not new at all. When the now famous painter Matisse, loved for his colorful and playful figures, showed his painting "Woman with a hat" in Paris in 1905, it was heavily criticized for its furious colors (Essers 2000). "A pot of paint has been flung in the face of the public," declared the critic Camille Mauclair (Chilvers and Glaves-Smith 2009, p. 228). Matisse was greatly occupied with colors and this painting of a woman could not be compared with anything that had been painted before. When we look back, the painting marked a shift in the work of Matisse and started the movement of the "fauves." Although most of the experts and the general public judged the painting negatively, it gained favorable attention from some art-lovers who used different criteria than the average experts. The painting was bought by a rich family who also stimulated others to buy Matisse's work. Although all stakeholders noticed that the "Woman with a hat" was different from things painted before, they had no consensus about the value of this newness.

Design and technology is, like the arts, characterized by its creative and generative nature. Based on new scientific insights in, for example, nanotechnology and the bio-based sciences, engineers provide us with a great many new products and processes. Designers develop products that have a great newness and relevance, for example, toys that support language abilities of autistic children. The following quotation, often attributed to Albert Einstein, emphasizes the generative nature of design and technology "*Scientists investigate what already is, engineers create that which has never been.*"

Teachers and learners are nowadays asked to be creative and need practical ways to get a grip on this learning intention. Assessment methods are needed in TE, but we need to know what kind of assessment really contributes to the mastering of creativity in classrooms. A central question in this chapter is: in what direction should the development of assessment methods for creativity in TE proceed? To answer this question, the nature of creativity is first discussed as this has consequences for assessment activities. In the second section, it is argued that formative assessment is the most suitable way to assess creativity. In the third section, the developed position is used to evaluate existing assessment approaches and discuss their use in formative assessment of creativity. Four different angles to evaluate creativity are discussed: products, processes, persons, and context. Approaches are taken from general creativity research and from research in TE education. The central idea is that assessment approaches should acknowledge the intangible nature of creativity.

The Nature of Creativity

The general agreement in creativity research is that creativity involves the development of something new and relevant (Mumford 2003), or, in other words, the production of "something original and worthwhile." In retrospect, it is often easier to understand the value of novelties; however, when they are first launched, their value is often difficult to establish.

History shows again and again that it is hard to recognize the true value of something new. An example is post-it notes that are now used all over the world. However, it took more than 12 years before the yellow "sticky" notes were accepted. Veldhoen (2004) describes this vividly. It all started in 1968 when 3M-researcher

Silver Spencer wanted to develop a very strong glue. However, the result was a kind of sticky stuff that remains gluey. Spencer and his 3M-colleagues were for years not able to find a relevant use for this glue (Veldhoen 2004). The use was found 6 years later when Fry starts to work at 3M. Fry, a singer in a choir, puts little papers in his songbook to find the songs more easily. However, the little papers keep falling out. It is at this point that Fry thinks “I need a sort of sticky bookmarkers” and remembers the glue made earlier by Spencer. After experimenting, Fry develops the first post-it notes and they are immediately a success with the secretaries of 3M. However, almost nobody outside the company wants to buy the post-it notes. They are much more expensive than normal paper and most people are not able to imagine how to use them.

To understand the difficulties in judging novelties, we first have to understand that there are different levels of novelty.

Cropley and Cropley (2010) describe four levels (see Table 1). Genesis is their highest level; these solutions are new in a foundational sense and suggest a general basis for further work. In these terms, “The woman with hat” painting, the glue, and the first post-it notes contain ideas that go beyond the immediate solution and are of the “Genesis” kind.

Why is judging novelties difficult? First of all, many ideas and products that have a high level of novelty (third or genesis level) do not work properly in the beginning. First tests will show weak results or none at all because designs need to be tuned and optimized to give best results. To be effective, any complex system normally requires a precise configuration of its elements and a series of iterations before the optimum is established (Walker 2006). This is especially true for solutions of the generative kind.

> For instance, early radios worked – they would transmit and receive radio frequency signals – but they were weak and unreliable. Through design research, engineers discovered more effective ways to amplify the signal, sharpen the tuning, reduce noise, and make the radio’s operation more reliable. (Walker 2006, p. 9)

Beside the iterations needed, there is a second element that hinders a clear view of the relevance of solutions which are radically new. When a first of a kind is made like Matisse’s painting of “the woman with hat,” the creator and the field are moving toward a new unknown territory and criteria for relevance have to be redefined or even completely developed. New ideas about color are needed to value Matisse’s work, and experts like the first buyers helped to create these new values.

The weak glue that remained sticky and the post-it notes were also of the genesis type. At first the 3M inventors did not know what to do with the glue nor did the public understand what to do with the relative expensive yellow sticky notes (Veldhoen 2004). At that point, they still had to discover the many possibilities of post-it notes in sharing and regrouping information that are now part of everyday life. Only when 3M provided free monsters and a flyer describing goals and ways to use the notes, the value of the novelty become clear and suddenly consumers were eager to buy them.

Table 1 Four levels of novelty (Cropley and Cropley 2010, p. 351)

Level of novelty of the solution	Indicator
First level of novelty: Solution draws attention to problems in what already exists	Diagnosis (solution draws attention to shortcomings in what already exists)
	Prescription (solution shows how what already exists could be improved)
	Prognosis (solution helps beholder to anticipate likely effects of change)
Second level of novelty: Solution adds to existing knowledge	Replication (solution is capable of being transferred to new settings)
	Redefinition (solution helps beholder to see new ways of using it)
	Combination (solution involves new mixtures of existing elements)
	Incrementation (solution extends the known in an existing direction)
	Reconstruction (solution shows that an approach previously abandoned is still useful)
Third level of novelty: Solution develops new knowledge	Redirection (solution shows how to extend the known in a new direction)
	Reinitiation (solution indicates a radically new approach)
	Generation (solution offers a fundamentally new perspective)
Genesis: Ideas in the solution go beyond the immediate solution	Foundationality (the solution suggests a general basis for further work)
	Transferability (the solution offers ideas for solving apparently unrelated problems)
	Germinality (the solution suggests new ways of looking at existing problems)
	Seminality (the solution draws attention to previously unnoticed problems)

Even experts with great domain and field knowledge may not directly recognize the qualities of domain-changing novel products. From this, we can conclude that not only the creation of novelties requires an open mind, this is also true for assessment of the value of novelties. Society has to develop new ways of looking and new criteria to fully understand the value of the created novelties.

What can we learn from the above when we develop sound practices for assessment of (little c) creativity in TE?

First, there are different levels of novelty that can be distinguished. It is important to realize that solutions that are generative and based on new principles may appear weak but contain promising lines of thought that are worthwhile to elaborate upon, not only of the specific idea but of the underlying principle as well.

It is, therefore, important to check for new dominant principles instead of criticizing the actual functioning of the product. In his book on lateral thinking, De Bono (1970) shows how this can be done when evaluating different machines to pick apples.

"It is important not to criticize actual mechanics. One designer of an apple-picking machine suggested putting bits of metal in each of the apples and then using powerful magnets buried in the ground under each tree to pull the apples down. It would be easy to criticize this as follows:

1. Just as much trouble to put bits of metal in each apple as to pick each one directly.
2. The magnet would have to be very powerful indeed to pull the apples down from such a distance.
3. The apples would be badly damaged on hitting the ground.
4. Buried magnets would only be able to collect apples from one tree.

These are all valid comments and one could make many more. But rather than criticizing in this manner, one could say: 'Here is someone who instead of going up to pick the apples like everybody else wants to attract the apples to the ground. Instead of having to find the apples and then to pick them one by one he can get them all together and all at once" (De Bono 1970, pp. 117–118).

Although the actual method is not practical, it is original as attracting apples from a distance is an uncommon principle.

Second, assessment based on fixed, preset standards is not possible in the case of a high level of creativity because solutions that have a high level of novelty are easily missed. In assessment, ample room for discussion on the applied criteria is needed to develop and redefine evaluation criteria alongside the development of novel products. Different views on the value of products should be acknowledged.

It is, therefore, not useful to try, as creativity scientists in the psychometric tradition strive for, to develop methods that provide one, final objective answer. When psychometric methods with fixed calculations are used, creativity might even be treated as a bad habit. "When students try being creative on a standardized test, they will get slapped down just as soon as they get their score" (Sternberg 2012, p. 3).

Inside and outside classrooms, we need to create learning communities that, through discourse, develop criteria to judge the relevance and added value of the novelties and use these to ground evaluations. Disagreements on the value of a solution are of utmost interest as they may indicate high levels of novelty. Assessment tools for creativity should stimulate learners to look for the source of disagreement in order to learn from it. Why do some learners think that the novelty produced has added value, while others think it is kind of scrap?

These discussions will increase awareness and resilience. What is hoped for is that students learn that people may simply not recognize the value of novelty at first sight. They learn that they should at times neglect critique and pursue their design paths. This is an important quality of creative designers. Csíkszentmihályi's (1996) interviews with creative people show that they often had to be rebellious.

Summing up, any assessment of creativity in classrooms should take the following into account:

1. There are different levels of novelty and highly original solutions may look weak at first sight or raise controversy.
2. Different opinions on relevance may exist as values often need redefinition when novelty is created.
3. Fixed standards to assess creativity have limitations and are often not useful; instead, people learn from each other through clarifying and sharing values and arguments.
4. Elaboration of ideas and prototypes based on new principles should be stimulated.

Learning Sources for One Another

The intangible nature of creativity and the impossibility of boxing it's assessment make a good marriage between creativity and formative assessment.

Wiliam describes the key functions of formative assessment:

> An assessment functions formatively to the extent that evidence about student achievement elicited by the assessment is interpreted and used to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions that would have been taken in the absence of that evidence. (Wiliam 2011, p. 43)

In general, formative assessment is one of the best strategies to effectively increase learning outcomes for traditional subjects (Wiliam 2011). In many cases, it effectively doubled the learning speed (Black and Wiliam 1998).

A well-known study that shows the power of formative assessment for higher order thinking skills has been conducted by White and Frederiksen (1998) who focus on skills of inquiry. Learners who applied formative assessment learnt more than twice as much as the control group. Knowing what to learn and the continuous self-monitoring and peer-assessment throughout the research lessons ensured that they knew what quality work looks like (Wiliam 2011).

The open nature of formative assessment and its focus on the day to day learning and classroom practices makes it an ideal way to assess creativity. It is meant to get to grips with the different ways to be creative and to move the learning forward by developing a sense of direction. The goal is not to develop final answers but to move the teacher and learners forward by providing feedback and stimulating ownership of learning. Instead of determining an end score at the end of a unit as one would in summative assessment, formative assessment of creativity is a process that flows throughout the unit.

In formative assessment, the following five strategies (Wiliam 2011, p. 2) can be applied:

1. Clarifying, sharing, and understanding learning intentions.
2. Engineering effective discussions, tasks, and activities that elicit evidence of learning.

3. Providing feedback that moves learners forward.
4. Activating students as learning resources for one another.
5. Activating students as owners of their own learning.

Setting the standard to judge the level of creativity is part of the formative assessment process in which ideas are shared between the learner, the teacher, and the peers. The five strategies give ample room for personal knowledge and insights on creativity and thus acknowledge the intangible nature of creativity.

Polanyi (1958), known for his domain-shifting work on personal knowledge, points out that although we are not able to provide rules for quality in many areas of human life, we can share our perceptions. This sharing can only function in the framework of personal, experiential knowledge. The learner relies on his own experiences related to creativity to understand the ideas of peers and of the teacher. The teacher will bring up examples, ideas, and concepts to let learners understand the different dimensions of creativity, but also learns from the students.

According to Hartell (2014), formative assessment of TE should be done on a day-to-day basis, directly related to classroom practices. Her research into Swedish practices shows that formative assessment of technology once a year, having no relation to the classroom, has no effect on the learning process and is a waste of time.

Based on positive results in many subject areas including TE, it is expected that formative assessment of creativity will be beneficial for the development of creative competences and attitudes of the TE learners if we find ways to conduct it in an effective way.

Ways to Assess Creativity in Various Research Traditions

The focus of this section is on practical techniques for formative assessment of creativity in TE. We will explore how practices to assess creativity in different research traditions such as psychometric creativity, computational creativity, and TE can be used in a formative way. The description follows the four P model of Rhodes (1961) that highlights four elements of creativity relevant for assessment: products, processes, person, and press. Press is a term used to refer to the context or environment of the creative process. Using these four elements provides teachers and pupils with a rich and holistic approach to assessment as well as a structure and a focus. Instead of a systematic overview, this section explores how formative assessment of creativity may look in future TE education.

Assessment at the Product Level

In psychometric creativity research, many tests to assess the level of divergent thinking of individuals have been developed. These tests go back to the early days of creativity research. Torrance (1968) was among the first to develop short and easy tests that are still in use today.

Examples are short verbal tests in which students have to think of other names, for example, for a body part such as a nose. Names like triangle and two holes will be common, while other names like microbe-obstructor will be scarce and are seen as more original. The other uses of familiar products test is related to form-function thinking. Students are, for example, asked to identify other uses of a car tire. A swing is commonly thought of and not new, but handcuffs for a giant is more original.

Based on criteria such as fluency, variety, originality, and elaboration, various algorithms are used to sum up the result in one score and rank the student's development. These tests are not as objective as often thought because test results depend on the algorithms used because one has to decide how many points a scarce idea gets. Furthermore, research shows that the emotional state of the person influences the test results (Zenasni and Lubart 2002).

Despite these problems, these tests are very useful for formative assessment in classrooms in providing evidence of divergent thinking as long as one realizes that not all elements of creativity are captured. Key advantages are that the tests are fun to do; most of them can be done by paper and pencil work. Furthermore, they are relatively easy to assess for teachers and learners because they have a specific focus and do not take the dynamic interplay of all factors into account (Cremin et al. 2012).

Instead of doing the tests for summative purposes with an external referee applying predefined standards, the Torrance tests can be used to improve the learners' understanding of creativity and to provide feedback on their current quality of divergent thinking. For example, students who developed new words for a nose can discuss which words are more original than others and why they are original. Students who have developed only a few original words will start to understand the heuristics to develop more original words.

Butler (1988) studied the effect of different types of feedback on the other-uses test. Fifth- and sixth-graders received feedback in the form of comments, grades or a combination of grades and comments. The comments had slight variations: "You thought of quite a few interesting uses; maybe it is possible to think of more uses" or "maybe you can think of more unusual uses which other children do not think of." Students who received only comments enjoyed the new tasks and developed more ideas, more varied ideas and more original ideas. However, the two other groups did not improve their divergent thinking significantly. Qualitative feedback with a recipe for action is helpful for learners, but grading seems to obstruct the creative process.

Another classroom approach is to cluster and sort the solutions developed in technology projects to get a feeling for variety and originality. A kindergarten design task could be to draw ideas to go from a boat to a rocky island. A kindergarten teacher could point to the results (see Fig. 1) and say: "Look around and see how many ideas our class has developed to get on the island. And see how varied they are, this group of drawings all use balloons, but here is one with a trampoline." In this way he marks the more special ideas using the dominant principle of De Bono.

There are many other ways to have a dialogue about products. Tassoul (2009), who teaches creative facilitation, developed the Interesting, Plusses, and Concerns (IPC) approach. It consists of three questions:

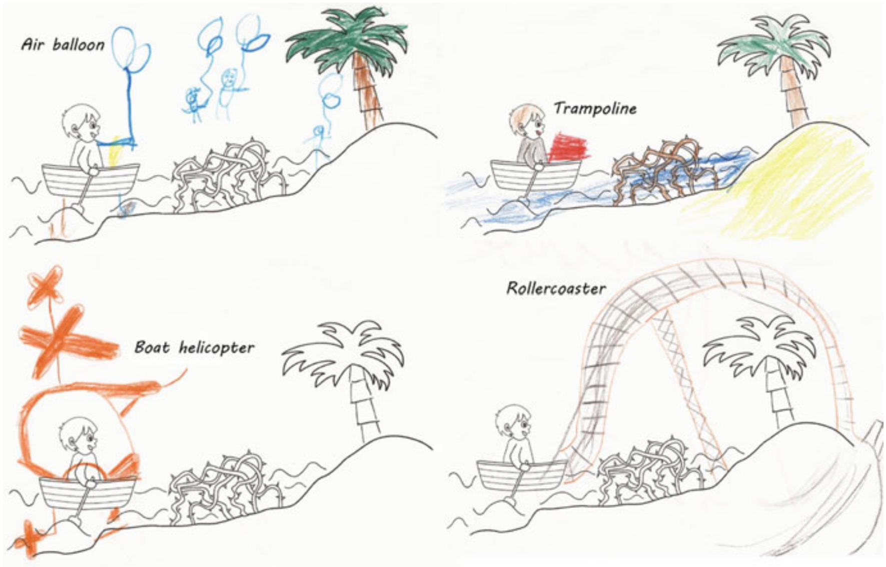


Fig. 1 Varied solutions from 4–5-year-olds

- Interesting: How and why is the idea interesting and functional (as a means to an end)?
- Plusses: How well it fulfills these functions?
- Concerns: Which aspects should we pay extra attention to if we were to implement this idea (uncertainties, weaknesses, and recommendations for further development)?

The IPC-approach provides a way to value ideas and prototypes that do not work properly but have a high level of novelty. For example, in a biomedical design project at a Dutch school near Delft, students developed products for a persona called "Uncle John" who loves cooking, but who has one arm missing. Opening a milk carton in a normal way is impossible. Two boys developed the following solution: throw the milk carton on a piece of wood with nails. The nails rip open the carton and the milk pours on the floor. When one would use the question "Does the prototype work?" the answer is "the milk is useless." However, in the IPC approach, one asks "How and why is the idea interesting?" The boy's prototype certainly is. Where most pupils focus on making the turning of the cap easier, the boys applied a more scarce principle, namely throwing and gravity. In terms of Cropley and Cropley, the piece of wood could be considered as a solution that offers a fundamental new perspective for the development of tools to open things in an easy way (Fig. 2).

One can also turn the table of Cropley and Cropley (2010) into a diagnostic instrument to start a dialogue about the creativeness of an idea. It works as follows:

Fig. 2 Testing the prototype

give each design idea a score of 0 or 1 on indicators for the three levels of novelty and genesis. Besides the 15 indicators shown in Table 1, indicators for relevance and elegance are also scored. Although there are a great many indicators, a workshop in Delft by Arthur Cropley and David Cropley for design teachers from secondary and tertiary education showed that people with design experience develop these scores very quickly. After scoring individually, the group discusses the given scores to understand why the novel idea is valued a certain way. In the next step, Arthur asked the participants to discuss if further elaboration of the idea would improve the score. This stimulated a divergent way of assessing the designs because recommendations for further development arose as well as ideas about the plausibility of improving the idea arose.

Review by a panel of experts in a certain field is a common technique to assess the creativity of products in the computational creativity research tradition (Amabile 1996). It is quite common to look for interrater reliability; however, to understand creativity, a focus on different opinions is needed. Therefore, a better way is to apply a Delphi approach in which various points of views and arguments are developed and confronted. A Delphi approach allows the development of a number of different positions on the newness and relevance of a solution. In classrooms, one could use a similar but simplified approach, for example, a classroom debate.

It is often advised to take the evaluation of specific clients and customer groups into account (Tassoul 2009). Each stakeholder will judge the novelty from a specific perspective. In assessment of creativity in classroom, it is also valuable to include many perspectives. Teachers may want to include other stakeholders such as parents, technical companies, external clients, and customers. Nicholl et al. (2013) describe how a girl designing for elderly gained feedback from potential users by demonstrating her prototype to them.

Assessment at the Process Level

Another way to approach creativity is by assessing the process. Any creative process has a dual nature, both divergent and convergent thinking are needed. At the process level, the key is about the effectiveness of the specific heuristics and approaches used to be creative. Assessment at the process level increases the learners understanding of how to achieve creative products.

As a process is more fluid than products, an important question is how to "catch" the design and technology process and how to collect evidence that shows the qualities of the followed process. In the late 1980s, Goldsmiths, University of London took up the challenge to make the design process of the learners visible (Kimbell and Stables 2007). Kimbell et al. developed many practical instruments to capture the design process and the learner's thinking processes. Their approach was to develop an "unpickled" portfolio (Stables and Kimbell 2000) to enable teachers and external referees to judge the quality of the process for summative reasons (Kimbell 2012). Students collected evidence by answering questions, uploading photographs, and recording short half-a-minute "sound-bites" in which they reflected on the intermediate results and their design approach. During the various trials, the researchers noted that the approach was not only powerful in capturing the process for external referees, the information captured helped pupils to reflect on their designs, to improve their designs, and stimulated mastering creative thinking skills (Stables and Kimbell 2007; Kimbell 2012). The mere looking back at series of photographs is like a mirror. The (captured) work itself provides feedback to the learners.

Currently, Stables et al. (2016) are developing new ways to encourage pupils to explicate their thinking processes and to provoke divergent thinking. Inspired by an approach in computer programming, Stables et al. provided learners with a rubber duck as a nonthreatening sounding board. When stuck, or looking for inspiration, students were invited to interact with the "little rubber duck" present in the classroom. In later trials, a duck moving on a screen was used in combination with a series of questions that helped learners to describe their design ideas. Prompts to stimulate speculations on how to develop the ideas further were given, for example, "How could it be used in the dark" or "How could smell or taste influence your ideas." Learners responded positively: "I felt it was useful coz it made me realise that there's more things that I do actually need to improve in the product . . . When I'm just doing it on the computer I'm kind of being safe about it whereas the duck asked me questions that I kind of needed to answer for my product to be better in the end" (Stables et al. 2016, p. 4). In this approach, evaluation is deeply embedded in learning.

Stop-and-think moments are valuable. A similar approach was applied in a Dutch study where young children aged 6 and 7 learn language using a computer game (Van de Sande 2015). A stop-and-think moment was added to the process by asking the pupils to tell their answer to a cuddly toy first. As a result, they were better able to work in an independent and quicker way and learnt more.

Studying feedback given in actual design processes was recently undertaken by Yilmaz and Daly (2016). They focused on feedback given by supervisors in relatively large design projects in three different design disciplines: dance, industrial design, and mechanical design. In some disciplines, feedback has a clear personal connotation. Dance instructors would discuss what "worked" for them in viewing the dance composition or suggest students to focus on the essence of the work, for example, "I don't get what that means so maybe a little more work on that. What is it to you?." Personalizing feedback is a good idea for TE because it emphasizes that different interpretations are possible.

Yilmaz and Daly distinguish three types of feedback: divergent, convergent, and feedback that is neither divergent nor convergent. In divergent feedback, a teacher may suggest to play around with ideas. To suggest a modification of a seat unit, an industrial design instructor said "Maybe you – what you do is play – work backwards from this." The instructor also stimulated students to look for various ways to include fun in the seat design: "look at the Herman Miller . . . it's extreme, but . . . you could get some inspiration from it" (Yilmaz and Daly 2016, p. 148). Convergent feedback consisted of reminding students of the date the work had to be finished or prompting students to rate several ideas in order of preference.

Yilmaz and Daly conclude: "Overall, feedback recommending convergent thinking was more prominent than feedback recommending divergent thinking" (p. 150–151). They also discovered that some of the convergent feedback directed students to minimize risk of failure in their design decisions. None of the three cases contained occasions where teachers pushed students to think more divergently into "unsafe" territories which could lead to design failures. As divergent thinking is an essential part of the design practice, teachers need to learn how to encourage divergent thinking and be less afraid to do so. In their recent work, Stables et al. (2016) also noted that teachers in secondary education made limited use of speculative questions in design and technology examination groups.

In formative evaluation, it is also important to clarify and share the nature of creative design competences with the students and to let students assess themselves on these design competences. Recently, the Delft University of Technology has developed an approach "Design in the Picture" based on all of the five strategies of formative evaluation classified by Wiliam (2011) (Fig. 3).

Seven key competences needed in a creative design process are defined, so they can be discussed and shared with the pupils. Teachers select, during a certain period or lesson, one or two competences to focus on and sharing the learning goals, collect evidence, and give feedback especially on these selected competences. Putting competences one by one in the limelight during a design project was inspired by the formative approach developed by White and Frederiksen (1998) for research competences. Student-teachers in the third year of the teacher academy who specialized in TE tested the tools, such as the Keep going cup (Fig. 4). The self-reports showed that most student-teachers got more grip on learning intentions related to creativity. Their lesson activities and feedback to the learners contained more prompts for competences such as "Make productive mistakes" or "Think in all directions."

Fig. 3 Model of key competences used in a formative assessment pilot Delft University of Technology

Together, the various research studies show the great value of capturing the design and technology process to enable both teachers and learners to explicitly deal with and reflect on divergent and convergent thinking activities as well as on related skills such as cooperation, communication, decision making, and developing empathy. When formative assessment is well applied, research shows that the learning speed doubles (Wiliam 2011). There are many signs that this will be true for formative assessment of creativity in TE as well.

Assessment at the Person Level

Assessment of creativity could also focus on the person. Creativity is characterized by Robinson (2001) as being at the heart of what it is to be human. For Robinson, creativity has not just social and economic value; he emphasizes the need for finding and developing one's own passion.

When students use their imagination and turn ideas into reality, they start to understand their own importance. They discover their own uniqueness in projects that have no preconceived answers, because nobody else has exactly the same idea or prototype.

Assessment at this level is meant to get a clearer view on how a specific learner is creative. Maybe the learner is creative in some domains and not in others. Furthermore, he will have developed a specific style of creativity (Cross 1985). Using portfolios that contain various design and technology projects of a certain student or a portfolio expanded with projects from various disciplines such as arts, literature,

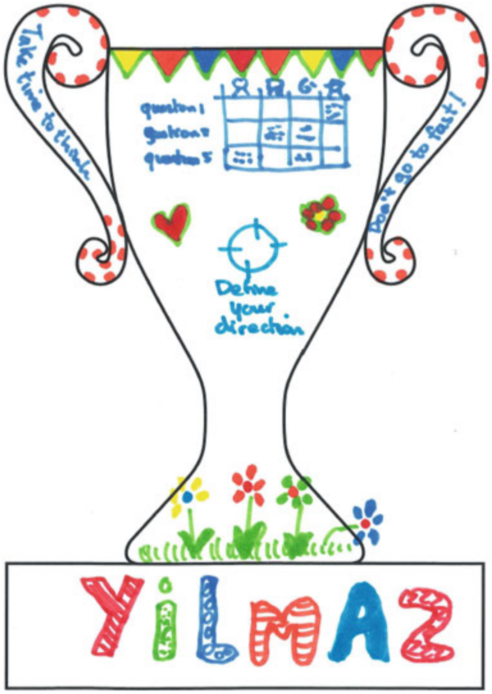


Fig. 4 Keep-going-cup acknowledges mastering a competence that is relatively difficult for a learner

sports, or science provides the necessary evidence. Such a portfolio should ideally contain all results, not only the best work (Wiliam 2011).

In order to support the learning process of each individual, it is required to value different design styles. A friend, following her bachelor at a fashion school, recently told me about her educational career. The first year, her mentor was a very conceptual teacher and designer. My friend's marks were low. In the second year, she got a new mentor who, like my friend, enjoyed designing by tinkering with materials, iterative prototyping, and so on. My friend's marks went up and she regained her confidence. However, in the next year, another conceptual designer became her mentor and my friend dropped out of school.

This can be prevented. Studies from the computational field show that we need teachers who are flexible and who have well-developed skills of close observation of learners (Cremin et al. 2012). They help learners to see what is valuable in their work (Woods and Jeffrey 1996). Personal traits that enable or disable creativity should become clear for the learner. Csíkszentmihályi (1996) and his fellow researchers interviewed approximately 100 persons who greatly contributed to various fields and noticed that they all had (developed) specific personal traits that were helpful in their pursuit of new, relevant contributions to society. Lawler and Howlett (2003) notes that professional designers have had a strong personal view of their role as designer.

What do we currently know about design styles? Studies in this area are relatively scarce. Cross (1985), based on Pask and Scott (1972) who describe different cognitive learning styles, distinguishes, for example, between serialists and holists. Cross (p. 157): “A serialist prefers to learn by proceeding in small logical steps, tries to get every point clear before moving on to the next, and pursues a straight path through the learning task, avoiding any digressions.” Cross continues “A holist proceeds much more broadly, picking up bits of information that are not necessarily logically connected, and learning things “out of sequence.” Lawler and Howlett (2003) speak of little steps versus looking for the big pictures.

Although literature on cognitive styles is abundant, it is hardly related to TE. However, what is needed is to develop this and relate these personal styles to the discipline of TE. Especially, ways to describe styles in designing (opposed to just cognitive styles) is beneficial for assessment at the level of the person. Only a few studies are available, e.g. Lawler (1997) and Lawler and Howlett (2003) who focus on ...design students preferred way of expressing ideas. Do these learners predominantly prefer to express their ideas in words, pictures, or three-dimensionally?

Matching teaching strategies with design styles is fruitful. In Lawler and Howlett’s case-study, teachers were invited to adapt their teaching style to the design styles of the pupils. The teachers regrouped their pupils in groups with similar design styles, for example, all pupils that are holists and wordists were grouped together. The teacher used strategies that fit in with the holist–wordist design style. After the intervention, the teachers were, without exception, enthusiastic and felt that what they were doing was “better” than before (Lawler and Howlett 2003, p. 66). The benefits of matching student (cognitive) styles to teacher strategies are also supported by Pask and Scott (1972) and Cross (1985).

It is also interesting to note that quite often different design styles are present in one project or one person. As Csíkszentmihályi shows, creativity is often about balancing two extremes, e.g., inward and outward orientation. A learner who is very imaginative and inward oriented may be stimulated to consult others and to start developing prototypes as a reality check.

Clarifying design and creativity styles and creating conditions to pursue and elaborate on this style are of a great necessity to nurture creativity. Without this, learners that are creative but have a different style drop out. Assessment at the level of the person enables teachers to give lessons and feedback attuned to various styles. TE would greatly benefit from an increased research effort into the indicators of design styles.

Assessment at the Context Level

Finally, formative assessment could focus on the context, the wider environment that influences creativity. The context of a design and technology project entails many elements such as the conditions in the classroom, the creative climate in the school, the openness of the learner’s family, and so on. In the four P model, press is the word used for the context.

According to Howard-Jones (2002), divergent and convergent thinking require each their own classroom conditions. Examples of favorable conditions for divergent thinking are:

- Relaxation is helpful to develop associations and new combinations of existing elements. A controlled experiment shows that adults scored higher in an alternate-uses test after a relaxing session in a floating tank (Forgays and Forgays 1992).
- Competition encourages a goal-oriented mentality that hampers divergent thinking (Amabile 1996).
- A change of location stimulates associative thinking (Howard-Jones 2002).

During design projects, teachers could focus the attention on the conditions available in the classroom by asking when learners felt like freewheeling and when they felt that it was hard to generate ideas. Learners then share experiences, for example, that it works better for them to have the brainstorm outside in the school garden or after a short break.

They could also discuss their family culture. Is their family open to other customs or does their family find it difficult to deal with other customs?

Once learners understand how the environment – including other people – influences their personal creativity, they are better able to develop favorable conditions in the future and may learn to become resilient toward negative influences.

Conclusion and Future Directions

Although assessment of creativity has been studied for over 60 years, the nature of creativity and the fact that criteria to understand and assess its value have to be developed alongside is often not acknowledged. It is important that in formative assessment of creativity, positive feedback is given when confronted with designs that are based on new principles, even when these designs are not seen as relevant by most observers and do not have good test results yet.

Formative assessment of creativity will speed up the mastering of creativity. We cannot just ask teachers and students to become more creative. Many of them need support from formative assessment in order to be effective in terms of knowing when a product is creative (novel and relevant), using sound processes, adapting to personal design styles as well as a wise use of the context. Research on personal styles and the context is relatively underdeveloped in technology education, but good starting points exist.

Four different angles to assessment of creativity in a formative way are available: product, process, person, and press. Each has its own value. In classrooms, these four angles need to be integrated. For example, a positive outcome at the product level can be related to the use of specific process strategies, certain personal traits, or to the press surrounding the project.

This kind of reasoning will give learners and teachers the opportunity to find a good lever for change when things do not go well. They may ask: what is our key problem or key factor that hinders us in developing creative solutions?

Problems can be related to a mismatch between the four P's. For example, the heuristics used in the design process are not wrong per se, but it is just not the preferred style of the learner. This learner will do better when he uses a different strategy. The mismatch between process and person is solved.

Looking from four angles gives more levers to stimulate creativity. When a learner does not dare to talk about his ideas, the teacher can change the environment by introducing a little rubber duck, just as Stables did. Talking to a little duck provides a safer environment to the learner. When the context changes, the person is able to be more creative.

The effort of research on assessment of creativity should not only go into the development of methods to assess creativity for scientific and summative purposes. Innovative formative assessment tools are needed to improve ownership of learners with respect to creativity. In essence, the learners need to know what creativity looks like and how to prompt themselves toward divergent, playful thinking.

References

Amabile, T. M. (1996). *Creativity in context*. Boulder: Westview.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice, 5*(1), 7–74.

Butler, R. (1988). Enhancing and undermining intrinsic motivation: The effects of task-involving and ego-involving evaluation on interest and performance. *British Journal of Educational Psychology, 58*(1), 1–14.

Chilvers, I., & Glaves-Smith, J. (2009). *A dictionary of modern and contemporary art*. USA: Oxford University Press.

Craft, A. (2001). Little C' creativity. In A. Craft, B. Jeffrey, & M. Leibling (Eds.), *Creativity in education*. London: Continuum International.

Cremin, T., Craft, A., & Clack, J. (2012). Creative Little Scientists: Enabling creativity through science and mathematics in preschool and first years of primary education, D2.2. Conceptual framework, Addendum 2 of 4; Literature Review of Creativity in Education. www.creative-little-scientists.eu. Accessed 14 July 2016.

Cropley, D., & Cropley, A. (2010). Recognizing and fostering creativity in technological design education. *International Journal of Technology and Design Education, 20*(3), 345–358.

Cross, N. (1985). Styles of learning, designing and computing. *Design Studies, 6*(3), 157–162.

Csíkszentmihályi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. New York: HarperCollins.

De Bono, E. (1970). *Lateral thinking: Creativity step by step*. New York: Harper & Row.

Essers, V. (2000). *Matisse*. Taschen GmbH.

Facaoaru, C. (1985). *Kreativitat in Wissenschaft und Technik*. Bern: Huber.

Forgays, D. G., & Forgays, D. K. (1992). Creativity enhancement through flotation isolation. *Journal of Environmental Psychology, 12*, 329–335.

Hartell, E. (2014). Exploring the (un-) usefulness of mandatory assessment documents in primary technology. *International Journal of Technology and Design Education, 24*(2), 141–161.

Howard-Jones, P. A. (2002). A dual-state model of creative cognition for supporting strategies that foster creativity in the classroom. *International Journal of Technology and Design Education, 12*(3), 215–226.

Kaufman, J. C., & Beghetto, R. A. (2009). Beyond big and little: The four C model of creativity. *Review of General Psychology, 13*(1), 1–12.

Kimbell, R. (2012). Evolving project e-scape for national assessment. *International Journal of Technology and Design Education, 22*(2), 135–155.

Kimbell, R., & Stables, K. (2007). Further performance assessment. In *Researching design learning: Issues and findings from two decades of research and development* (pp. 99–138). Dordrecht: Springer.

Lawler, T. (1997). Exposing and improving the metacognition of designing through practical structured workshops, IDATER 1997 Conference, Loughborough: Loughborough University.

Lawler, T., & Howlett, M. (2003). Designing styles: A new way of looking at design and technology learning and teaching, DATA International Conference.

Mumford, M. D. (2003). Where have we been, where are we going? Taking stock in creativity research. *Creativity Research Journal, 15*, 107–120.

Nicholl, B., Hosking, I. M., Elton, E. M., Lee, Y., Bell, J., & Clarkson, P. J. (2013). Inclusive design in the key stage 3 classroom: An investigation of teachers' understanding and implementation of user-centred design principles in design and technology. *International Journal of Technology and Design Education, 23*(4), 921–938.

Park, N. K., Chun, M. Y., & Lee, J. (2016). Revisiting individual creativity assessment: Triangulation in subjective and objective assessment methods. *Creativity Research Journal, 28*(1), 1–10.

Pask, G., & Scott, B. C. E. (1972). Learning strategies and individual competence. *International Journal of Man-Machine Studies, 4*(3), 217–253.

Polanyi, M. (1958). *Personal knowledge, towards a post critical epistemology*. Chicago: University of Chicago.

Rhodes, M. (1961). An analysis of creativity. *Phi Delta Kappan, 42*(7), 306–307.

Robinson, K. (2001). Introduction. In K. Robinson (Ed.), *Out of our minds: Learning to be creative*. Capstone: Chichester.

Saltelli, A., & Villalba, E. (2008). How about composite indicators? In *Measuring creativity: The book*. European Commission (17–24).

Stables, K., & Kimbell, R. (2000). The unpickled portfolio; pioneering performance assessment in design & technology. In *D&T international millennium conference: Learning from experience; modelling new futures*. Wellesbourne: Design and Technology Association.

Stables, K., & Kimbell, R. (2007). Evidence through the looking glass: Developing performance and assessing capability, 13th International Conference on Thinking, Norrköping, Sweden.

Stables, K., Kimbell, R., Wheeler, T., & Derrick, K. (2016). Lighting the blue touch paper: Design talk that provokes learners to think more deeply and broadly about their project work, PATT Conference, Utrecht, the Netherlands.

Sternberg, R. J. (2012). The assessment of creativity: An investment-based approach. *Creativity Research Journal, 24*(1), 3–12.

Tassoul, M. (2009). *Creative facilitation*. Delft: VSSD.

Torrance, E. P. (1968). *Torrance tests of creative thinking*. Lexington: Personnel Press, Incorporated.

Van de Sande, E. (2015). *Executive functions for early literacy learning*. Nijmegen: Radboud Universiteit.

Veldhoen, L. (2004). *Onverwacht succes*. Rotterdam: Ad. Donker.

Walker, D. (2006). Toward productive design studies. In J. Van den Akker, K. Gravemeijer, S. McKenney, & N. Nieveen (Eds.), *Educational design research* (pp. 8–13). London: Routledge.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction, 16*(1), 3–118.

Wiliam, D. (2011). *Embedded formative assessment*. Bloomington: Solution Tree Press.
Woods, P., & Jeffrey, B. (1996). *Teachable moments: The art of creative teaching in primary schools*. Buckingham: Open University Press.
Yilmaz, S., & Daly, S. R. (2016). Feedback in concept development: Comparing design disciplines. *Design Studies, 45*, 137–158.
Zenasni, F., & Lubart, T. (2002). Effects of mood states on creativity. *Current Psychology Letters, 8*, 33–50.

Teachers' Self-Efficacy in Assessment in Technology Education

55

Eva Hartell

Abstract

Self-efficacy is the belief in one's ability to organize and execute the course of action required to produce results under different conditions using the skills one possesses; teachers' self-efficacy is related to student achievement. This chapter provides an overview of self-efficacy theory related to teachers' assessment practices within technology education, emphasising the great importance of strengthening teachers' self-efficacy and collective efficacy as well as assessment literacy regarding their assessment practices in technology education as it affect students' learning opportunities in school.

Keywords

Assessment • Collective efficacy • Engineering education • Formative assesssment • Self-efficacy • STEM education • Teacher efficacy • Technology education

Contents

E. Hartell (✉)
KTH Royal Institute of Technology, Stockholm, Sweden
e-mail: ehartell@kth.se

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_56

Introduction

Teachers' individual *self-efficacy* in classroom assessment is an individual teacher's belief in their ability to plan, organize, and pursue activities related to assessment. This can include assessments meant to support learning during everyday instructional activities in the classroom, such as formulating learning intentions, designing questions, planning and executing instructional activities, eliciting evidence of learning, and interpreting students' questions and answers in text-based data or real-time classroom activities, as well as certifying student achievement and reporting levels of achievements as grades. People are both products and producers of their environments, enabling them to influence what happens and shapes their lives. Teachers' individual self-efficacy guides and motivates their course of action based on their beliefs in their abilities to plan, organize and pursue required educational activities, and will influence student outcome. However, more importantly is how teachers collectively think about their impact is most relevant to the success for their students (Eells 2011). Teachers' collective efficacy relates to a "group's shared beliefs in the conjoint capabilities to organize and execute courses of action required producing a given attainment" (Bandura 1997, p. 477).

School leaders and their ability to organize are important for building collective efficacy. Efficacious schools structure learning activities to promote all students' senses of personal capability by embedding monitoring, tailoring programs for their students, and promoting good classroom behavior instead of punishing bad (Bandura 1997). These institutions are less likely to organize their students according to their abilities and are found to be supportive of raising student achievement (Hattie 2009). School leaders on all levels must therefore focus on finding ways to empower teachers to overcome limitations on behalf of their students (Eells 2011). Hattie (2016) emphasizes the importance of providing affordance for building collective efficacy and the necessity and complexity regarding follow-up impact on student achievement throughout the organization.

Teaching conditions are perceived as adequate; however, teachers must also be capable and confident in their abilities to provide affordances, or support and resources, for student learning. Here, *affordance* is considered the quality of the environment that allows teachers to take and perform action, including both material and nonmaterial prerequisites, and includes teacher capability and their beliefs in their own capacities. Teachers' attitudes toward and their disposition of these perceived abilities influence the instructional actions they take, and further, the environment in which they are situated influences them. Their capability to convert the provided prerequisites or to cover for the prerequisites when they are not provided in their environment is dependent on their self- and collective-efficacy.

Classroom instruction must meet students where they are and continue ensuring student progress. Since learning is unpredictable, it is not possible to assume students' starting points based on prior instruction or expected standards according to textbooks or curricula. Instead, some sort of qualitative assurance and follow-up is necessary, in which teachers elicit evidence of learning while engineering learning activities. This is a process of inference, which must be embedded in instruction to ensure that instruction helps rather than hampers student-learning progress. Teachers must use evidence and adapt to better meet learners' needs and use assessment processes to support student learning – or verify the like – dependent on context and situation. Teachers must have the capability to assess students' aptitudes by using adequate methods effectively and interpreting evidence of learning, as well as maintaining knowledge of the impact of assessment practices on students; this is what Stiggins (1991) and Webb (2002) call *assessment literacy*. To observe findings and to be aware of student current understanding or misunderstandings is not enough. Teachers also need to act and apply their findings appropriately in practice, which is dependent on purpose and context. However, for this to happen, teachers need to believe in their capability to accomplish what they set out to do.

This chapter focuses on teachers' self-efficacy, or their beliefs about their abilities to succeed in specific situations (Bandura 1997). Self-efficacy is a substantial area of research, and this chapter will narrow the focus to situations related to assessment in technology education. Both self-efficacy and assessment literacy are highly context dependent and, therefore, difficult to measure. However, both have been found to strongly influence students' learning outcomes (Bandura 1997; Eells 2011; Hattie 2012; Tschannen-Moran et al. 1998). Teachers' self-efficacy on assessment in technology education is particularly difficult, since different countries, states, jurisdictions, and contexts not only have different assessment systems but also different understandings of the topics that "technology" should include, as well as how and when these topics should be taught in schools. Nevertheless, the differences between countries are fewer than similarities concerning teaching and learning in daily classroom practice.

Self-Efficacy Theory

The American psychologist Albert Bandura (1997) coined the term self-efficacy in the 1970s. It is grounded in social cognitive theory, which is concerned with the three levels of human agency – personal, proxy, and collective – and the ways people exercise a level of control over their lives. In his famous book, *Self-Efficacy: The Exercise of Control* (1997), the American psychologist Stanford University professor Alberto Bandura summarizes research exploring the exercise of human agency through people's beliefs in their capabilities to produce desired effects through their actions. Self-efficacy is a strong predictor for instruction behavior and influences student outcome achievement (Goddard et al. 2000; Hattie 2016; Tschannen-Moran et al. 1998).

Self-efficacy theory distinguishes between the data source (i.e., the individual) and the level of the phenomenon being measured (i.e., personal efficacy). For teachers' self-efficacy on assessment, there are three levels of concern: (1) Individual teachers' self-efficacy refers to beliefs in one's capabilities to organize and execute the courses of action required to produce a given attainment (Bandura 1997, p. 3); (2) Collective self-efficacy of the particular group of teachers and school leaders, which is argued by Goddard et al. (2000) to be an extension of individual teacher efficacy to the organization level to which an individual teacher currently belongs and are situated in; and (3) Student self-efficacy, which is both an individual and collective trait and is highly relevant regarding teachers' self-efficacy.

Multiple opportunities and time to reflect to consolidate concepts and an understanding of technology are important factors in technology learning situations. Students' self-efficacy and view of the subject being taught affect their willingness to try and to engage in learning activities. Opportunities to engage with technology anticipate the courage to try; thus, multiple opportunities to try have been identified as important factors in the learning process in technology (Benson 2012; Skogh 2001).

Estimating and appreciating one's self-efficacy inevitably involves acknowledging one's perceived personal traits, but such an appreciation is also influenced by the group dynamics of the context in which one is situated. Thus, the affordances provided – or rather, one's perception of affordances provided – influence one's self-efficacy.

Importance and Consequences of Teachers' Self-Efficacy

Because self-efficacy is influenced by beliefs and external factors, it is not always possible to predict or measure self-efficacy. An individual may have high self-efficacy in one area but not in a closely related area, and self-doubt can overrule knowledge and skill. Moreover, self-efficacy can overrule one's literacy within a field. For example, a teacher may have a strong belief in their ability to teach one content area for a group of students, and that same teacher may experience lower self-efficacy when teaching the same content area to another group of students or when teaching different content areas to the same group of students.

People with high self-efficacy – those who consistently believe they will perform well – are more likely to see challenges as something to be mastered instead of something to avoid. Self-efficacy can affect individual motivation to learn; people with high self-efficacy are more likely to make sufficient efforts to complete a task. This may lead to a greater likelihood of success; highly self-efficacious people pursue challenging tasks longer due to their strong perception of having control over their lives. However, such a view could result in highly efficacious people preparing less well for a task than those with lower self-efficacy. Less efficacious people, having incentives to accomplish their tasks, tend to view tasks as more complicated than the tasks really are. Therefore, they give up more easily or may prepare unnecessarily when faced with unfamiliar subjects or situations in which they perceive themselves as less likely to succeed. However, the increased amount of preparation that less efficacious teachers do may lead to better instruction, so students maight still gain in the end but at the same time their fixed mindset may cause them to drop out instead. However, in terms of teachers' workload, this must be under caution. Skaalvik and Skaalvik (2010) found a risk of burnout among less efficacious teachers who work too much to prepare instructional activities.

Collective Self-Efficacy: General Theory

Both individual and collective teacher's self-efficacy influences student achievement (Eells 2011; Hattie 2012, 2016; Tschannen-Moran et al. 1998). Collective efficacy fosters groups' motivational commitment to their missions, resilience to adversity, and performance accomplishments' (Bandura 2000, p. 75). Collective efficacy is dependent on context; it is not a static group trait. Rather, Bandura argues, it is an emergent group-level property and not the sum of every group member's self-efficacy. Collective efficacy is situated in the minds of group members as their beliefs in their ability as a group. Peoples' shared beliefs in their collective power to produce desired results are key ingredients in collective agency (Bandura 2000).

Teachers are influenced by the environment they are situated in and therefore, teachers' instructional efficacy could be weakened by their working conditions, such as having responsibility for many low-achieving students in socio-economically disadvantaged areas. This may lead to a negative spiral in which teachers create collective cultures whose member's demoralize the efficacy of the group. Teachers with high instructional self- and collective-efficacy operate on the belief that challenging students are teachable through extra effort and appropriate technique. Highly self-efficacious teachers are more likely to devote more time to academic activities, whereas teachers with lower self-efficacy spend more time on nonacademic activities and are not as persistent with students. Teachers with low self-efficacy believe there is nothing they can do to influence their students. When students are not making expected progress, less efficacious teachers are more likely to criticize their students' failures (Bandura 1997; Hattie 2016). Instead, teachers who view intelligence as an acquired attribute also believe their students can succeed regardless of their backgrounds, creating an atmosphere of collective group efficacy. Teachers who view intelligence as an inherited trait believe that there is not much they can do to change social conditions and do not build the collective self-efficacy of either students or colleagues (Eells 2011; Hattie 2016).

Building a strong collective ability can compensate for less efficacious individuals by providing educational arenas where teachers work together to find ways to address learning, motivation, and behavior problems of their students. Schools with this focus are more likely to enhance teachers' beliefs of efficacy (Tschannen-Moran et al. 1998). Thus, school leaders are of great importance in providing affordance for every teacher to increase their efficacy and in strengthening the efficacy of the school through organizing peer work, leading discussions for teachers, and creating connections within and between organizations (Goddard et al. 2015), which technology teachers have limited access to according to Hartell (2012), arguing that teachers are left alone to plan, execute, and follow-up and cover up for deficiencies in school organization.

Assessment as the Bridge Between Teaching and Learning

One of the greatest challenges of schooling is that learners do not learn everything they are taught. Frequent check-ups and adjustments to instruction plans are required to bridge teaching and learning. There is a strong body of evidence showing that formative assessment can cater to student learning but can also hamper learning when feedback focuses on personal traits instead of process and grit, causing lower self-esteem instead of promoting learning (Hattie 2009; Wiliam 2011). Therefore, formative assessment, where evidence of learning is used to make inferences regarding what to do next to help learners, needs to be handled gently and be firmly embedded into practice (Black and Wiliam 1998b; Wiliam 2009).

Formative assessment is part of good teaching. However, it is not the *same* as good teaching; assessment signals the importance of making inferences and acting upon information, informed decision-making. When discussing the significant impact formative assessment can have on student learning (Black and Wiliam 1998a; Hattie 2009, 2012), a crucial time factor must be considered (Black et al. 2004; Black and Wiliam 1998a; Wiliam 2009). The process of formative assessment is more likely to have a positive influence on student achievement when it falls within what Wiliam (Black and Wiliam 1998a, 2009; Wiliam 2009) called "short-cycle formative assessment," where inferences are drawn and adjustments made to better meet learners' needs within minute-by-minute or day-by-day classroom practice. This is difficult to accomplish in classroom practices. These difficulties are often forgotten in discussions regarding embedding formative assessment in classroom practice with the consequence of superficial implementation (Black and Wiliam 1998a; Moss and Brookhart 2009).

In designing teaching and learning opportunities for their students, teachers are best suited both to navigate and hold the helm starting from where the learners are and provide the necessary affordances to move them forward on their learning journey. For this to happen, teachers need to know when to push and when to hold back, using evidence of learning to adapt what happens in the classroom to best meet their students' needs in each individual context.

However, teachers cannot do this alone. The quality of leadership is of great importance in influencing efficacy by organizing the milieu in which teachers work and thereby contributing to teachers' self- and collective instructional- efficacy (Goddard et al. 2000, 2015; Hattie 2012; Pettersson 2009; Timperley 2011). Therefore, it is very important to invite school leaders from every level of the educational system to participate in providing affordances for teachers' assessment practices and embedding assessments to bridge teaching and learning.

Bridging Teaching and Learning in Technology Education

Research regarding assessment is a growing field in general and an uncharted area of the subject of technology education (Hartell 2015; Jones et al. 2013; Ritz and Martin 2012; Williams 2011, 2016).

An integral part of all teaching, including technology education, is working with formative assessment where elicited evidence is acted upon to adapt what happens next to better meet learners' needs (Black 2008). However, schools need to embed an assessment infrastructure supporting the everyday classroom practices to ensure that their students progress according to the regulations and principles that govern education within their context. Teachers need to invite students to become owners of their learning through engineering effective discussions and learning activities and by inviting students to join discussions, classroom talk, and intentional dialogues, promoting risk-taking, and incorporating mistakes as learning opportunities (Wiliam 2013). This is of particular importance in technology classrooms (Black 2008; Moreland et al. 2008, 2013; Skogh 2001).

The structure of lessons, including the embedding of formative assessments for learning, strongly influences how students approach their assignments. Stressing the importance of students being given sufficient time to explore and consolidate their thoughts and proceed with their work based on possible feedback, Benson (2012), Dakers (2007), and Kimbell (2007) highlight the importance of technology teachers ensuring sufficient time for individual reflection and peer work and allowing students to finish their tasks to their own satisfaction. Fragmented instruction and a lack of progress undoubtedly hinder students' ability to learn technology. Benson (2012), Benson and Lunt (2009), as well as Skogh (2001) all emphasize importance of sufficient time especially when working with younger students. They argue that students require opportunities to engage with technology to gain the courage to try; thus, multiple opportunities to experiment are important factors in the learning process. Emphasis on the importance of learning opportunities should not only be provided in later years of schooling, which is often the case with technology education. When investigating what criteria for success teachers' emphasizing while assessing student work, Hartell and Skogh (2015) found that teachers put most emphasize on the narrative of the design process. However, teachers cued completion of task as criteria for success, which also stress the importance of sufficient instruction time for students. Several reports have expressed concerned for the limited instruction time available for students (ASEI 2012; Hartell 2011; Skolinspektionen 2014; Swedish School Inspectorate 2009; Teknikföretagen 2005).

Kimbell (2013), Harrison (2009), and Wiliam (2011) emphasized the importance of planning assessments ahead of time instead of at the spur of the moment during classroom practice. This planning should include learning activities such as teachers and learners posing qualitative questions that are designed to elicit evidence of learning and provide information for the teacher and/or student on the next step in the learning process. It is challenging to design qualitative questions and interpret student responses and questions; teachers need both content knowledge and a firm understanding of misconceptions and the thresholds that students need to cross. This requires creativity in formulating questions that either promote thinking among learners or provide information on teachers' next steps (Black and Wiliam 2009; Hattie 2009; Leahy et al. 2005; Moreland et al. 2008; Wiliam 2009). Making inferences based on students' responses and putting them into practice by adapting classroom activities to better meet students' needs are considered fundamental in classroom formative assessment (Wiliam 2011). However, thorough planning is also demanded, both individually by each teacher and together with other professionals in a permissive atmosphere (Harrison 2009; Hartell 2012). Hence, teachers must plan their questions in advance, prepare for possible responses, and consider different options for their next steps, while also providing sufficient time for students to reflect and respond (Black et al. 2004; Kimbell 2007; Leahy et al. 2005).

Teachers should also have the self-efficacy to take action from informed decisions. The importance of discussions and reflection among teachers regarding teaching, learning, and assessment has previously been highlighted in general but also regarding the study of technology in particular (Black and Wiliam 1998b, 2009; Blomdahl 2007; Hartell 2013; Klasander 2007; Nilsson 2008, 2013; Pettersson 2009). To establish a firm understanding of formative assessment, Wiliam (2009) and Bennett (2011) stress that teachers need time and space to experiment, discuss, and reflect on their work to implement a process and mechanism for learning assessment and the thinking behind it. Through that, teachers can change their behaviors in classroom practice to better adapt to students' needs. Unfortunately, these circumstances are rare but are both needed and asked for by technology education teachers (Blomdahl 2007; Hartell 2015; Hartell and Skogh 2015).

According to Blomdahl (2007) and Hartell (2013), planning for teaching and learning is secondary for technology teachers in their current professional milieu. Instead of focusing on teaching and learning, as well as having the opportunity to discuss with other professionals, technology teachers must spend their time covering up for institutional weaknesses, such as a lack of material and other equipment as well as allocated instruction time. These restraining frame factors are shown by Skaalvik and Skaalvik to have a negative impact on teachers' self-efficacy. This is a systemic problem and not one for teachers to solve on their own, which, according to a doctoral thesis presented by Hartell (2015), is the expectation in Sweden; affordance for teachers' assessment practices must be increased to bridge teaching and learning.

Self-Efficacy on Assessment in Technology Education

Teachers' education, professional development, and jurisdiction on who is allowed to teach vary across the world. Every teacher who teaches technology is educated to do so, and many teachers express concern in teaching this subject (Nordlander 2011; Rohaan et al. 2012; Teknikföretagen 2005). Technology is a dynamic subject whose constructs change frequently; therefore, continuous professional development is an absolute necessity. Regarding assessment in technology education, individual and collective self-efficacy is highly context-bound, which is particularly important due to a lack of consensus regarding construct definition and understanding of technological knowledge among technology educators (Norström 2014). Norström emphasizes consequences for disparate instructional practices and student limited access to equity in assessment, confirmed by the Swedish School Inspectorate report (Skolinspektionen 2014), also emphasizing the lack of student limited access to instruction.

Life-long learning and development practice must be embedded into teachers' assessment practices regarding not only how well students are assessed and which tools are used but also what is assessed related to subject-specific training, focusing constructs, and pedagogy (Wiliam 2010). Such an approach would drive development of the subject and help instructors teach the subject – or rather "subjects," as technology subjects encompass a broad range and differ across nations.

Rohaan et al. (2012) investigate the possible relationships between subject-content knowledge, pedagogical-content knowledge (PCK), and the attitudes and self-efficacy of Dutch primary teachers. They show that developing subject-content knowledge and PCK among teachers will improve teachers' instructional self-efficacy, and their increased instructional self-efficacy will positively affect their attitudes towards technology education. Correspondingly, increased instructional self-efficacy and positive attitudes increase the frequency of technology education activities. This creates a virtuous cycle for primary technology teachers, where their experiences of teaching technology strengthen their PCK and subject-content knowledge, leading to increased self-efficacy, improving their attitudes toward the subject, and hopefully benefiting the quality of primary technology education.

The importance of education for teachers found by Rohaan et al. (2012) is strengthened by the research of Hartell et al. (2015), which shows significant differences in teachers' self-efficacy in assessments between Swedish teachers in comprehensive schools who are educated in the subject of technology compared with those who are not. The results from that study were based on a five-point Likert questionnaire launched among 88 respondents with different backgrounds but all working as technology teachers in compulsory school in Sweden. Results showed differences in self-efficacy for assessments among different groups of teachers who teach technology. Hartell, Gumaelius, and Swärdh find that teachers who are educated in the subject expressed greater self-efficacy in assessing their students' knowledge formatively. This is evident among those who had a teacher training degree and those who did not; educated teachers reported a significantly greater use of the national curriculum as the basis for their teaching than their peers who lacked a teacher training degree. Educated teachers who also received subject-specific education expressed greater self-efficacy than their noneducated peers in describing what is expected of their students. Teacher education, including subject-specific training, fosters self-efficacy and constructive alignment among technology teachers, especially when teachers experience both subject-specific and pedagogic training.

Rohaan et al.'s findings are concurrent with the work of Nilsson (2008, 2013) and Palmer et al. (2015) regarding science education, an area closely related to technology education. Their findings emphasize subject-content knowledge and pedagogical-content knowledge as strengthening self-efficacy among teachers. Teachers' self-efficacy regarding their instructional ability and content knowledge do not always match (Nilsson 2008). Nilsson emphasizes the importance of strengthening teachers' self-efficacy regarding both their understanding of content knowledge and their ability to teach a subject, especially the intersection between these two – that is, pedagogical content knowledge (PCK). Palmer et al. (2015) and Nilsson suggest this can be fostered when teacher-students experience and practice how to teach, e.g., field placement and courses at teacher training. Rohaan et al. (2012) also suggest that teachers themselves should have the opportunity to experience hands-on activities – teaching what they preach – to increase confidence and self-efficacy. According to their study, this involves gaining relevant subject-content knowledge and learning how to use it to engineer student learning opportunities, including pedagogical approaches relevant to technology education. Teachers should also continue to be made aware of the nature of teaching technology, which requires designing, provoking questions, and repertoires of explanations, as well as recognizing common misconceptions.

From an assessment point of view, this could be explained as the importance of embedding the five key strategies for formative assessment: clarifying and sharing learning intentions and criteria for success; engineering effective classroom discussions, questions, and learning tasks; providing feedback that progresses learners; activating students as owners of their own learning; and activating students as instructional resources for one another (Leahy et al. 2005).

According to the theory of self-efficacy (Bandura 1997), strengthened self-efficacy is a strong predictor of the increased likelihood of individuals proceeding with their assignments and instructional behavior. Rohaan et al. (2012) suggest that teaching experience increases teachers' instructional behavior, self-efficacy and their attitudes towards the subject they teach. Teachers' views of and attitudes towards the subject they teach influence both their teaching and their assessment practices (Gipps 2004; Gipps and Murphy 2010). Moreland et al. (2008) argue that assessments become problematic when teachers hold a limited view of technology and thus do not embrace the whole curriculum. Teachers tend to select the topics they believe they can teach and that are more familiar, place varying emphasis on different areas or topics of school subjects, and sometimes even ignore certain areas of a curriculum. Klasander (2007) showed this to be case when dealing with technological systems, which is an area almost completely forgotten in instruction within the Swedish setting but emphasized greatly in the Swedish national curriculum for technology (NAE 2011).

According to Hartell et al. (2015), subject-trained teachers lacking pedagogical training report using national curriculum as the basis for their teaching to a lesser extent than those with teacher education degrees, which presents a challenge for curriculum alignment and fairness in grading. That same study reports that teachers who have both subject-specific training and teaching education expressed greater self-efficacy in informing students about criteria for success as well as reporting students' level of knowledge. However, findings from this study suggest that having a teaching degree supports technology teachers' self-efficacy in grading but not as much as subject-specific training does. However, in terms of constructive alignment the authors question teachers' actual ability to award reliable grades according to a regulation. Authors' base their assumption of lack of constructive alignment from informants' responses on what they base their grading on compared with statistics of grading in the schools included in the study.

The importance of a permissive social climate in the technology classroom cannot be overstated. Classrooms should be places where students can ask questions, try out ideas, learn from their mistakes (Benson 2012; Black 2008; Moreland et al. 2008), and have opportunities to learn through instruction. Students benefit when taught by teachers who are transparent about what they expect of their learners; such practice will benefit low achievers most (Jönsson 2010). An awareness of the criteria for success instills a sense of security among students (Bandura 1997). However, criteria for success must be relevant to the particular subject topic and not, as indicated by Bjurulf (2008), as simple as teachers suggesting that students work on their own and not ask questions. Leaving students to their own un-reflective performance can be devastating, although quite common (Swedish School Inspectorate 2014).

Despite difficulties in measuring efficacy, the importance of being aware of the concept and the context dependence of self-efficacy is crucial. Fostering individual and collective efficacy via teacher education to enter the profession is just as important. However, it is more relevant to consider life-long learning among technology teachers as a group by focusing our discussions on how to make a difference for student learning in technology education.

Future Research

Despite the difficulties in measuring self-efficacy, being aware of one's self- (and collective) efficacy is important when deciding what actions to take. Students taught by highly self-efficacious teachers are more likely to have more opportunities to learn about technology than peers who are not when they are given tasks that seem to require great effort or struggle. Wiliam (2016) states that, "when one's beliefs in one's ability to succeed and follow through with plans are high, goals are like to be more ambitious and bold." When individual self-efficacy is low, small steps are likely to be more appropriate for teachers while preparing learning activities for their students. In the context of technology education, this fine balancing act is something to consider particularly carefully due to the nature of technology. Technology education often, though not exclusively, include open-ended problem solving activities with complex and audacious goals, which create space for differentiated learning activities with nondefined product outcomes.

To prepare students to become conscious creators, evaluators, and users of technology, education for all is necessary. It may be even more challenging to bridge teaching and learning regarding technology than for other subjects, as technology embraces and crosses traditional boundaries of the natural sciences, engineering sciences, social sciences, and fine arts. Teachers with a broad subject repertoire and a wide range of pedagogical skills should lead learning opportunities for students. Teachers must be assessment-literate and highly self- and collectively efficacious regarding technology, as well as devoted to growing professionally by focusing on what makes a difference for student learning. This endeavor should lead to an increased sense of agency among teachers as they build the skills necessary for providing affordance for student learning. More importantly, it should also build strong beliefs about teachers' own and joint capabilities to organize and execute the courses of action required to help every learner thrive in technology education.

Due to the dependence of context for self- and collective-efficacy, it is highly relevant to build knowledge regarding teachers' self-efficacy in assessment in technology education in particular context. A natural and sensible continuation would be to extend studies undertaken in technology education in particular contexts (e.g. Hartell et al. 2015; Rohaan et al. 2012). In order to build understanding of construct and literacy regarding different purposes of assessments, and for the sake of research in technology education, we also need to invite international comparative studies to build understanding construct definition for the subjects of technology education and in a wider international perspective support teachers' efficacy.

International collaboration regarding what teachers emphasize while assessing student work is important. Students do benefit when teachers share learning intentions and criteria for success. Teachers will need to understand how to be clear about their expectations without limiting student learning to simple facts and spoil the journey of learning. Wiliam (2016) and Hattie (2009) argue for the use of worked examples to describe requirements instead of rubrics. This chapter points toward the possible use of e-portfolios for investigating worked examples. Worked examples could serve as tools for uniting international research and constructs, sampling understanding of criteria for success, contributing to teacher education and student success. Hartell (2011) also argue for the use of worked examples as beneficial and cost-efficient way of sharing learning intentions and criteria for success among professionals.

Building on expertise regarding assessment and optimizing teacher capacity is another research avenue well worth pursuing, investigating possible use of new technologies such as digital portfolios (Cf. Stables and Lawler (2012) and chapters by Stables et al., and Kimbell in this handbook). Inviting and enabling students to capture multimodal evidence of learning is important; digital portfolios and ACJ may provide affordance to do so. It would be interesting to explore possibilities to use digital portfolios and ACJ to provide affordance for teachers' assessment practices to grow their expertise and assessment literacy. Where teachers (and why not students) –like a connoisseur of wine – taste and discuss authentic student work with peers; develop a nose for quality in technology education in an environment that provide them with opportunities to do so. Enabling educators, and learners, to listening to students' voices, reading their texts, following narratives along design tasks, watching the final products of their assignments, and witnessing narratives of design for that product – in a sense, inviting educators to classroom situations. However, assessments must be designed deliberately, targeting specific skills for specific audiences and specific purposes. For this we need a better understanding of teachers' assessment practice and construct of technology.

Unpacking teachers' assessment practices in different way, for example by using comparative judgments (Pollitt 2012) and also Kimbell and Seery & Canty in this handbook). Comparative judgments can be based on authentic evidence of learning that students are involved in documenting. The use of digital portfolios opens up possibilities for teachers to invite other professionals to participate fairly easily, and they can share student work via the Internet. Students are involved in the gathering of data, which can decrease the workload for teachers, but, more importantly, it will increase the validity of measurements, since students can choose what they want to show. However, portfolios tend to get flooded with information, which will create a need for decision-driven data collection, where we will also find what is suitable to assess, and how, and under which circumstances, which will perhaps drive teacher assessment literacy. The benefits of comparative judgment also include the possibility to collaborate and build common expertise. From my experience, teachers welcome working with e-portfolios with authentic student work and comparative judgment because – as some of my informants said – *E-portfolios and comparative judgments invites me to other colleagues' classrooms activities without too many organizational complications and helps me foster my understanding of what student work might look like.*

Technology education and engineering is often combined with science and mathematics as part of the STEM movement. We need a firmer understanding of construct, where teachers will need to know which aspects are subject-specific and which are integrative in order to increase students' capabilities and interest within this area. Teachers' self-efficacy regarding assessment will need to be strengthened to increase learning opportunities for all students. It is possible that the digital technologies mentioned previously will be a useful tool for strengthening self-efficacy among teachers. However, we shall not put focus on how and what tool to use for assessment without considering what to assess and for what purpose and who. Construct definition must come in first then the purpose and then select tool appropriately and let technology be the servant and not the driver.

Similar to Hartell and Skogh (2015), continue to investigate teachers' assessment practices during assessment activities using both comparative judgments and think-aloud-protocols, it may be possible to not only investigate but also build teachers' actual and perceived assessment literacy within different contexts. By investigating possible international consensus regarding criteria for success and progress in technology education, we can build construct clarity where learning intention are transparent which benefits all learners and especially for those struggling. This is where teachers' professional competencies can influence technology education, demanding assessment literate and self- and collectively efficacious teachers.

References

ASEI. (2012). Teknikämnet i träda. Retrieved from http://www.teknikforetagen.se/documents/utbildning/teknikamnet_i_trada.pdf

Bandura, A. (1997). *Self-efficacy. The exercise of control* (13th ed.). New York: W. H. Freeman and Company.

Bandura, A. (2000). Exercise of human agency through collective efficacy. *Current Directions in Psychological Science, 9*(3), 75–78.

Bennett, R. E. (2011). Formative assessment: A critical review. *Assessment in Education: Principles, Policy & Practice, 18*(1), 5–25. doi:10.1080/0969594X.2010.513678.

Benson, C. (2012). Conformity or diversity: Developing creativity in design and technology in the early years. In H. Middleton (Ed.), *Explorations of best practice in technology, design and engineering education* (Vol. 1, pp. 42–51). Brisbane: Griffith Institute for Educational Research.

Benson, C., & Lunt, J. (2009). Innovation and risk-taking in primary design and technology: Issues arising from the evaluation of the pilot phase of the curriculum development project "Butterflies in My Tummy". In E. Norman & D. Spendlove (Eds.), *The Design and Technology Association* *international research conference 2009* (pp. 37–46). Wellesbourne: The Design and Technology Association. Retrieved from https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/5093/1/CBensonJLunt.pdf.

Bjurulf, V. (2008). *Teknikämnets gestaltningar : en studie av lärares arbete med skolämnet teknik* (1st ed.). Karlstad. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:kau:diva-2729.

Black, P. (2008). Formative assessment in the learning and teaching of design and technology education: Methods and techniques. *Design and Technology Education: An International Journal, 13*(3), 19–26.

Black, P., & Wiliam, D. (1998a). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice, 5*(1), 7–74. doi:10.1080/0969595980050102.

Black, P., & Wiliam, D. (1998b). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan, 80*(2), 139–148. doi:10.1002/hrm.

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability, 21*(1), 5–31. doi:10.1007/s11092-008-9068-5.

Black, P., Harrison, C., Lee, C., Marshall, B., & Wiliam, D. (2004). Working inside the black box: Assessment for learning in the classroom. *Phi Delta Kappan, 86*(1), 8–21. Retrieved from http://www.questia.com/PM.qst?a=o&se=gglsc&d=5007120502.

Blomdahl, E. (2007). *Teknik i skolan: en studie av teknikundervisning för yngre skolbarn*. Stockholm: HLS förlag. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-6868.

Dakers, J. R. (2007). Incorporating technological literacy into classroom practice. In M. de Vries, R. Custer, J. Dakers, & G. Martin (Eds.), *Analyzing best practice in technology education* (pp. 125–137). Rotterdam: Sense Publisher.

Eells, R. J. (2011). *Meta-analysis of the relationship between collective teacher efficacy and student achivement*. Chicago: Loyola University.

Gipps, C. (2004). *Beyond testing. Towards a theory of educational assessment*. London/New York: The Falmer Press.

Gipps, C. V., & Murphy, P. (2010). *A fair test? Assessment, achievement and equity.* Buckingham: Open University Press.

Goddard, R. D., Hoy, Wayne, K., & Woolfolk Hoy, A. (2000). Collective teacher efficacy: Its meaning, measure, and impact on student achievement. *American Educational Research Journal, 37*(2), 479–519.

Goddard, R., Goddard, Y., Sook Kim, E., & Miller, R. (2015). A theoretical and empirical analysis of the roles of instructional leadership, teacher collaboration, and collective efficacy beliefs in support of student learning. *American Journal of Education, 121*(4), 501–530. doi:10.1086/681925.

Harrison, C. (2009). Assessment for learning. A formative approach to classroom practice. In A. Jones & M. deVries (Eds.), *International handbook of research and development in technology education* (pp. 449–459). Rotterdam: Sense Publishers.

Hartell, E. (2011). Hur sätter man betyg i teknik? In S.-O. Hansson, E. Nordlander, & I.-B. Skogh (Eds.), *Teknikutbildning för framtiden- perspektiv på teknikundervisningen i grundskola och gymnasium* (pp. 75–87). Stockholm: Liber AB.

Hartell, E. (2012). *The inefficient loneliness. A descriptive study about the complexity of assessment for learning in primary technology education*. Stockholm: Royal Institute of Technology.

Hartell, E. (2013). Looking for a glimpse in the eye: A descriptive study of teachers' work with assessment in technology education. In I.-B. Skogh & M. J. De Vries (Eds.), *Technology teachers as researchers: Philosophical and empirical technology education studies in the Swedish TUFF research school* (1st ed., pp. 255–283). Rotterdam: Sense Publishers.

Hartell, E. (2015). Assidere necesse est: Necessities and complexities regarding teachers' assessment practices in technology education. KTH Royal Institute of Technology. Retrieved from http://www.diva-portal.org/smash/get/diva2:788413/INSIDE01.pdf.

Hartell, E., & Skogh, I.-B. (2015). Criteria for success: A study of primary technology teachers' assessment of digital portfolios. *Australasian Journal of Technology Education, 2*(1). doi:10.15663/ajte.v2i1.27.

Hartell, E., Gumaelius, L., & Svärdh, J. (2015). Investigating technology teachers' self-efficacy on assessment. *International Journal of Technology and Design Education, 25*(3), 321–337. doi:10.1007/s10798-014-9285-9.

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. London: Routledge.

Hattie, J. (2012). *Visible learning for teachers maximizing impact on student learning*. Exeter: Routledge.

Hattie, J. (2016). Shifting away from distractions to improve Australia's schools: Time for a reboot Jack Keating memorial lecture. In Jack Keating Memorial Lecture (p. 24). Melbourne: University of Melbourne. Retrieved from http://education.unimelb.edu.au/__data/assets/pdf_file/0008/1993904/Deans-lecture-June-2016-Jack-Keating-lecture.pdf.

Jones, A., Buntting, C., & Vries, M. J. (2013). The developing field of technology education: A review to look forward. *International Journal of Technology and Design Education, 23*(2), 191–212. doi:10.1007/s10798-011-9174-4.

Jönsson, A. (2010). *Lärande bedömning*. Malmö: Gleerups.

Kimbell, R. (2007). Assessment. In M. de Vries, R. Custer, J. Dakers, & G. Martin (Eds.), *Analyzing best practices in technology education* (pp. 247–258). Rotterdam: Sense Publishers.

Kimbell, R. (2013). Understanding assessment, its importance; its dangers; its potential. In J. P. Williams (Ed.), *Technology education for teachers* (Vol. 7, 1st ed., pp. 137–166). Rotterdam: Sense Publishers.

Klasander, C. (2007). *Talet om tekniska system: förväntningar, traditioner och skolverkligheter*. Norrköping: Institutionen för samhälls- och välfärdsstudier. Linköpings universitet.

Leahy, S., Lyon, C., Thompson, M., & Wiliam, D. (2005). Classroom assessment: Minute by minute, day by day. *Educational Leadership, 63*, 18–24. Retrieved from http://nj.gov/education/njpep/classroom/arts_assessment/worddocs/ClassroomAssessment.pdf.

Moreland, J., Jones, A., & Barlex, D. (2008). *Design and technology inside the black box assessment for learning in the design and technology classroom*. London: GL Assessment.

Moreland, J., Cowie, B., & Otrel-Cass, K. (2013). *Expanding notions of assessment for learning inside science and technology primary classrooms* (online). Sense Publishers. doi:10.1007/978-94-6209-061-3.

Moss, C. M., & Brookhart, S. M. (2009). *Advancing formative assessment in every classroom: A guide for instructional leaders*. Alexandria: Association for Supervision & Curriculum Development (ASCD).

Nilsson, P. (2008). *Learning to teach and teaching to learn primary science student teachers' complex journey from learners to teachers*. Norrköping: Linköping university.

Nilsson, P. (2013). What do we know and where do we go? Formative assessment in developing student teachers' professional learning of teaching science. *Teachers and Teaching, 19*(2), 188–201. doi:10.1080/13540602.2013.741838.

Nordlander, E. (2011). Vad tycker teknikläraarna? In S.-O. Hansson, E. Nordlander, & I.-B. Skogh (Eds.), *Teknikutbildning för framtiden -perspektiv på teknikundervisning i grundskolan och gymnasium* (pp. 90–102). Stockholm: Liber AB.

Norström, P. (2014). How technology teachers understand technological knowledge. *International Journal of Technology and Design Education, 24*(1), 19–38. doi:10.1007/s10798-013-9243-y.

Palmer, D., Dixon, J., & Archer, J. (2015). Changes in science teaching self-efficacy among primary teacher education students. *Australian Journal of Teacher Education, 40*(12), 26–40. doi:10.14221/ajte.2015v40n12.3.

Pettersson, A. (2009). Bedömning- varför, vad och varthän? In L. Lindström & V. Lindberg (Eds.), *Pedagogisk bedömning* (2nd ed., pp. 31–42). Stockholm: Stockholm universitets förlag.

Pollitt, A. (2012). The method of adaptive comparative Judgement. *Assessment in Education: Principles, Policy & Practice, 19*(3), 281–300. doi:10.1080/0969594X.2012.665354.

Ritz, J. M., & Martin, G. (2012). Research needs for technology education: An international perspective. *International Journal of Technology and Design Education, 23*(3), 767–783. doi:10.1007/s10798-012-9215-7.

Rohaan, E. J., Taconis, R., & Jochems, W. M. G. (2012). Analysing teacher knowledge for technology education in primary schools. *International Journal of Technology and Design Education, 22*(3), 271–280. doi:10.1007/s10798-010-9147-z.

Skaalvik, E. M., & Skaalvik, S. (2010). Teacher self-efficacy and teacher burnout: A study of relations. *Teaching and Teacher Education, 26*(4), 1059–1069. doi:10.1016/j.tate.2009.11.001.

Skogh, I.-B. (2001). Teknikens värld - flickors värld: en studie av yngre flickors möte med teknik i hem och skola. Retrieved from http://libris.kb.se/bib/8375742?vw=full.

Skolinspektionen. (2014). Teknik – gör det osynliga synligt Om kvaliteten i grundskolans teknikundervisning. Stockholm.

Stables, K., & Lawler, T. (2012). *Assessment in my Palm: E-scape in Israel evaluation of phase 2*. London: Goldmiths, University of London.

Stiggins, R. J. (1991). Assessment literacy. *Phi Delta Kappan, 72*(7), 534–539.

Swedish School Inspectorate. (2009). Skolinspektionsmyndigheten (Swedish School Inspectorate). Retrieved from http://www.skolinspektionen.se/Documents/Rapporter/Mora_Inspektionsrapport.pdf?epslanguage=sv.

Teknikföretagen. (2005). *Alla barns rätt till teknikundervisning*. Stockholm: Teknikföretagen.

The Swedish National Agency for Education (Statens Skolverk). (2011). Curriculum for the compulsory school, preschool class and the recreation centre, 2011. Sweden. Retrieved from http://www.skolverket.se/publikationer?id=2687.

Timperley, H. (2011). *Realizing the power of professional learning*. Chippenham: Open University Press.

Tschannen-Moran, M., Woolfolk Hoy, A., & Hoy, W. K. (1998). Teacher efficacy, its meaning and measure. *Review of Educational Research, 68*(2), 202–248.

Webb, N. L. (2002). Assessment literacy in standard-based urban education setting. In *Annual meeting of the American Educational Research Association* (pp. 1–20). New Orleans: American Educational Research Association. Retrieved from http://facstaff.wcer.wisc.edu/normw/AERA 2002/Assessment literacy NLW Final 32602.pdf.

Wiliam, D. (2009). *Assessment for learning: Why, what and how? An inaugural professorial lecture by Dylan Wiliam*. London: Institute of Education University of London.

Wiliam, D. (2010). What counts as evidence of educational achievement? The role of constructs in the pursuit of equity in assessment. *Review of Research in Education, 34*(1), 254–284. doi:10.3102/0091732X09351544.

Wiliam, D. (2011). What is assessment for learning? *Studies in Educational Evaluation, 37*(1), 3–14. doi:10.1016/j.stueduc.2011.03.001.

Wiliam, D. (2013). Feedback and instructional correctives. In J. H. McMillan (Ed.), *SAGE handbook of research on classroom assessment* (Vol. 1, pp. 197–214). Thousands Oaks: SAGE Publications.

Wiliam, D. (2016). *Leadership for teacher learning. Creating a culture where all teachers improve so that all students succeed* (1st ed.). West Palm Beach: Learning Sciences International.

Williams, P. J. (2011). Research in technology education: Looking back to move forward. *International Journal of Technology and Design Education, 23*(1), 1–9. doi:10.1007/s10798-011-9170-8.

Williams, P. J. (2016). Research in technology education: Looking back to move forward . . . again. *International Journal of Technology and Design Education, 26*(2), 149–157. doi:10.1007/s10798-015-9316-1.

Part VII

Social and Ethical Issues

Social and Ethical Issues in Technology Education: Section Introduction

56

Steve Keirl

Abstract

This chapter summarizes the five chapters featured in part "Social and Ethical Issues" in the Handbook of Technology Education.

Keywords

Western dominance • Holism • Industry • Technology communication • Gender

Contents

Introduction

This section of the handbook presents a few of the many social and ethical issues with which the field of (Design and) Technology Education [(D&)TE] finds itself entangled. I say "entangled" because these issues apply strongly within the field yet reach far beyond it. A major educational challenge involves weighing up how to integrate such issues in educationally valid ways into a complex and crowded curriculum. Since the curriculum (at least in democratic societies) is to serve individuals, society, and, increasingly, the global good alike then that challenge is significant. There are nuanced questions to be explored around why something is an issue, why we should engage with it as a profession, and how we might explore it in meaningful ways with our students.

S. Keirl (✉)
Goldsmiths, University of London, London, UK
e-mail: s.keirl@gold.ac.uk

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_74

There are two ways that “issues” might be understood here. First, we can consider issues to be *matters about which people have concerns*, and, second, issues *come from a context*; they *issue from* or out of some prior source or phenomenon. Technologies themselves are one of the great sources of social and ethical issues in our world simply because they intertwine our lives. It is because technologies are never neutral (Feenberg 2002) and because designers’ intentions can never guarantee intended outcomes (Ihde 2006) that close examination of the phenomenon of technologies in the world illuminates how they are, in fact, controversial (Keirl 2012). Where there is technology, there are concerns. However, focussing on technologies and their progenitors is only one perspective. When people have concerns about something, those concerns are informed by personal sets of values, by social norms, and by ethical standpoints. Thus, differing values frameworks inform differing value judgments and where values dissonance exists then issues arise.

It is also important to understand how social and ethical issues arise when change occurs. Significant values differences can emerge when change is proposed, when ways of living are challenged, or when senses of injustice are aroused, and this is as true of technologies as it is of life in general. Whether by subtle or explicit means, emergent technologies and systems alter lives and societies; and tensions arise when unknown futures begin to present themselves. There are educational opportunities for values interrogation and ethical reflection at any phase of a technology’s emergence – whether at its mere conception in someone’s mind; in its design phase, during processes of manufacture; in how, when, and why it is used; and in the consequences of its existence (Keirl 2009).

How, then, do we bring to education these general observations about the social and ethical issues that accompany technologies as they intertwine with our lives? Clearly, the responsibility cannot lie with (D&)TE alone. Equally, (D&)TE cannot deny responsibility toward playing a role in such an education. Two points need to be made here. Firstly, if (D&)TE is conceived narrowly as a specialized subject in the curriculum, it will have great difficulty addressing social and ethical issues within such confines. Here, (D&)TE is reconceptualized not only as a subject but also as a contributor to the general education of all students as some form of technological literacy. Secondly, because the social and ethical issues that accompany technologies entangle both (D&)TE and society at large, we can see that other subjects and other literacies can contribute to students’ understanding and learning. As the following chapters show, the issues that each engages interweave the curriculum in many ways. There are threads that bring the chapters together because of their distinct focus on (D&)TE, but the authors also show how these threads reach across general education too. These chapters not only present significant (D&)TE research, but, in doing so, they show (D&)TE’s positive engagement with what are major challenges for education and societies alike.

Mishack Gumbo offers a comprehensive critique of the issues that arise from the damaging dominance of Western educational practices and their displacement of indigenous knowledge systems. Here we witness how nobody wins when rich forms of knowledge and ways of knowing are undervalued and marginalized. In such circumstances, the cultures and the ways of learning of both dominant and dominated are devalued. Gumbo brings together rich perspectives, international research, and best practice to bear on what is a challenging problem for (D&)T educators. The Western model of a compartmentalized curriculum does not sit well with the deep holism of indigenous learning just as many senses of globalization cannot accommodate holistic ways of being in the world. Nonetheless, Gumbo shows the potential for scholars, teachers, and communities to work together to bring positive change by presenting practical pedagogical strategies to achieve holistic and integrated (D&)T curriculum models.

The matter of holistic curriculum approaches is also engaged by Margarita Pavlova when she suggests a holistic and multifaceted approach for (D&)TE to play its part in advancing the 16 Sustainable Development Goals of the United Nations (2015). Key to achieving a globally sustainable future is *values transformation* which she recognizes as offering particular challenges to (D&)T educators. She points to the curriculum challenge for (D&)TE of embracing not only sustainability problem-solving by "technical fix" but also the need for "value change" to help develop young people as responsible citizens. Pavlova also argues that local contexts must be understood and that the curriculum challenges for (D&)TE in one country will differ from those of another. She elaborates the pedagogical issues that accompany such challenges and illustrates the kind of pedagogical repertoire that may be drawn upon to achieve sustainability goals. As with all issues-based curricula, Pavlova calls for sustainability to be a whole-school concern.

Gabriele Graube and Ingelore Mammes outline the phenomenon of "Industry 4.0" and the "...increasing interlinking of production and information as well as communications technology." Their chapter points to the omnipresence of digitalization and its influence on design, technology, and society alike. A particular education is needed for understanding what it means for each of us to be actors in multiple socio-technological systems, and (D&)TE surely has a role to play here. The authors offer valid reflections on industry – whether as system component, as source of employment, or as itself a rapidly changing entity – and they argue for closer rapport between industry and schools in advancing understandings of the digital dimension of (D&)TE. Once more, the issues are of real concern for all players – for the individual who must locate themselves within increasingly complex socio-technological systems, for the curriculum and its delivery, and for society at large which finds itself in an unprecedented form of ongoing change.

The bringing together of technology education and technology communication into a *braid* is the focus of the contribution from Maarten van der Sanden, Dury Bayram-Jacobs, and Giovanni Stijnen. These authors face the realities of the complex ways that technologies and people interact, and they present the case for (D&)TE's role in supporting social learning to advance responsible research and innovation. They, too, argue for a holistic approach to (D&)TE that engages professionals and scholars in working for the benefit of individuals, society, and innovation alike. Van der Sanden et al. discuss innovation, social learning, ethics, and technology communication along with notions of distributed ideas, beliefs, and learning. Their discussion underpins two recent successful projects as examples of transformative practices that break disciplinary boundaries to advance the goal of social ecosystems of distributed learning.

Some of the issues in this section of the handbook address emergent phenomena, but the issue of gender is not new to the field. As Sonja Niiranen shows, this perennial issue remains a major concern for (D&)TE. This is not to say that things aren't changing because she evidences some good news in employment fields along with ongoing challenges. Her study celebrates the many strategies that are available to schools and teachers as well as the necessity for political and social commitment to confront the ongoing gendered relations that exist with technologies. Once more, this is a matter for whole-school and societal action, but this does not mean that (D&)T educators don't have a significant role to play in meeting the challenge. Niiranen shows clearly that curriculum arrangements, teacher attitudes, and pedagogical strategy can all make real differences – not least when difference and diversity are celebrated through technological literacy, creativity, and innovation.

Conclusion and Future Directions

Collectively, these chapters present rich and necessary (D&)TE research. They embrace holism, curriculum integration, and interdisciplinary approaches into very real matters of concern – issues. The chapters are not exclusive. Many other concerns and issues await research and integration into (D&)TE curricula. The reach of such issues stretches from the lives and education of individual students out across society into the world beyond and back again. It is not the role of (D&)TE to "solve" these "problems." Rather, the sample of issues addressed here shows how (D&)TE can play a role in contributing to better worlds in empathetic and meaningful ways.

References

Feenberg, A. (2002). *Transforming technology: A critical theory revisited*. Oxford: Oxford University Press.

Ihde, D. (2006). The designer fallacy and technological imagination. In J. R. Dakers (Ed.), *Defining technological literacy: Towards an epistemological framework* (pp. 121–131). Basingstoke: Palgrave MacMillan.

Keirl, S. (2009). Seeing technology through five phases: A theoretical framing to articulate holism, ethics and critique in, and for, technological literacy. *Design and Technology Education: An International Journal*, *14*(3), 37–46. http://jil.lboro.ac.uk/ojs/index.php/DATE/article/view/1274/1239

Keirl, S. (2012). Technology education as "controversy celebrated" in the cause of democratic education. In T. Ginner, J Hallström, & M. Hulten (Eds.), *Technology education in the 21st century: Proceedings of the PATT 26 conference, Stockholm, Sweden, 26–30 June, 2012* (pp. 239–246). Linköping Electronic Conference Proceedings No 73, Linköping University, Sweden. http://www.ep.liu.se/ecp/073/028/ecp12073028.pdf

Rethinking Teaching of Technology: An Approach Integrating Indigenous Knowledge Systems

57

Mishack T Gumbo

Abstract

The significance of indigenous knowledge systems (IKS) lies in how they can enrich technology education (TE) and its teaching. This significance is shown through the indigenous students' knowledge which can also benefit all other students, IKS' contribution toward alternative ways to manipulate the environment for sustainable development, and, teaching and learning strategies. Therefore, this significance creates a need for the integration of IKS in TE, rather than keeping to the dominant conventional approach. This chapter argues for this integration and backs this argument with culturally relevant teaching (CRT) and the framework for the teacher practice. A modified Seemann's Technacy Framework (STF) which can be used to facilitate this integration is suggested ultimately.

Keywords

Integration • Technology • Technology Education • Indigenous Technology • IK Systems

Contents

M.T. Gumbo (✉)
Department of Science and Technology Education, University of South Africa, Pretoria, South Africa
e-mail: gumbomt@unisa.ac.za

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_58

Introduction

Indigenous knowledge systems (IKS) are the "dynamic, complex human systems comprising experiences of trial and error, practical wisdom, applied knowledge and historically acquired experiences, embedded and shared locally through collective structures and diverse learning modes" (Mudaly and Ismail 2013, p. 181). To a larger extent, IKS can be regarded as technology for their practical nature (Grenier in Robyn 2002, p. 199; Kimbell 2008, p. 9). Hence, in this chapter the meaning of IKS includes indigenous technology.

TE and its teaching promotes a western approach to the TE subject (Gaotlhobogwe 2012) much to the detriment of non-western or indigenous students' learning. It is easier to understand this because TE was conceptualized and promoted by western scholars. Unfortunately, this underrepresents indigenous contexts where TE and technology students from indigenous and multicultural contexts are underserved by this approach. The nonindigenous students are also denied the opportunity to learn other forms of technology, indigenous technology in this chapter, to be specific. Thus, this chapter provides an indigenous perspective to the teaching of TE. Ogunniyi (2007), echoed by Mundaly and Ismail (2013, p. 181), argues that science as a school subject is characterized by a parochial conceptualization compared to the holistic, plural, redemptive views of human experiences promulgated by IKS. This argument is true for TE as well. Indigenous technology should therefore find space in TE. In most cases, everything that indigenous students see in classrooms and curriculum is western, and thus they are confronted by a task of negotiating their way into it (Shipp 2013, p. 24). Shipp writes that if these students cannot fit, they disengage. Rains (1999, p. 328) contests:

> When we fail to include sophisticated understandings of IK in the curriculum, when we fail to teach well, when we fall prey to historical amnesia, when we buy into the contemporary intellectual authority, we are granting jurisdiction over complacency within the status quo.

Shipp (2013, p. 24) contends that "it makes a difference to Australian Aboriginal students when they see themselves, their cultures, their histories and communities reflected on the walls and in the hallways of their school." In fact, this reflection should not be confined to a display but be part of the curriculum and teaching. This might have something to do with exploring the meaning of the concepts taught to students from indigenous and nonindigenous contexts. For example, Bevan et al. (2010) report a study in which two teachers at Broome Secondary School in Australia described a learning sequence about a narrative taught to a mixed class, i.e., indigenous and nonindigenous students. These teachers began by asking indigenous students about the meaning of a story. The students' answers included things such as family, law, truth, country, painting, sculpture, elders, and links to other stories and told orally. The nonindigenous students' responses were fiction, for entertainment, written in books, lots of details, and descriptions, and anybody can create.

According to Owusu-Ansah and Mji (2013, p. 1), knowledge cannot be divorced from a peoples' history, cultural context, and worldview. That is why students' understanding of the content and their responses to the teachers' questions differ, but both indigenous and nonindigenous students can benefit from how the content and concepts are explained from their contexts. That is however only possible if teachers can begin to think indigenously about their teaching, not westernly only. There is paucity of research on the integration of IKS in the teaching of technology. This chapter, in the first instance, advances an argument that TE does not integrate IKS. Next, the chapter contests the integration of IKS. Then the relevance of CRT for the integration is discussed. STF is suggested as a framework which can facilitate the integration of IKS in TE ultimately.

Western Knowledge Systems (WKS) and IKS

IKS have always been perceived through the western thought until recently. In the 1300s, for example, when the IKS paradigm emerged in Europe, they were suspected of superstition, witchcraft, or folk belief (Roland 2016). The fifteenth century explorers, colonists, and missionaries, who for the first time encountered indigenous groups outside of Europe, gave a false description of IKS. They referred to them as riches which deserved to be commodified, heretical beliefs which had to be eradicated, or even valuable insights which facilitated life in new and different environments (Roland 2016). In the context of the new theories of selection and evolution which are supported by classical economic theory, IKS were then regarded as primitive compared to WKS which were regarded as evolved or civilized. It was from this frame of the understanding of IKS that the science and economic theory elevated WKS above IKS – claimed WKS to be individually created and owned – and they could thus be bought or sold. But Roland (2016) presents a different view about IKS compared to WKS: It was claimed that IKS are subjective and based on observation, whereas WKS are objective and based on replicable experimentation; IKS are holistic in the sense that knowledge and value are inseparable because values codify human behavior, whereas WKS are fragmented and value free; indigenous societies generally regard themselves as part of nature, whereas western societies see themselves separate from the nature; IKS are time and space situated and ground people in place and encourage collective learning, whereas WKS promote mobility, specialization, and individual learning. The attitude of elevating WKS above IKS created a rivalry between them instead of acknowledging and celebrating their differences and similarities. For example, experts increasingly argue that even western knowledge, which is traditionally perceived as science, is not value free

(Compton and Jones 2004; Roland 2016), which provides to explore the synergy between it and IK. TE stands to benefit from this integration for the sake of students.

The sidelining of IKS triggered the women and human rights movements of the eighteenth to twentieth century. These movements, which focused on the interdependence of society and nature, voiced concerns about the social, environmental, and economic issues prompted by a history replete with environmental degradation and numerous wars (Roland 2016). They advanced the IKS paradigm which is about uniquely offering alternative means of understanding the world (Roland 2016). Many anthropologists and ecologists began to view traditional environmental knowledge as a means to understand the complex systems, giving rise to recognizing the value of IKS even more – this sparked the integration of IKS into the educational curricula and development efforts (Roland 2016). It is thus a logical fact that TE and its teaching should honor the efforts to integrate IKS.

In educational curricula efforts, however, it is important to recognize how IKS work, which have a fundamental bearing on the pedagogical imperatives. Roland relates the snapshot of these imperatives. According to Roland (2016), IKS are primarily transmitted orally and kinaesthetically – the young observe their elders and replicate their behavior. IKS and values are also transmitted through symbols, designs, games, music, and dance. All knowledge is not shared by all members of the society as some of it is regarded sacred; knowledge is age based as well – young people rely on the knowledge of more experienced and wise elders. Knowledge is also not equally distributed or equally produced as that may be determined by the societal roles, gender, or class. These determine knowledge sources and domains. Considering gender, for example, women normally undertake reproductive, productive, and community management activities, while men undertake productive activities and are involved in community politics. Technology teachers should thus be on the alert of the pragmatic views which students bring from their respective environments, which are prompted by kinaesthetics, and allow them space to orally narrate their complexities. Teachers should hone in students' design skills which relate to their technological milieus. Connection with communities, especially the elderly, should be considered as a resource for teaching while drawing from the domains of technological knowledge as expressed in such communities.

Technological solutions heavily connect with the environment. In the process much havoc is caused on the environment. Thus, the teaching of technology should in a way be a sustainable development and conscientization project with care taken that it is not detached from the cultural imperatives for the sake of benefiting future societies. According to Pavlova (2006), TE is instrumental in addressing education for sustainability with relevance to context and culture being important.

Teaching for Sustainable Development

The fact that conventional technological activities threaten the environment is reason for concerns about environmental depletion. This raises a need to teach for sustainable development. According to Roland (2016), sustainable development as a concept "can be traced back to the 1972 Stockholm *Conference on the Human Environment* and to the 1980 *World Conservation Strategy.*" This concept featured in the Bruntland Commission Report entitled *Our Common Future*. The Brundtland Commission defines sustainable development as "the ability to make development sustainable–to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (Kates et al. 2005, p. 10). Sustainability has been the issue of international discussion since early 1980s (Pavlova 2006, p. 42). Sustainable development is made up of two important words, *sustainability* and *development*. Sustainability is about nature (earth, biodiversity, ecosystems) and life support (ecosystem services, resources, environment) and community (cultures, groups, places), while development is about developing people (child survival, life expectancy, education, equity, equal opportunity) and economy (wealth, productive sectors, consumption) and society (institutions, social capital, states, regions) (Kates et al. 2005). But the United States "contested the call for the more affluent to adopt lifestyles within the planet's ecological means" (Roland 2016). It refused to sign the Kyoto Protocol and convention on Biological Diversity, as well as contested the evolving definition of sustainable development (Roland 2016). From an education point of view, this refusal can be understood as a reaction to the preference of bio-solutions to environmental problems, which suggest IKS as viable alternatives. This is corroborated by Pavlova (2006) when she claims that the fact that sustainability implicates ethics or values makes its acceptance more difficult. By implication, therefore, the integration of IKS in TE is faced with challenges to support sustainable development. On the contrary, the holistic nature of IKS can support the students in terms of their critical views and attitudes toward the environment and thus become sensitive engineers, architects, and artisans.

TE Curriculum and Teaching is Devoid of IKS Integration

The approach to TE and its teaching is being criticized for having been influenced by WKS (Williams 2000; Hoppers 2002; Emeagwali 2003). Knowledge (which is mostly referred to as science) in western contexts has become an ideology (Volmink 1998, p. 62) both as a discipline and method of treating knowledge. Worldwide, science and TE are paraded as essential prerequisites for modernization and economic development (Naidoo and Savage 1998, p. xiii). As such, science is treated as a universal phenomenon and is thus blamed for suppressing IKS.

In this sense, the technological design model (identify the problem/need/want, formulate a design brief, investigate/research, generate possible solutions, select optimum option, develop chosen solution, make, communicate, evaluate, and redesign if necessary) is a replica of the scientific investigation approach. Williams (2000, p. 50) states in this regard that the reductionist approach as an essential of science has taken advantage of TE. Though the idea is to engage the design model in a cyclical manner, technology teachers often teach it linearly. This scientific approach does not represent the way technology is practiced in real contexts (Williams 2000; Fleer 2015). Williams (2000, p. 49) argues that students "invent a process as they proceed toward task completion." This implies that framing students' thinking in the prescribed design process limits their creativity which is informed by their contexts and/or worldviews. Williams (2000, p. 50) declares that TE is more than the accomplishment of a set of process steps. This is so because the outcome of a design or solution to a problem involves more variables than can be represented in a sequence of process steps (Williams 2000, p. 50). TE should thus observe other multiple realities evident in students' knowledge and their contexts.

To illustrate the complexity of a design from an indigenous context, a design and construction of a dhow at a beach site in Zambia was observed being done without drawings (Kimbell 2008). The builders demonstrated their knowledge of the strength of timber and techniques to shape and fix it under the guidance of experienced elderly men. It is on the basis of sidelining alternative knowledge and perspectives such as this that TE is being criticized for its marginalizing effect on IKS. Though efforts are made to consider IKS such as in England and Wales, Eggleston (1992, p. 64) notices a lack of commitment to the declaration of Design & Technology Working Group in its report, which states:

> Cultural diversity has always been a feature of British life. . .[providing] a richer learning environment for all. . .the teaching of design and technology will require perceptiveness and sensitivity from teachers [to take account of] different beliefs and practices, especially when food, materials and environmental designs are involved. . .there are rich opportunities here to demonstrate that no one culture has the monopoly of achievements in design and technology.

In the United States, Custer (1995) contends that to deny multicultural perspectives in the study of technology is to fail to engage students in the importance of culture which affects them daily. Custer is backed by Wicklein (1997, p. 4), who argues:

> To deny our technology education students a chance through the curriculum to delve into contrasting cultures of the past and present is pure tunnel vision as technology is relative to time and culture.

These criticisms suggest alternative ways to TE. For instance, Mavhunga (2008) declares that integrating the native Zimbabweans' indigenous knowledge (IK) into the conventional curriculum would enhance such curriculum's relevance and better understanding of concepts. Zengeya-Makuku et al. (2013) add that IK integration can connect what students learn at school with their daily lives at home. A space should thus be found for IK in what Emeagwali (2003) calls the current Eurocentric curriculum. According to Zengeya-Makuku et al. (2013), IK has great scope and implications for curriculum and pedagogy – among other things, agricultural practices, soil conservation, water management techniques, animals and animal diseases, botany, human health, and craft skills offer scope for subject content (Zengeya-Makuku et al. 2013; Gumbo 2015). On the other hand, storytelling, anecdotes, improvisation, indigenous games, and the use of specialist resource persons (Grenier in Robyn 2002; Gumbo 2016a) offer pedagogical strategies which could enrich the current conventional ones. In this regard, Demmert (2001) writes that teachers should engage students in authentic and purposeful problem-solving as well as in investigating key concepts embedded in culturally relevant knowledge and tasks. Demmert (2001), corroborated by Gumbo (2003), argues that students are more motivated to learn when their culture is valued in the classroom. Zengeya-Makuku et al.'s (2013) study surveyed 100 Zimbabwean secondary school teachers' conceptions of IK in 8 randomly sampled schools in Harare. Their study revealed teachers' adequate understanding of IK (p. 446). They thus suggest that in order to improve learning, teachers should draw from students' local knowledge and language to illustrate concepts. They also suggest further research into content and pedagogy of infusing IK into the curriculum, which is the mission of this chapter. Zengeya-Makuku et al.'s (2013) recommendation to involve IK and language should actually not end with illustrating concepts only, but it should be used throughout the teaching of technology. This chapter suggests an integrated approach and thus heeds the recommendation made. Certain relevant frameworks are worth considering which can facilitate the integration in question especially in the teaching of technology.

Frameworks for Integrating IKS in TE

The deliberations in the previous section create a need to integrate IKS in TE. Mudaly and Ismail (2013) declare: "…all knowledge systems not rooted in the western mode of thinking are naturally subaltern" (p. 178), in that "colonial education was transmitted in a way that stifled engagement with a gamut of different epistemologies" (p. 179). While Mudaly and Ismail (2013) acknowledge that IKS have made inroads into the critical pedagogy theory, and that indigenous methodologists vociferate in favor of the oppressed and colonized persons living in postcolonial situations of injustice, these authors claim that IKS are still developing and thus require more sustained research into school and university curriculum. There is therefore a lot to learn in IKS especially when considering the fact that they are characterized by holism in their relation to nature. One really believes that they still have a large scope to research and exploit. It is uneasy for one to subscribe to the notion of IKS being confined in the past. What is needed, rather, is to stretch our thinking as far back as the histories of their custodians – how they lived and continue to live their lives, their human activities and how they perceived and continue to perceive the world, and their relationship to it. That will help to enhance the students' understanding of IKS and unquestionably accept their evolution – more so if what they bring (knowledge) into the learning situation is recognized (Buntting et al. 2015). In education this suggests that the marginalization of IKS in TE, apparently because IKS are alleged to be inadequate and primitive, cannot be justified.

A western-based curriculum is foreign to what Mudaly and Ismail (2013) call autochthons (i.e., indigenous people) so much that the postcolonial era has critiqued the curriculum (p. 179) for being a means to "cultural superiority, ideological indoctrination, power and control over others" (Kanu 2006, p. 9). This has created a need to integrate IKS epistemologies even though there is still resistance to some extent. There has been a commitment in certain contexts such as Australia, Canada, and African contexts especially those with colonial experience such as South Africa, Botswana, and Namibia, to infuse policy imperatives to ensure the integration of IKS epistemologies. In South Africa, for example, the Curriculum and Assessment Policy Statement (CAPS) promotes the grounding of knowledge in local contexts. Specifically, the CAPS encapsulates the IKS principle stated thus "Valuing IK systems, acknowledging the rich history and heritage of this country as important contributors to nurturing the values contained in the Constitution" (Department of Basic Education (DBE) 2011, p. 3). The third specific aim of CAPS for technology, to "appreciate the interaction between people's values and attitudes, technology, society and the environment" (DBE 2011, p. 10), implicates IKS, which is stated thus:

> Wherever possible, students should be made aware of different coexisting knowledge systems. They should learn how indigenous cultures have used specific materials and processes to satisfy needs, and become aware of indigenous intellectual property rights (DBE 2011, p. 10).

But this statement seems to be all that the CAPS Technology says about IKS. Disappointingly, the statement makes IKS even more vulnerable by using phrases which make sheer reference to IKS, i.e., "where possible," "made aware," "become aware," and "have used," which restrict IKS to the past only. Gumbo (2016a, b) gives full account of this criticism elsewhere. This treatment of IKS compromises the commitment to teach about them and does not recognize their evolutional reality. No wonder, teachers report that they receive minimal support in the teaching and content knowledge of IKS integration (Mudaly and Ismail 2013, p. 180). Although these authors conducted their study in science, this is true even for technology teachers.

In his *Pedagogical principles in Technology Education: An indigenous perspective*, Gumbo (2016c) explored a few theories/models resonant with pedagogical approaches which give regard for IKS. A short summary of these theories/models is presented in Table 1. The table shows the theory/model, what the theory/model purports, and the scholars who can be consulted on these theories/models.

It can be noticed in Table 1 that these theories/models encourage the principle of working togetherness espoused by Fleer (2015, p. 41), participatory learning, and learning which promotes relevance to the students' contextual knowledge. From an assessment perspective, Stables (2015, p. 121) argues against a behaviorist paradigm and in favor of "constructivist and sociocultural approaches to learning and teaching." For purposes of this chapter, the culturally relevant teaching (CRT) and Seemann's Technacy Framework (STF) models are used.

Culturally Relevant Teaching

CRT, also referred to as culturally responsive teaching or culturally responsive pedagogy, is defined as teaching which integrates a student's background knowledge and prior home and community experiences into the curriculum and the teaching and

Table 1 Theories/models relevant for teaching which integrates IKS

Theory/model	What the theory or model purports	Scholars
Southern theory	Social science perspectives: multi-centered, function of critiques, many forms of knowledge, relevant to democracy	Wahyudi (2014)
Culturally relevant teaching/ culturally responsive teaching/culturally responsive pedagogy	Regard for students' background knowledge, prior home, community experiences	Ladson-Billings (2000, 2002), Montgomery (2001), Ontario's Equity and Inclusive Education Strategy (2013)
Social constructivism	Students' varied lived experiences, locally situated learning, inquiry-based learning, cocreation of knowledge, collaboration, diverse learning styles	Vygotsky in Subban (2006), Shackelford and Maxwell (2012)
Communities of practice	Learning as a communal event, linked to social theory – meaning, practice, community, identity	Lave and Wenger (1991), Wenger (1998)
Blended model	Integrates knowledge forms	Salia-Bao (1989), Yishak and Gumbo (2015)
Participatory modeling	Expressed in varied forms (personal mental model and mathematical equations and physical model), represents people's understanding of world, useful in decision making, productive environment for social learning	Standa-Gunda et al. (2003)
Technacy	Social empowerment, development, and sustainability; holistic approach to teaching, practicing, and learning technology; holistic problem-solving, communication, and practice; technology recognized as value laden; integrated approach toward subjects	Seemann (2000)

learning experiences which take place in the classroom (Ladson-Billings 2000). All students, according to CRT, learn differently as informed by their backgrounds, language, family structure, and social or cultural identity. Scholars allude to the three tenets of CRT, which are institutional, personal, and instructional dimensions

(Ontario's Equity and Inclusive Education Strategy 2013). Institutional dimension refers to the values which are enshrined in school policies and practices enacted by administrators and leaders. Schools need to critically examine processes of schooling which may reproduce patterns of marginalization. Teachers should intentionally identify, interrupt, and change such patterns. Personal dimension calls for the change of the mindset of teachers to support the development of their students without bias or prejudice. Instructional means "knowing students well and considering the classroom practices which lead to a culturally responsive classroom" (Ontario's Equity and Inclusive Education Strategy 2013, p. 2). Technology teachers should approach their practice bearing in mind these three tenets. It is important to emphasize the teacher's pedagogical content knowledge and role because a teacher's belief determines what he/she can allow and not allow in the learning situation (Buntting et al. 2015, p. 2).

Culture is about ways of knowing and is reflected in the learners' multiple social identities (Ontario's Equity and Inclusive Education Strategy 2013, p. 1). It should thus be viewed as a resource rather than a barrier for learning. If teachers are not properly prepared, they will be limited in their pedagogical practices and material choice which reflect contexts which benefit students from white middle-class and high socioeconomic status (Aceves and Orosco 2014; Kozleski 2016, p. 1) declares:

> By embracing the sociocultural realities and histories of students through what is taught and how, culturally responsive teachers negotiate classrooms cultures with their students that reflect the communities where students develop and grow.

In a culturally mixed learning situation, teachers are called upon to relinquish their status as knowledge brokers to negotiating norms and standards which acknowledge differences and similarities among and between individuals and groups (Kozleski 2016, p. 1). Kozleski's (2016) view of CRT suggests a facilitative role on the part of the teacher, which operates in the context of communities. Such a role encourages academic and cultural excellence which frees students to facilitate their and fellow students' learning, thus assuming leadership for learning, makes students feel comfortable exploring differences of opinion, and makes students see the classroom and their interactions from multiple perspectives. Put in context, Kozleski (2016, p. 2) writes that "the achievement gap in the US often separates groups of students by drawing differences between Whites, middle class students and their peers who may be American Indian, African-American, Asian American and/or Latino/a." Kozleski argues that seeing performance according to gaps is harmful as it unduly privileges some kinds of knowledge over others. Kozleski further argues in favor of indigenous ways of knowing, referring to them as practical and that they offer great insight and have ecological and social significance. This is important for teaching students about ecologically friendly technologies especially in these times when conventional methods and designs threaten the environment. Kozleski regards CRT as a framework which can facilitate transformational knowledge which leads to socially responsible action. A culturally responsive teacher's teaching strategy is guided by key features which encapsulate diversity. Such a teacher, according to Kozleski (2016, pp. 3–4):

- Communicates high expectations for his students.
- Actively engages students in learning.
- Is not a knowledge broker, but a learning facilitator .
- Understands assets and capabilities that students' families bring to their parenting.
- Anchors the curriculum in the everyday lives of their students.
- Selects participation structures for learning which reflect students' ways of knowing and doing.
- Shares control of the classroom with his students.
- Engages in reflective thinking and writing.
- Explores personal and family histories.
- Acknowledges membership in different groups.
- Learns about the history and experiences of diverse groups.
- Visits students' families and communities.
- Visits or reads about successful teachers in diverse settings.
- Develops and appreciation of diversity.
- Participates in reforming the institution.

The CRT model is depicted in Fig. 1 in terms of the six characteristics which a teacher who cherishes students' diverse cultures can be identified by.

These six characteristics can be customized to the technology teacher and are briefly explained that way:

Sociocultural Consciousness

The teacher reflects on his own biases to develop his understanding about his position in social, historical, and political context surrounding technology; questions his own attitudes, behaviors, and beliefs about (indigenous) technology; and reflects on how social identities are shaped by society and the role that technological forms play in them.

High Expectations

The teacher dismisses perceptions that indigenous technology is outdated, primitive, and out of tune with conventional technological modes and cannot play any significant role socio-economically; has a strong belief in indigenous students' potential and holds positive and affirming views that they are able to learn and achieve academically; respects students equally and the active role that their families and other community members can play in helping to understand technology; and

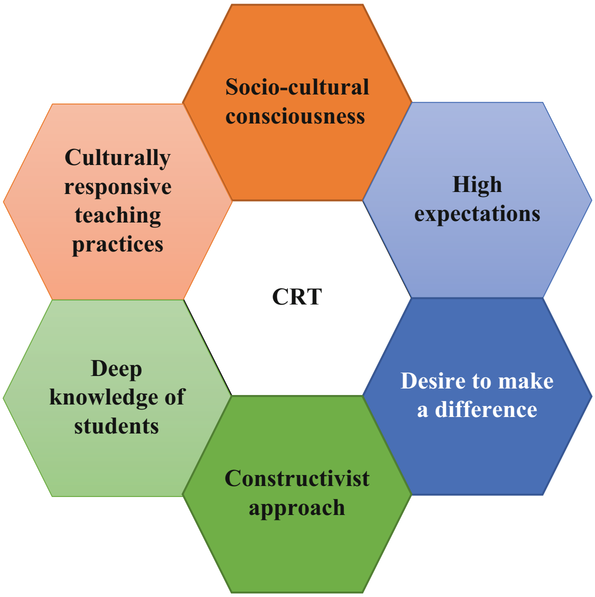


Fig. 1 A Model of characteristics of a culturally responsive teacher (Adapted from Ontario's Equity and Inclusive Education Strategy 2013)

believes that students' social identities are assets and not deficits in the learning of technology and thus respects their inputs in the learning process, e.g., thinking about technological scenarios and case studies which are relevant to their local contexts.

Desire to Make a Difference

The teacher sees himself as an agent of social change committed to remove problematic systemic and institutional barriers which are engineered to make students underachieve in TE by promoting the love for indigenous technologies and creates conditions for learning which are beneficial for all students while ensuring equitable and inclusive education where indigenous learners in particular feel free to express their understanding of technology.

Constructivist Approach

The teacher builds upon varied experiences of students by drawing locally situated learning into daily instruction and learning processes in TE, e.g., he assigns students projects which yield relevant technological solutions in view of ensuring sustainability; promotes inquiry-based and active learning, allowing students to express their curiosity and to create learning experiences for themselves and their peers by putting forward diverse ideas informed by their technological backgrounds; and allows students to cocreate knowledge and makes learning relevant to their experiences as they work harmoniously in groups or teams across their cultural boundaries.

Deep Knowledge of Students

The teacher shows interest in and builds relationships with students' families as an effort to know students much better and to be better informed about local technologies which they engage, with which to can enrich his teaching, and bridges between home and school and adopts a collaborative teaching and learning, all of which are important teaching strategies required in the teaching of technology due to the subject's project- and practice-based approach; this facilitates relevant learning as students will see themselves in the curriculum which they learn when their technological worldview is acknowledged (refer to Table 2 below).

Culturally Responsive Teaching Practices

The teacher has high expectations for his students' learning and recognizes and honors their lived experiences which inform their technological knowledge and understanding; uses his knowledge of students to give them access to learning about technology relevant to their contexts; and commits to the relevant and authentic learning for students in relation to student, parent, and community knowledge of technology in order to bring value and importance in the learning of students.

In turn, in order for a teacher to operate successfully in a culturally diverse school environment, in view of the key features listed above and the characteristics in Fig. 1, such a teacher should be properly trained. The relevant training framework is suggested by King (2009). This is illustrated in Fig. 2.

Technological Designs which are Based on Seemann's Technacy Framework (STF)

Gumbo (2015) has engaged this framework in his chapter on *Indigenous technology in Technology Education curricula and teaching* because he found it much relevant to the indigenous perspective to TE. According to Seemann (2000, pp. 1, 3 and 10), technacy is a holistic approach toward teaching, practicing, and learning technology – a holistic technology problem-solving, communication, and practice; a view that perceives technology as value laden; and an integrated approach to subjects resembling the philosophy of life out there. Seemann (2009, p. 117; 2010, p. 1) argues that the understanding of technology should be expanded so that it mirrors values and peoples' means of building new knowledge and their

Fig. 2 Principles of professional learning to prepare culturally responsive teachers (Adapted from King et al. 2009)

relationship to the eco-environmental features. This is important for indigenous communities who live very close to the environment. It is due to this assertion that an adapted STF version is recommended in the teaching of technology (see Table 2 in this regard).

Conclusion

This chapter has advanced an adapted STF in TE which can facilitate the integration of indigenous technology. The conventional approach was confronted in favor of the IKS-integrated approach. IKS, as one of the contemporary issues in TE, puts TE under the spotlight of criticism for transformation, thus creating a need for it to integrate indigenous technology. As we teach students to become tomorrow's technological problem-solvers and/or needs addressers, while at the same time seeking sustainable solutions, we cannot afford to teach students conventional technologies only. Thus, moving forward, indigenous technologies need to be integrated. IKS can make learning relevant to indigenous students but also benefit all other students who will begin to learn about and appreciate them, enrich the TE curriculum and teaching, and make teachers teach for sustainable development. STF provides a framework which could guide such desired transformation. More research into detailing the how of integration should be considered. At practice level, technology teachers are called upon to expand their knowledge of the subject by learning about indigenous technology so that they can service students of diverse cultures effectively.

Table 2 STF for TE which suits indigenous or diverse contexts (Adapted from Seemann 2000)

STF	Application	Sources of examples
Central goal	To develop and produce a skilled and holistic thinking student who can select, evaluate, transform, and use appropriate technologies responsive to local contexts and human needs	Making children's toys whose designs resemble local culture; student investigates local cultural images first which inform his/her designs
Technological content knowledge	Relates to or is packaged from technologies which exist locally and which can sustain lives of people Consider the following strands Indigenous definition of technology first before global perspective Epistemological issues about concept of technology Local cultural values underlying technology and designs Evidence of existing technologies and designs in local contexts including case studies Technological resources and materials available in local indigenous context Principles of technological applications in local indigenous contexts Profile prominent local designers and innovators Trade value of technologies in local indigenous context	Technologies of processing sour milk, hut making, baking bread, hunting, ploughing, slaughtering a cow, dress making, etc. See Senanayake (2006), Seemann (2000, 2009), Obikeze (2011), Ogunbure (2014) for definitions Ways of technological knowledge generation and how; who are fountains of this knowledge? What are sources of this knowledge? Types of knowledge, etc. Botho (ubuntu), holism, spirituality, value wisdom of elders, etc. (see Gumbo 2016c) Case studies, e.g., house construction (design, structure, materials, etc.) Human (elders/local experts), physical (wood, stones, animal leather, etc.) Observation, group approach, experiential, demonstration, etc. (see Gumbo 2015) David Adjaye, Francis Kéré, Mokena Makeke, Mpheti Morojele, etc. Ceramic products, textile materials, art of all sorts
Learning support materials and equipment	Local learning support materials and equipment which students can better identify with: Textbooks and other resources Examples and student activities TE classroom/lab equipment	Indigenous authors and artefacts Engage with elders on local technologies, identify local engineers, architects, identify local problems, and design relevant sustainable solutions using locally available resources, etc. Indigenous designs and manufacturing; open labs, i.e., learning and doing practical activities in an open – engaging technological experts in communities

(*continued*)

Table 2 (continued)

STF	Application	Sources of examples
Pedagogical approaches	Varied pedagogical strategies Critical epistemological discourses about technology Curriculum content Adopt the community model of coteaching student with local technologists (especially elders) Learning activities (social cohesion, development, and sustainability) Flexible approach	Culture and technology, values issues in technology, intangible technologies, etc. Local symbols and content – Great Zimbabwe ruins, Mapungubwe, iron smelting, brick making, etc. Group design projects that engage community members for guidance Alternative ways such as emergent designs rather than follow design process blindly Orality, storytelling, demonstration by elders and/or experts, gamification, simulation, singing, etc.
Assessment	A planned-in assessment (pre-planned and integrated in the learning activities) Strictly related to learning materials and content Targets applied knowledge and is context based Helps to graduate student who masters local technologies Relevant to student's personal domains	Based on content and experiences which students can identify with rather than on rote learning Enrich assessment with holistic experiences Interest in local technologies such as transport modes so student can respond relevantly to local technological needs Balance academic assessment with physical, emotional, and spiritual forms; shift from zone of cognitive competence to zone of trustful intuition

References

Aceves, T., & Orosco, M. J. (2014). *Culturally responsive teaching*. Gainesville: University of Florida.

Buntting, C., Williams, P. J., & Jones, A. (2015). The more things change, the more (some) things stay the same. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education: Contemporary issues in technology education*. Singapore: Springer.

Bevan, C., Shillinglaw, D., & Bigges, M. M. (2010). Teaching two way: Codeswitching cultures and dialects. *Literacy Learning: The Middle Years, 18*(2), 11–17.

Compton, V., Jones, A. (2004). The nature of technology: Briefing paper prepared for the New Zealand Ministry of Education Curriculum Project. [Internet]. Cited 9 Dec 2016. Available from: http://www.tki.org.nzcurriculum/whats_happening/index_e.php.

Custer, R. L. (1995). Examining the dimensions of technology. *International Journal of Technology and Design Education, 5*(3), 219–244.

Demmert, G. W. (2001). *Improving performance among native American learners: A review of the research literature*. ERIC Clearing House on Rural Education and Small Schools: Charleston.

DBE. (2011). *Curriculum and assessment policy statement grades 7–9 technology*. Pretoria: Government Printers.

Eggleston, J. (1992). *Teaching design and technology: Developing science and technology education*. Buckingham: Open University Press.

Emeagwali, G. (2003). African indigenous knowledge systems (AIK): Implications for the curriculum. In T. Falola (Ed.), *Ghana In Africa and the world: Essays in honour of Adu Boahen*. New Jersey: Africa World Press.

Fleer, M. (2015). Theorising technology education from a cultural-historical perspective: Foundations and future imaginings. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education: Contemporary issues in technology education*. Singapore: Springer.

Gaotlhobogwe, M. (2012). The role of IK systems in addressing the problem of declining enrolments in Design and Technology. A paper presented at PATT26 Conference. Stockholm, Sweden.

Gumbo, M. T. (2003). Indigenous technologies: Implications for a technology education curriculum. Unpublished PhD thesis. Pretoria: Vista University.

Gumbo, M. T. (2015). Indigenous technology in technology education curricula and teaching. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *Contemporary issues in technology education: The future of technology education*. Singapore: Springer.

Gumbo, M. T. (2016a). *The question of technology education: A pertinent issue. Inaugural lecture*. Pretoria: Unisa.

Gumbo, M. T. (2016b). An indigenous perspective on technology education. In P. Ngulube (Ed.), *Handbook of research on IK systems in developing countries*. Hershey: IGI.

Gumbo, M. T. (2016c). Pedagogical principles in technology education: An indigenous perspective. In G. Emeagwali & E. Shizha (Eds.), *African IK and the sciences: Journeys into the past and present*. Rotterdam/Boston/Taipei: Sense.

Hoppers, C. A. (2002). Introduction. In C. A. Hoppers (Ed.), *Indigenous knowledge and the integration of knowledge systems*. Claremont: New Africa Books.

Kanu, Y. (2006). Introduction. In Y. Kanu (Ed.), *Curriculum as cultural practice*. Toronto: University of Toronto Press.

Kates, R. W., Parris, T. M., & Leiserowitz, A. A. (2005). What is sustainable development? Goals, indicators, values, and practice. *Environment: Science and Policy for Sustainable Development, 47*(3), 8–21.

Kimbell, R. (2008). IK, know-how, and design & technology. *Design and Technology Education, An International Journal, 10*(3), 8–10.

King, K. A., Artiles, A. J., & Kozleski, E. B. (2009). Professional learning for cultural teaching. [internet]. Cited 24 April 2017. Available from: http://www.equityallianceatasu.org/sites/default/files/Website_files/exemplarFINAL.pdf.

Kozleski, E. B. (2009). Culturally responsive teaching matters! [internet]. Cited 7 May 2016. Available from: http://files.eric.ed.gov/fulltext/ED520957.pdf.

Ladson-Billings, G. (2000). Fighting for our lives: Preparing teachers to teach African American students. *Journal of Teacher Education, 51*(3), 206–214.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Mavhunga, J. P. (2008). Africanising the school curriculum: A case for Zimbabwe. *Zimbabwe Journal of Educational Research, 20*(1), 30–48.

Montgomery, W. (2001). Creating culturally responsive, inclusive classrooms. *Teaching Exceptional Children, 33*(4), 4–9.

Mudaly, R., & Ismail, R. (2013). Teacher learning through tapping into IK systems in the science classroom. *Alternation, 20*(1), 178–202.

Naidoo, P., & Savage, M. (1998). Introduction. In P. Naidoo & M. Savage (Eds.), *African science and technology education into the new millennium: Practice, policy and priorities*. Kenwyn: Juta.

Obikeze, D. S. (2011). IK systems and the transformation of the academy in Africa: The CULPIP model. [internet]. Cited 02 Nov 2016. Available from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.164.9357&rep=rep1&type=pdf.

Ogunbure, A. A. (2014). The possibilities of technological development in Africa: An evaluation of the role of culture. *The Journal of Pan African Studies, 3*, 86–100.

Ogunniyi, M. B. (2007). Teachers' stances and practical arguments regarding a science: Indigenous knowledge curriculum. Part 1. *International Journal of Science Education, 8*(18), 963–986.

Ontario's Equity and Inclusive Education Strategy. (2013). Capacity building series: Culturally responsive pedagogy – Towards equity and inclusivity in Ontario schools. [internet]. Cited 14 Jan 2016. Available from www.edu.gov.on.ca/eng/literacynumeracy/inspire/.

Owusu-Ansah, F. E., & Mji, G. (2013). African IK and research. *African Journal of Disability, 2*(1), 1–5.

Pavlova, M. (2006). Technology education for sustainable futures. *Design and Technology Education: An International Journal, 11*(2), 41–53.

Rains, F. V. (1999). IK, historical amnesia and intellectual authority: Deconstructing hegemony and the social and political implications of the curricular "other". In L. M. Semali & J. L. Kincheloe (Eds.), *What is IK: Voices from the academy*. New York: Falmer.

Robyn, L. (2002). IK and technology: Creating environmental justice in the twenty-first century. *The American Indian Quarterly, 26*(2), 198–220.

Roland, M. L. (2016). Indigenous and neotraditional knowledge systems and their role in creating and maintaining ecological sustainability. [internet]. Cited 20 Nov 2016. Available from http://www.eolss.net/sample-chapters/cll/E6-61-05-06.pdf.

Salia-Bao, K. (1989). *Curriculum development and African culture*. London: Edward Arnold.

Seemann, K. W. (2000). Technacy education: Towards holistic pedagogy and epistemology in general and indigenous/crosscultural technology education. Paper presented at the International Conference on Technology Education Research. Gold Cost, Australia.

Seemann, K. W. (2009). Technacy education: Understanding cross-cultural technological practice. In J. Fien, R. Maclean, & M. G. Park (Eds.), *Work, learning and sustainable development: Opportunities and challenges*. Bonn: Springer.

Seemann, K. W. (2010). Learning how everything is connected: Research in holistic and cross-cultural indigenous Technacy education. Paper presented at the International Conference of Research in Technological Learning & Thinking. Vancouver, Canada.

Senanayake, S. G. J. N. (2006). IK as a key to sustainable development. *The Journal of Agricultural Sciences, 2*(1), 87–94.

Shackelford, J. L., & Maxwell, M. (2012). Sense of community in graduate online education: Contribution of learner to learner interaction. *The International Review of Research in Open and Distance Learning, 13*(14), 228–250.

Shipp, C. (2013). Bringing aboriginal and Torres Strait islander perspectives into the classroom: Why and how. *Literacy Learning: The Middle Years, 21*(3), 24–29.

Stables, K. (2015). Assessment: Feedback from our pasts, feedforward for our futures. In P. J. Williams, A. Jones, & C. Buntting (Eds.), *The future of technology education: Contemporary issues in technology education*. Singapore: Springer.

Standa-Gunda, W., Mutimukuru, T., Nyirenda, R., Prabhu, R., & Haggith, M. (2003). Participatory modelling to enhance social learning, collective action and mobilization among users of the Mafungaitsi Forest. *Zimbabwe. Small-Scale Forestry, 2*(2), 313–326.

Subban, P. (2006). Differentiated instruction: A research basis. *International Education Journal, 7*(7), 935–947.

Volmink, J. (1998). Who shapes the discourse on science and technology? In P. Naidoo & M. Savage (Eds.), *African science and technology education into the new millennium: Practice, policy and priorities*. Kenwyn: Juta.

Wahyudi, R. (2014). Democratic online courses as "glocalized communication" in English language teaching and applied linguistics: A proposal. *Journal of Global Literacies, Technologies, and Emerging Pedagogies, 2*(3), 248–260.

Wenger, E. (1998). Communities of practice: Learning, meaning and identity. New York: Cambridge University Press.

Wicklein, R. C. (1997). Curriculum focus for technology education. *Journal of Technology Education, 8*(2), 1–6.

Williams, P. J. (2000). The only methodology of technology? *Journal of Technology Education, 11*(2), 48–60.

Yishak, D. M., & Gumbo, M. T. (2015). A stand-alone, blended or restructured approach to the indigenization of curriculum? A critical perspective. *International Journal of African Renaissance Studies, 10*(1), 60–82.

Zengeya-Makuku, V., Kushure, L., Zengeya, A., & Bhukuvhani, C. E. (2013). Secondary school teachers' conceptions of IK: A basis for its inclusion into the school curriculum. *International Journal of Innovative Research & Development, 2*(8), 446–452.

Sustainability as a Transformative Factor for Teaching and Learning in Technology Education

58

Margarita Pavlova

Abstract

The need for the transition to a low carbon future, and more sustainable models of development, has led to a number of economic changes such as green economic restructuring (often underpinned by innovation in new green technologies and growing opportunities for new green sector developments) and raising of awareness with respect to social and environmental challenges. This chapter reflects on the research on sustainability/sustainable development (these terms are used interchangeably in this chapter) in technology education (TE) and examines examples of TE in the national curricula where sustainability issues have been addressed. The chapter reflects on two major challenges related to curriculum development and explores additional challenges related to teaching and learning. It concludes with the suggestion that a holistic and multifaceted approach should be adopted for the inclusion of sustainability in TE that is underpinned by values transformation and is aimed at creating young people who are responsible citizens and who understand the need for a sustainable future and behave accordingly. In this suggested form, TE can help meet the changing demands of economic, environmental, and social developments in modern societies that are in turn informed by the sustainability agenda.

Keywords

Sustainability in technology education curriculum • Value change • Social and environmental dilemma • Teaching and learning for sustainability • Holistic approach to sustainability integration

---

M. Pavlova (✉)
The Education University of Hong Kong, Hong Kong, Hong Kong
e-mail: mpavlova@eduhk.hk

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_57

Contents

Introduction

The importance of sustainable development to the future of humanity has been recognized at different levels of society, including high-level international agendas. Sixteen Sustainable Development Goals (SDGs) were adopted at the United Nations Summit in September 2015 and formulated specific targets for governments in guiding their countries' sustainable developments. The need for the transition to a low carbon future, and more sustainable models of development, has led to a number of economic changes such as green economic restructuring (often underpinned by innovation in new green technologies and growing opportunities for new green sector developments) and raising of awareness with respect to social and environmental challenges. These new realities that are linked to transitions toward a sustainable future and the necessity to end poverty bring about peace and security as well as solving environmental challenges and they relate all SDGs to education.

The United Nations Development Program (UNDP 2016) argues that innovation should be at the top of the agenda in order to drive the implementation of the SDGs as innovation could improve productivity, decrease environmental impact, and support citizens in co-designing solutions to development challenges (UNDP 2016). Therefore, innovation, associated with design and technology, could play a positive role in achieving a sustainable future as it stimulates sustainable growth in different industries, "from agriculture to manufacturing and tourism; from the provision of healthcare to other social services and to finding solutions to environmental challenges" (UNDP 2016). For example, design and technology can reduce greenhouse gas emissions and combat climate change; they can also lead to the creation of green technologies to manage the use of resources and recover waste at different stages of the lifecycles of products. Design and technology is widely utilized for the purposes of recycling, product redesign, and conservation processes and is certainly a positive contributor to the goal of sustainable development. Therefore, technology education (TE) has an important role to play in supporting the implementation of SDGs as TE often incorporates creativity, innovative solutions to problems, and systematic "from cradle to grave" thinking.

This chapter reflects on the research on sustainability/sustainable development (SD or ESD) in technology education and examines examples of TE in the national curricula where sustainability issues have been addressed. The terms "sustainability" and "sustainable development" are used interchangeably in this chapter, despite arguments concerning their differences. The chapter reflects on two major challenges related to curriculum development and explores additional challenges related to teaching and learning. The chapter concludes with the suggestion that a holistic and multifaceted approach should be adopted for the inclusion of sustainability in TE that is underpinned by values transformation and is aimed at creating young people who are responsible citizens and who understand the need for a sustainable future and behave accordingly. In this suggested form, TE can help meet the changing demands of economic, environmental, and social developments in modern societies that are in turn informed by the sustainability agenda.

Technology Education Research on Sustainable Development

Design and technology educators understand the importance of designing for sustainability. Research by Ritz and Martin (2013) used the Delphi method to identify topics international researchers are interested in exploring in the area of design and technology education. Participants in the study were recognized by their peers as leading international experts in the TE area. They were asked to identify, reflect, and reach consensus on issues that are important to research in order to establish a rigorous knowledge base for the subject. The issue of *Designing for sustainability and global citizenship* was ranked third among the most important issues that need to be researched in K-12 technology (and engineering) education. These findings reflect the recognition of the importance of this particular issue for academics and professionals in the field, as well as the importance of understanding the ways SD can be related to technology education.

Analysis of the actual research published or presented in the area of TE (Williams 2015) reveals that the topic of *sustainability/environmental issues* was one of the top ten topics addressed in the years between 2006 and 2013. Williams (2015) reviewed three different journals in the area as well as four conference proceedings between 2006 and 2010 – a total of 472 manuscripts (published or presented) over that period. He analyzed an additional 713 manuscripts for the period 2011–2013 using a slightly different combination of sources. Williams finds that between 2006 and 2010, *sustainability/environmental issues* in technology education was the most frequently published research topic in the *International Journal of Technology and Design Education*, accounting for 10% of the total published papers (Williams 2015), whereas from 2006–2013, they were the second most common topics in the same journal. In 2009 the journal published a special issue that addressed the topic from different perspectives: from arguments for the redesign of the whole approach to TE to classroom realities where students have difficulties being involved in eco-design projects and where teachers have not addressed environmental awareness systematically in their practice. Studies in this special issue indicate that the "technology education profession is still at an early stage of the ESD journey" (Pavlova 2009c, p. 107). Over two periods, across all the sources Williams (2015) analyzed, *sustainability/environmental issues* leapt from the tenth (2006–2010 period) to the sixth (2011–2013) most frequently addressed research topics.

Both studies by Ritz and Martin (2013) and Williams (2015) demonstrate an increased recognition of the importance of sustainability issues for TE. A recent book edited by Stables and Keirl (2015) is additional proof of that. Therefore, an understanding of the need to address aspects of sustainability and actual research on the topic is well presented in the field. However, there are multiple interpretations of sustainability and how it could be addressed in TE. This is also reflected in curricula.

Sustainability in Curriculum

Sustainability in the technology and design context is largely associated with the use of resources to create products and deliver outcomes or services that can solve present pressing needs. In many parts of the world, TE is an academic subject or learning area that aims to provide practical, hands-on, technical learning experiences that stimulate creativity and imagination in primary and secondary school students to solve real and relevant problems. Some curricula focus on crucial skills required for work. Many countries included sustainability in the major concepts incorporated in the TE curriculum. Students taking the subject are required to practice or learn sustainability from the technological and design perspectives to achieve sustainable and environmentally sensitive outcomes. The following section provides some examples that illustrate differences in approaches toward the inclusion of sustainability in the TE curriculum in several countries.

England

In England, design and technology (D&T) is included in the National Curriculum and is offered as a foundation subject to primary and secondary students in years 1–9 (key stages 1–3). The national curriculum D&T in England does not incorporate sustainability contexts in its learning objectives and aims. However, students are evaluated in terms of "*understanding developments in design and technology, **its impact on individuals, society and the environment,** and the responsibilities of designers, engineers and technologists*" in key *s*tage 3 (lower secondary school) of the D&T curriculum (Department for Education 2013). One interpretation of this is that although sustainability is not a specified learning outcome in key stage 3, environmental and social awareness and related aspects are indicators of the students' learning.

Table 1 Design in technology – knowledge of design (indicator of progression) information chart

	Level 6	Level 7	Level 8
Learning objective	Demonstrate understanding of basic concepts in design	Demonstrate understanding of advanced concepts in design	Demonstrate understanding of complex concepts in design
Indicators	Explain how lifecycle considerations determine the focus for design interventions Explain the elements that underpin design within a specified context Discuss the quality of a design in relation to design elements and considerations of the specific context in which the design is situated	Explain the relationship between lifecycle design, innovation, and **sustainability** Explain how issues identified by lifecycle analysis lead to design innovation Discuss the competing priorities and compromises made as a result of lifecycle analysis when developing a **sustainable technology**	Evaluate the quality of the design of a technological outcome using contemporary design judgement criteria Discuss the impact of contemporary judgement criteria on design decision-making Justify the evaluation of a technological outcome's design
Achievement level	Basic understanding of sustainability in design	In-depth understanding of sustainability in design	Comprehensive understanding of sustainability in design

Compiled by the author from New Zealand Government, Ministry of Education (2012a) and New Zealand Qualifications Authority (2014)

New Zealand

The New Zealand curriculum specifies six specialist strands for technology at levels 6, 7, and 8. Three of the six specialist strands, including design in technology, manufacturing and design, and visual communication incorporate sustainability in the indicators of expected student performance/understanding. At levels 7 and 8 of the "Design in Technology" strand, students are required to demonstrate their understanding of advanced and complex concepts in design as well as to demonstrate their understanding of sustainability in design (New Zealand Government Ministry of Education 2013). At level 8, teachers guide students to explore innovative designs for sustainable futures (New Zealand Government Ministry of Education 2013) (Table 1).

In another specialist strand, "Manufacturing," students are required to develop an understanding of advanced manufacturing concepts and techniques at level 7, so they need to take into consideration key drivers of manufacturing, such as environmental imperatives (New Zealand Government Ministry of Education 2013). Students should be able to discuss the environmental factors that can affect quality control mechanisms and yield. *Knowledge of Manufacturing* (level 8) aims to "develop understanding of, and implement, a 'green' manufacturing process" among students (New Zealand Government Ministry of Education 2012b). At level 8, teachers provide support to students to develop and implement a "green" manufacturing process through the following methods (New Zealand Government Ministry of Education 2015a):

1. Stimulate discussion among students on how “green” considerations impose a heavy influence on technological outcomes and manufacturing.
2. Help students to develop their understanding of “green” manufacturing processes.
3. Discuss contemporary judgment criteria, based on the principles of good design, and how these may impact on the development and implementation of “green” manufacturing processes.
4. Provide examples of optimization in terms of energy and resources that exemplify “green” manufacturing processes.
5. Support students to analyze a technological outcome in order to determine its suitability for “green” manufacture and to make design changes as required.
6. Support students to modify their techniques and use of resources as well as quality control procedures to tailor the “green” manufacturing process according to the constraints and/or opportunities of the manufacturing location.
7. Support students to evaluate the success of their manufacturing process in meeting “green” considerations.

In the “Design and Visual communication” strand, on the other hand, students focus on the knowledge of design and graphics practice and are expected to develop an understanding of qualities and potential of design ideas in terms of aesthetics and function as well as sustainability and how design ideas are influenced by societal, environmental, historical, and technological factors (New Zealand Government Ministry of Education 2015b).

Consequently, curriculum and guiding materials for teachers, in New Zealand, stipulate a number of requirements and clear instructions in terms of incorporating sustainability in TE.

Australia

Design and technology is one of the two subjects included in the Australian curriculum “The Technologies.” An overarching idea of the newly designed “The Technologies” curriculum is *creating preferred futures*. Students are given opportunities to develop solutions and consider the possible benefits and risks now and into the future and to weigh up possible short- and long-term impacts. Among the aims of “The Technologies” is to “develop the knowledge, understanding and skills to ensure that, individually and collaboratively, students. . .make informed and ethical decisions about the role, impact and use of technologies in the economy, environment and society for a sustainable future” (Australian Curriculum, Assessment and Reporting Authority 2016).

In the Design and Technologies subject (one of the subjects in “The Technologies” curriculum), students are taught to plan for the sustainable use of resources in their projects and to "take into account ethical, health, and safety considerations and personal and social beliefs and values." Students develop systems thinking as well as design thinking that are essential prerequisites for developing sustainable solutions for preferred futures. In Design and Technologies "students recognise the connectedness of and interactions between people, places and events in local and wider world contexts and consider the impact their designs and actions have in a connected world"; they consider "economic, environmental and social impacts that result from designed solutions" (Australian Curriculum, Assessment and Reporting Authority 2016).

The whole Australian "The Technologies" curriculum is shaped by ideas of sustainability. Since the Australian F-10 Curriculum (Foundation – Year 10) was endorsed in September 2015 by state ministers in each state and territory, the systems and schools within it are responsible for its implementation. However, the state and territory education authorities themselves determine the timeframe for the adoption of the Australian curriculum. In Western Australia, for example, "The Technologies" curriculum should be fully implemented by 2018.

Issues of sustainability have been included in the technology curriculum across different states in Australia for at least a decade. In New South Wales, for example, the subject was compulsory for years 7 and 8, and students were required to identify and explain "ethical, social, environmental and sustainability considerations related to design projects" (outcome 4.6.2). The curriculum also specified the units of work that should lead to this outcome: in introductory unit 7.1 "Snack Food for the Cinema," food products are designed using food technologies; in unit 7.3 "Show the Way," students examine innovation and emerging technologies and focus on graphics technologies to design, produce, and evaluate a brochure or magazine; in unit 8.1 "Lights, Camera, Robo Action," a video clip is designed and produced for a robot by students; and in unit 8.2 "Place and Space," students engage in open-design projects according to environmental design specifications. If students choose D&T as an elective subject in years 7 through to 10, they continue to consider the environmental impacts of technologies and sustainability to further raise their awareness and take a more active role in protecting the environment. Students evaluate the impact of design and innovation on society and the environment, but they also need to understand the ethical and environmental issues as well as sustainable technologies (Board of Studies NSW 2013a, b).

Other states have sustainability included in their technology curriculum. South Australia's 2001–2016 D&T curriculum had cross-curricula Essential Learnings directly related to ESD (DETE 2001). Queensland introduced sustainability as one of the foundation subjects of TE. Aspects such as systems to ensure sustainability, eco-footprint, recycling, lifecycle analysis, and principles of sustainable design were included (Queensland Studies Authority 2007). Across these two states, the curriculum work of critical literacy scholars had a huge impact on the national curriculum development, particularly on its focus on enhancing students' capacity to shape preferred futures.

Hong Kong

Hong Kong also offers an elective subject to secondary S4–S6 students in the last three years of schooling, called Design & Applied Technology, designed to cultivate attributes of innovation and entrepreneurship among students. Sustainability is incorporated as a learning element in the curriculum, which includes Green Design Technology and Sustainable Architecture. For Green Design Technology, students are assigned an individual task of making a "green" toy. Students learn about green design and products, 4Rs principles (reduce, rent, reuse, recycle), and theory on clean production and proceed to make use of visualization and computer-aided design (CAD) to create the "green" toy (Education Bureau 2013a). In a similar vein, Sustainable Architecture focuses on green buildings, eco-building materials, and energy efficiency. Students work in groups on green potential developmental projects or existing buildings in Hong Kong with the use of CAD modeling and by applying design implementation and material processing (Education Bureau 2013b).

Thailand

Design and Technology is taught as a learning area, rather than a specific subject, under the Basic Education Core Curriculum, BE 2551, in Thailand. The aim is to enable students to acquire knowledge, competence, and essential skills needed for work as well as to become familiar with creative technology to design objects, utensils, and methodologies that increase efficiency in everyday work. The learning outcomes include (The Ministry of Education, Thailand 2008):

- Creatively select technologies that are beneficial to the environment
- Sustainably manage existing technologies by making them cleaner

The examples of these five countries demonstrate that the TE curriculum has addressed issues associated with sustainability to different extents. Such issues such as the environmental and social impact of design and green manufacturing, green/sustainable technologies, green design and even green architecture, and sustainable solutions for preferred futures provide the main focus for sustainability thinking in the TE curriculum. As demonstrated by the above examples, there is a stronger emphasis on technologies and the ways in which they can be used to solve problems combined with a strong emphasis on environmental sustainability.

Challenges in Addressing Sustainability in Technology Education the Curriculum Development Level

The previous examples of curriculum drawn from five countries highlight at least two challenges at the level of curriculum development. The first relates to ways of solving sustainability problems. A "technical fix" together with a "value change" are among the two major approaches of achieving sustainable development (Robinson 2004) with a whole spectrum in between. Although the TE curriculum concentrates on a "technical fix" whereby problems can be solved through technological solutions, the importance of "value change" should not be underestimated and should be explicitly included in the TE curriculum. Academics within the discipline argue that the "value change" approach should frame the whole TE curriculum. This "rethink" attitude (e.g., Elshof 2009; Pavlova 2009b, 2012; Pitt and Lubben 2009; Stables and Keirl 2015) requires a new *frame of mind* that promotes the mutual flourishing of human and nonhuman beings and is well expressed through the principle of *Respect and care for the community of life, meaning duty to care for other people and other forms of life now and in the future,* formulated for the "Caring for the Earth" strategy by the International Union for Conservation of Nature and Natural Resources and the World Wide Fund for Nature (IUCN, UNEP, WWF 1991). The Australian curriculum that highlights the *creation of preferred futures* closely coheres with ideas of sustainable development and education formulated in an objective of the UN on Education for Sustainable Development (ESD) (2004–2015): "to integrate the values inherent in sustainable development into all aspects of learning to encourage changes in behavior that allow for a more sustainable and just society for all" (UNESCO 2005, p. 26). The first challenge then is to move beyond a focus on just technological solutions in TE and to incorporate a new *frame of mind* that is based on ethical principles of transformative education (Pavlova 2013) and which brings about a "value change" in the ways sustainability is addressed in TE.

The second challenge relates to environmental/social dimensions of sustainability. As argued by Pavlova (2011), while the rationale for TE in all countries needs to be framed by a concern for the human condition, due to contextual differences, the emphasis in the TE curriculum varies. For developed countries, although understanding the impact of design on societies is included in the curriculum, attention is mainly given to the environmental aspects of sustainable development (e.g. green technologies, green manufacturing, and green design based on lifecycle analysis). For developing countries, on the other hand, the social aspects of sustainable development (sustainable design) are prioritized (Pavlova 2011). For example, African TE academics understand the need to address SD through technology education. Participants in the study prioritized social aspects of sustainability, although they acknowledged that social development needs to be framed by environmental concerns (Pavlova 2011). These results support the analysis conducted by UNEP (2011) that used each country's natural and human capital and its relative level of development as indicators for identifying specific challenges for sustainable development. Two dimensions of this analysis are *ecological footprint* as an instrument to measure the impact of our lifestyle on the environment and the *Human Development Index* (HDI) as an indicator of health, education, and standard of living. Two different groups of countries identified in this analysis should take different measures to address the requirements of sustainable development. The first needs to reduce their per capita ecological footprint without impairing quality of life; the second needs to improve the well-being of its citizens without drastically increasing their ecological footprints. In other words, the TE curriculum should have a different emphasis in learning activities across different countries. TE educators from several African countries prioritized themes for the subject, such as illiteracy, clean water and sanitation, and poverty alleviation (Pavlova 2012). In addition, issues such as the support and promotion of cultural diversity and ways to address the issue of infectious diseases were also included. From this perspective, the challenge of improving the HDI through TE surfaces strongly in participants' views. However, participants of the study possessed a high level of environmental awareness and understood that social development could not be achieved without conserving the earth's vitality and diversity or keeping development within earth's carrying capacity. Therefore renewable energy, the sustainable use of natural resources, and biodiversity loss were also viewed as crucial issues to be addressed through TE. The second challenge, therefore, is to identify the sustainability issues that are a priority for the country in question and address them in the TE curriculum. It should be noted that both the social and environmental aspects should be included, regardless of country.

Teaching and Learning

The links between teaching and learning are well established in research at both university and school levels. Rohaan et al. (2009, 2010), for example, identified links between teachers' understandings of technology and learners' concepts of, and attitudes toward, technology. Therefore, it is critical that teachers and university academics are aware of their own interpretations, inclinations, and beliefs about SD and the ways it could be addressed through TE. Differences between teachers' perceptions of SD are made transparent by research conducted across different contexts. Studies conducted by Elshof (2005), Hill and Elshof (2007), Pitt and Lubben (2009), and Pavlova (2009a, 2012) highlight differences in teachers' perceptions of ESD and in the level of readiness to address these issues through teaching in differing countries' contexts (Canada, UK, Russia, and several African countries). Through the use of different methodologies, these studies concluded that teachers' perceptions of what they considered important and their readiness to address these issues were reflected in their classroom practices. For example, the majority of TE teachers in Russia involved in the study (Pavlova 2006a, b) defined ESD as contributing toward the development of moral values and responsibilities and changing the way people think. This response is closely related to the local context, as in Russia, "upbringing" (values development) has historically been seen as an important part of education. Education and training of TE teachers can help them to reflect on their interpretations of SD and to increase their commitment toward including different aspects of SD in their teaching. The study by Pitt and Lubben (2009) reports that as a result of in-service training, "nine out of the twenty teachers in the sample reported considerable changes in their understanding of, and confidence in, integrating the social dimension of SD in their D&T teaching" (p. 175).

Research on specific aspects of teaching and learning revealed different approaches adopted in classrooms to address sustainability issues in design:

collaborative learning by multidisciplinary teams at the university level helps to tackle complex issues (McMahon and Bhamra 2016), an emphasis on issues related to sustainability of materials used (e.g, recycled fabric, creating a long-lasting garment and the use of sustainable fabric) (Compton and Compton (2013), the utilization of problem-solving strategies for addressing sustainability as a design problem (Middleton 2009), and the importance of appropriateness in relation to the contexts of the students' age, location, and interests (e.g., year 3 students were designing board games to teach a friendly monster about eco-food) (Pavlova and Turner 2007). It is important that further studies are undertaken to determine the types of projects and themes relevant to different ages and different contexts as well as the appropriate pedagogy that should be applied.

In addition, a critical approach toward technology needs to be developed. Although technology is one of the most effective tools to deal with sustainability challenges, it can also have negative effects. Technology needs to stand the test of time to determine its real impact on society and environment. Therefore lessons from the past should be examined, so students can learn about design and technological developments, avoid mistakes in the future, understand the interaction between groups, and finally contribute to the design and development of technology. This critical examination can equip students with the capacity to address conflicts, challenges, and failures and to become familiar with their own capacity to resolve the consequences of their decisions (Rockstroh 2013, p. 401).

An emphasis on developing *positive attitudes* toward sustainability is vital, rather than simply addressing the knowledge and skills required for sustainable design. Research by McGarr (2010) highlights the need to go beyond awareness raising in teachers and students. It is essential to fully integrate ESD into TE rather than addressing separate elements in isolation. Haug (2016) and Keirl (2015) highlight the importance of ethics in terms of the incorporation of sustainable solutions into design. The right design intention can inspire students to develop sustainable solutions. As Ruff and Olson (2009) indicate, although design undergraduates label themselves environmental and sustainability supporters, their actual comments revealed their indifference to the environment. Explanations and examples of environmentally sustainable methods and products are not sufficient to trigger and promote environmentally sustainable design among these students. Therefore, there is a need to go beyond just the simple provision of knowledge and skills in TE classes.

Research on sustainability in TE identified challenges in teaching and learning that are related to teachers' perceptions of sustainability, the need to adopt multi-dimensional approaches to address sustainability in the TE classroom, the complexity of issues to be addressed in the class, and the need to "discuss and visualise desirable futures that could be shaped by technological decisions" (Pavlova 2015). As Pavlova (2015) argues, classroom activities should go beyond a collection of design briefs for students to solve; all learning in technology education should target students' understandings of preferred futures. Therefore, teaching approaches central to fostering emancipatory transformative learning need to include *critical reflection* (identify the ways learning can transform society and students' own reality), a *liberating approach to teaching* (facilitating cognition through problem-posing and discussion), and *equal, horizontal student-teacher relationships* (Freire and Macedo 1995). Project-based learning in TE provides opportunities to address these different ways of learning in a systematic and holistic manner by addressing SD challenges.

Conclusions

If we are to achieve a set of universal, ambitious, and transformative United Nations Sustainable Development Goals, tools are required such as economic instruments, legislative measures, and financial incentives that can stimulate technological changes and drive innovation. In today's world, there is a greater reliance on technology to resolve sustainability challenges; therefore TE has a clear role to play in supporting the implementation of SDGs by educational means. However, education for sustainable development is much more than that:

> ESD is far more than teaching knowledge and principles related to sustainability. ESD, in its broadest sense, is education for social transformation with the goal of creating more sustainable societies. ESD touches every aspect of education including planning, policy development, programme implementation, finance, curricula, teaching, learning, assessment, administration. (UNESCO 2012)

Analysis of the ways in which sustainability is addressed in TE and challenges identified by research highlights an increased awareness of the need to include sustainability in teaching and learning in TE. Students, as designers, can determine the material to be used, the manufacturing processes, and the disposal of the design, thus recognizing that actions on the part of designers have significant impacts on both the environment and society (Papanek 1995). Negative changes in the environment that we can currently observe are the result of human activity so it is imperative that students understand the interdependence between humans and nature, the limitations of design, its eco-friendliness, and the concept of waste elimination and take different viewpoints and use innovative solutions to complete the design process. As sustainable design covers broader issues of development and ethics within a societal context, it can assist with the transition toward green economies and sustainable societies. TE should focus on developing young people as responsible citizens alongside teaching them to be designers and creating technologies. To achieve this, a transformative pedagogy that is aimed at visualizing desirable futures and that leads to deep shifts in understanding, attitudes, and behavior should be applied in TE classrooms (Pavlova 2012). This pedagogy can help students recognize a situation as ethically (morally) problematic, enable them to have a voice and express their feelings and thoughts and to find a solution that serves the best interests of all parties and meets the vision for our planet (Pavlova 2012).

In summary, there are a number of challenges at different levels that are important to reflect upon.

At the level of curriculum: to understand the nature of sustainable development in TE (technical fix – value change) as some curricula adopt a very technocratic approach (e.g., Hong Kong) or focus on work requirements alone (e.g., Thailand); to understand a country's development priorities in terms of sustainable development.

At the level of school: to consider training requirements for teachers and the development of specific guidelines for incorporating sustainability in TE; to ensure a whole school approach for addressing sustainability, so teachers can reflect on their perceptions of SD and the ways it can be addressed through specific subjects such as TE within which multifaceted and coherent approaches are required.

At the student level: to develop values that support change in understanding and behavior in order to create a preferred sustainable future through design and technological solutions.

References

Australian Curriculum, Assessment and Reporting Authority. (2016). The technologies: key ideas [Internet]. Cited 2016 June 10. Available from http://www.australiancurriculum.edu.au/technologies/key-ideas

Board of Studies NSW. (2013a). Technology (mandatory) years 7–8 [Internet]. Updated 2003 June; cited 2016 June 10. Available from http://www.boardofstudies.nsw.edu.au/syllabus_sc/pdf_doc/technology_md_78_syl.pdf

Board of Studies NSW. (2013b). Design and technology stage 6 syllabus [Internet]. Updated 2008 August; cited 2016 June 10. Available from http://www.boardofstudies.nsw.edu.au/syllabus_hsc/pdf_doc/design-technology-st6-syl.pdf

Compton, V. J., & Compton, A. D. (2013). Teaching technological knowledge: Determining and supporting student learning of technological concepts. *International Journal of Technology and Design Education, 23*(3), 637–674.

Department for Education. (2013). Design and technology programmes of study: key stage 3. National curriculum in England [Internet]. [Updated on 2013 September; cited 2016 June 10]. Available from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/239089/SECONDARY_national_curriculum_-_Design_and_technology.pdf

Department of Education, Training and Employment (DETE). (2001). *South Australian curriculum standards and accountability framework* (SACSA). URL: http://www.sacsa.sa.edu.au

Education Bureau. (2013a). 高中設計與應用科技課程主題式學習活動(六).

Education Bureau. (2013b). 高中設計與應用科技課程主題式學習活動(九).

Elshof, L. (2005). Teachers' interpretations of sustainable development. *International Journal of Technology and Design Education, 15*(2), 173–186.

Elshof L. (2009). Towards sustainable practices in technology education. *International Journal of Technology and Design Education, 19*(2), 133–147.

Freire, P., & Macedo, D. P. (1995). A dialogue: culture, language, race. *Harvard Educational Review, 65*, 377–402.

Haug, A. (2016). Educating ethical designers. *International Journal of Technology and Design Education, 26*(3), 1–11. DOI: 10.1007/s10798-016-9367-y .

Hill, A. M., Elshof, L. (2007). Sustainable practices as an aspect of technological literacy: Research findings from secondary school teachers' and their classrooms. Paper presented at the PATT-18 Pupils Attitudes Towards technology International Conference on Design and Technology education research, Glasgow.

IUCN, UNEP, & WWF. (1991). *Caring for the earth: A strategy for sustainable living*. Gland: IUCN.

Keirl, S. (2015). Global ethics, sustainability, and design and technology education. In K. Stable & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 33–52). Rotterdam: Sense Publishers.

McGarr, O. (2010). Education for sustainable development in technology education in Irish schools: A curriculum analysis. *International Journal of Technology and Design Education, 20*(3), 317–332.

McMahon, M. & Bhamra, T. (2016). Mapping the journey: Visualising collaborative experiences for sustainable design education. *International Journal of Technology and Design Education*, 1–15.

Middleton, H. (2009). Problem-solving in technology education as an approach to education for sustainable development. *International Journal of Technology and Design Education, 19*(2), 187–197.

New Zealand Government Ministry of Education. (2012a). Indicators of progression for the learning objectives for the technology specialist knowledge and skills strands [Internet]. Updated 2012 December; cited 2016 June 10. Available from http://technology.tki.org.nz/content/download/36231/179049/file/LO%20IOPs%2002%20DET_%20Knowledge%20of%20Design.pdf

New Zealand Government Ministry of Education. (2012b). Manufacturing: Knowledge of manufacturing [Internet]. Updated 2012 December; cited 2016 June 10. Available from http://technology.tki.org.nz/content/download/36233/179055/file/LO%20IOPs%2004%20MFG_%20Knowledge%20of%20Manufacturing.pdf

New Zealand Government Ministry of Education. (2013). Specialist strands and component descriptors [Internet]. Updated 2013 October 7; cited 2016 June 10. Available from http://seniorsecondary.tki.org.nz/Technology/Learning-area-structure/Specialist-strands-and-components

New Zealand Government Ministry of Education. (2015a). Manufacturing: Learning objectives, indicators of progression, and teacher guidance [Internet]. Updated 2012 December; cited 2016 June 10. Available from http://technology.tki.org.nz/content/download/36144/178318/file/Indicators-Manufacturing-loaded%20june%202015.pdf

New Zealand Government Ministry of Education. (2015b). Design and visual communication: Learning objectives, indicators of progression, and teacher guidance [Internet]. Updated 2012 December; cited 2016 June 10. Available from http://technology.tki.org.nz/content/download/36153/178377/file/Indicators-DVC-loaded%20june%202015.pdf

New Zealand Qualifications Authority. (2014). Authority achievement standard [Internet]. Updated 2014 November 20; cited 2016 June 10. Available from http://www.nzqa.govt.nz/nqfdocs/ncea-resource/achievements/2015/as91363.pdf

Papanek, V. (1995). *The green imperative: Ecology and ethics in design and architecture*. London: Thames & Hudson.

Pavlova, M. (2006a). Education for sustainable development: The nature of the issue in the multicultural world. In P. Ruohotie & R. Maclean (Eds.), *Communication and learning in the multicultural world*. Hameenlinna: University of Tampere Press.

Pavlova, M. (2006b). Comparing perspectives: comparative research in technology education. In M. de Vries & I. Mottier (Eds.), *International handbook of technology education: Reviewing the past twenty years*. Rotterdam/Taipei: Sense Publishers.

Pavlova, M. (2009a). *Technology and vocational education for sustainable development: Empowering individuals for the future*. Dordrecht: Springer.

Pavlova, M. (2009b). Conceptualisation of technology education within the paradigm of sustainable development. *International Journal of Technology and Design Education, 19*, 109–132.

Pavlova, M. (2009c). Editorial to the special issue of the journal: Introduction. *International Journal of Technology and Design Education, 19*(2), 105–107.

Pavlova, M. (2011). ESD through technology education: Contextualisation of approaches. *African Journal of Research in Mathematics, Science and Technology Education, 15*(3), 41–55.

Pavlova, M.. (2012). Perceptions of sustainable development and education for sustainable development by African technology education academics. In T. Ginner, J. Hallstrom, M. Hulten, (Eds.). Technology Education for the 21st Century, proceedings of the PATT 26 conference, Stockholm.

Pavlova, M. (2013). Teaching and learning for sustainable development: ESD research in technology education. *International Journal of Technology and Design Education, 23*(3), 733–748.

Pavlova, M. (2015). Design and technology education for sustainable futures: In preparation for global citizenship. In K. Stable & S. Keirl (Eds.), *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures* (pp. 87–100). Rotterdam: Sense Publishers.

Pavlova, M., & Turner, S. (2007). It's never too early: Education for sustainable development. *The International Journal of Environmental, Cultural, Economic and Social Sustainability, 2*(7), 69–76.

Pitt, J., & Lubben, F. (2009). The social agenda of education for sustainable development within Design & Technology: The case of the sustainable design award. *International Journal of Technology and Design Education, 19*(2), 167–186.

Queensland Studies Authority. (2007). *Technology studies syllabus*. Brisbane: The State of Queensland.

Ritz, J. M., & Martin, G. (2013). Research needs for technology education: An international perspective. *International Journal of Technology and Design Education, 23*, 767–783.

Robinson, J. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics, 48*, 369–384.

Rockstroh, D. (2013). Are we there yet? Questioning whether sustainability is the destination or journey for design & technology education. PATT 27 conference proceedings. Technology Education for the Future: A Play on Sustainability, Dec 2–6, 2013, Christchurch. Cited 2016 June 10. Available from https://www.academia.edu/5662472/Editor_of_PATT_27_Conference_Proceedings_Technology_Education_for_the_Future_A_Play_on_Sustainability?auto=download

Rohaan, E. J., Taconis, R., Wim, M. G., & Jochems, W. M. G. (2009). Measuring teachers' pedagogical content knowledge in primary technology education. *Research in Science Technological Education, 27*(3), 327–338.

Rohaan, E. J., Taconis, R., Wim, M. G., & Jochems, W. M. G. (2010). Reviewing the relations between teachers' knowledge and pupils' attitude in the field of primary technology education. *International Journal of Technology and Design Education, 20*(1), 15–26.

Ruff, C. L., & Olson, M. A. (2009). The attitudes of interior design students towards sustainability. *International Journal of Technology and Design Education, 19*(1), 67–77.

Stables, K., & Keirl, S. (Eds.). (2015). *Environment, ethics and cultures: Design and technology education's contribution to sustainable global futures*. Rotterdam: Sense Publishers.

The Ministry of Education, Thailand. (2008). The basic education core curriculum B.E. 2551 (A.D. 2008) [Internet]. Updated 2008 July 11; cited 2016 June 10. Available from http://www.act.ac.th/document/1741.pdf

UNDP. (2016). Helen Clark: Keynote speech on leveraging innovation for sustainable development [Internet]. Updated on 2016 May 18; cited 2016 June 10. Available from http://www.undp.org/content/undp/en/home/presscenter/speeches/2016/05/18/helen-clark-keynote-speech-on-leveraging-innovation-for-sustainable-development-.html

UNEP. (2011). Towards a green economy: Pathways to sustainable development and poverty eradication [Internet]. France: UNEP. Cited 2016 June 10. Available from https://docs.google.com/gview?url=http://sustainabledevelopment.un.org/content/documents/126GER_synthesis_en.pdf&embedded=true

UNESCO. (2012). ESD sourcebook: Learning & training tools, no. 4 [Internet]. Paris: UNESCO. Cited 2016 June 10. Available from http://unesdoc.unesco.org/images/0021/002163/216383e.pdf

UNESCO. (2005). United Nations decade of education for sustainable development 2005–2014. International Implementation Scheme, Draft, January 2005. Paris: UNESCO.

Williams, P. J. (2015). Research in technology education: Looking back to move forward . . . again. *International Journal of Technology and Design Education*, 1–9.

Industry Involvement in Technology Education

59

Gabriele Graube and Ingelore Mammes

Abstract

Industry 4.0 is omnipresent and describes the optimization of production through establishing communication between humans and machines. Hereby it repositions the human in the socio-technological framework of the digital world. Such a shift in roles, among others from being a user to being a creator, also has to lead to changes in technological education and convey necessary skills and competencies in order to make people capable of acting in such a socio-technological system. In the background of Industry 4.0, technological processes are hardly visible in school education. The illustration of the processes is complex and needs adequate equipment and expertise. Schools can hardly afford those challenges. Thus, it has to be discussed if and how companies can get involved in this mission of education, especially because they need qualified employees.

Keywords

Digital word • Industry 4.0 • Responsibility of industry • Socio technology system • Technological education

Contents

G. Graube
Technical University of Braunschweig, Braunschweig, Germany
e-mail: g.graube@tu-braunschweig.de

I. Mammes (✉)
Faculty of Education, University Duisburg-Essen, Essen, Germany
e-mail: ingelore.mammes@uni-due.de

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_60

Introduction

The modern society is a knowledge-based one in which the remarkableness of knowledge, especially technological knowledge, increases due to the use of exigent technologies in services, households as well as industry. This technological change is reinforced by a new development, namely, Industry 4.0, and thus introduces a digital dimension for technology education. Industry 4.0 is defined as the fourth Industrial Revolution and designates the increasing interlinking of production and information as well as communications technology. Hereby the focus is on the application of internet technology in the context of communication between people and machines with the aim of optimizing technical processes. Thus, digitalization is omnipresent and does not only change technology but also society and people's relation to technology and therefore has an influence on society itself.

While mass production led to an exclusion of the individual from processes of design and production during the third Industrial Revolution, digitalization now opens up ways of shaping individual products. Herewith the individual is granted freedom of design and becomes the creator of his product. Although this conception is still at an early stage, further development in the direction of products that are adjusted to people's demands is on its way (customized production).

This fourth Industrial Revolution therefore leads to profound and permanent transformations of economic and social relationships, working and living conditions, and demands people to reorientate within the socio-technological framework. Hereby it should be scrutinized where the individual anchors himself within the system and, resulting therefrom, which competencies need to be acquired in order for him to remain capable of acting within this system.

But it also has to be examined which form of education would be worthwhile against the background of mature individuals. Against the background of Industry 4.0, technological processes are hardly visible in school education. The illustration of the processes is complex and needs adequate equipment and expertise. Schools can hardly afford those challenges. Thus, it has to be discussed if and how companies can get involved in this mission of education especially because they are in need of qualified employees.

This chapter wants to present a first contribution to answering these and similar questions and thus give a thought-provoking impulse in the direction of a reorientation regarding the digital dimension of technology education.

Industry 4.0 and Technological Change

Industrial Revolutions always mark turning points in society which are identified through a fundamental and permanent reconstruction in forms of production and working as well as through a social change. The first Industrial Revolution was triggered in the middle of the eighteenth century by the introduction of mechanic production facilities (work machine) which were powered by hydropower and steam power (engines). Steam engines rendered the industrialization of the textile and iron industry possible. The characteristic of the second Industrial Revolution is the 1870 implementation of collaborative mass production with usage of electrical energy and assembly lines as well as conveyors. The third Industrial Revolution started with the beginning of the 1960s when electronic engineering and informational technology (digitalization) were introduced in order to further automatize processes of industrial production (Bauernhansl et al. 2014). Therefore, this revolution often goes by the names of Electronic Revolution or Digital Revolution.

The term Industry 4.0 now represents the fourth Industrial Revolution (cf. Roth 2016). However, it is not undisputed whether the far-reaching digitalization of data, the usage of this digital information, cyber-physical systems, and the global networking really mark a new industrial revolution. In this context, some only speak of this development as the "second phase of digitalization" (Hirsch-Kreinsen 2015). Insofar it remains to be clarified what makes the fourth Industrial Revolution fundamentally different from the third Industrial Revolution or whether the current development might be just another stage in the development of digitalization.

Definition/Explanation of Terms Regarding Industry 4.0

Digitalization initially includes the conversion of analog to digital data, their processing, storage, and transfer. As a consequence, new technologies have been developed to support these processes (e.g., internet technology) which were, however, mainly developed outside of the production sector. Thus, systems that are linked and communicate through the internet are treated as standard in many fields (e.g., Car2Car-Communication).

Transferring this fundamental concept – digitalization, interconnection, and communication of systems through the internet – onto the field of production is commonly understood as Industry 4.0 in Germany. In the USA, the same development is called ICC, "Industrial Internet Consortium"; Japan and Asia use the term IV-I, "Industrial Value-Chain Initiative" (bitkom 2016; Bauerhansl et al. 2014; Manzei et al. 2016). These synonyms also represent, just like the German term Industry 4.0, initiatives and consortiums for promoting and supporting research and development of internet technologies.

Characteristics for these new steps of production are the following (bitkom 2016; Roth 2016):

- Networking of all human and mechanical actors throughout the entire value chain through internet technologies
- Digitalization and real-time evaluation of all relevant information
- Significant increase in flexibility and improvement of added value throughout the entire life cycle of a product
- Optimization of customer benefit through intelligent and customized products and services

Through the explicit comprehension of the entire value chain throughout the life cycle of products as well as through the communication between humans, machines and products Industry 4.0 differs from the earlier developed concept of "Computer Integrated Manufacturing" (CIM) that dominated the 1970's. However, the Industry 4.0 subsumed technological concepts represent a combination and further development of old concepts, so that one should rather speak of an evolution than of a revolution (Roth 2016). From the technological perspective Industry 4.0 marks a consistent further development of computer-integrated production. Discourses revolving around Industry 4.0 are, however, not restricted to technological concepts but are by now carried out on a larger scale (Roth 2016):

- Core concept of internet technologies (cyber-physical systems, Internet of things, product lifecycle management, connected logistics (optimization of the value chain), manufacturing execution systems (MES))
- Standardization (standardization process, semantic interoperability from a sensor to the Cloud)
- Legal questions and security issues
- Role of the human: man-machine-collaboration, day-to-day work 4.0, (continuing) educational concepts suiting new demands

Stages of Development in Industry 4.0

Industry 4.0 is not designed as a self-contained construct but builds on three technological stages of development:

Stage 1 is characterized by the plentiful and omnipresent spread of computer technology – ubiquitous computing (Siepmann 2016): The development of information technology and communications technology and microelectronics led to a significant coalescence in hardware and software. Amongst others, processors, sensors, communication modules and memory modules could thus become more miniaturized, more energy-efficient, more powerful, and cheaper. As a result more and more products could and can be equipped with highly efficient computer components ("embedded computing"). The hereby evolved intelligent objects

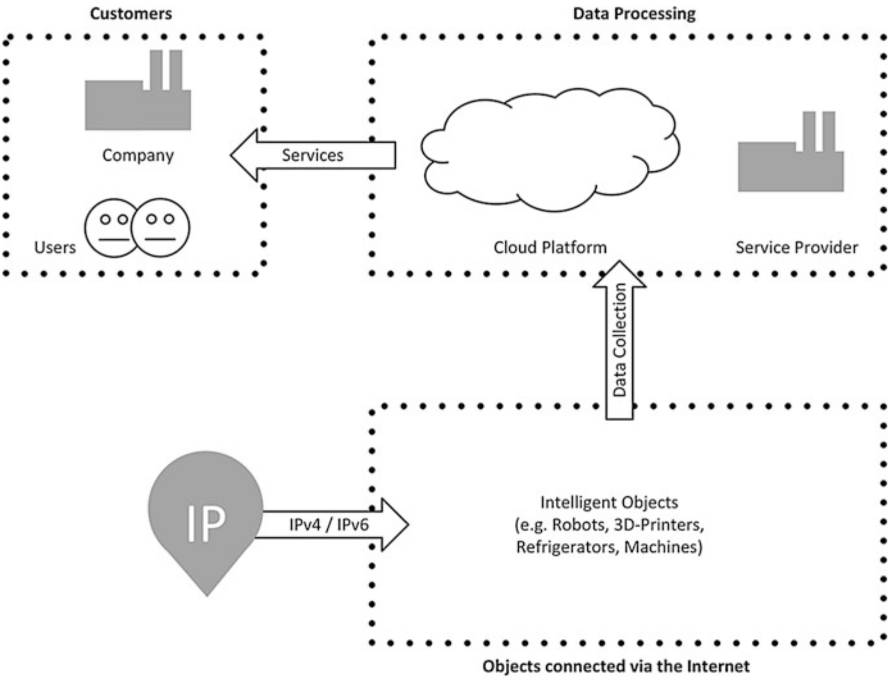


Fig. 1 Internet of Things (cf. Siepmann 2016, p. 27)

cover the fields of everyday objects, such as smoke detectors, refrigerators or coffee machines, smartphones and toys, as well as the field of manufacturing machines.

Stage 2 includes the creation of the Internet of things (Fig. 1) and services (IoTS) (Siepmann 2016): This stage is about extending the internet to intelligent objects. These objects have own IP addresses so that they can be explicitly identified while being online. In this way, linked objects permanently generate data while being used. This data can be retrieved and processed in order to offer services via the internet based on the collected data (e.g., smart cars, smart city, smart home, smart building, smart traffic, or smart grid). Thereby a communication between intelligent objects, the analysis of data, and the influence of processes is rendered possible without people having to be involved directly.

Stage 3 focuses on industrial production and should fundamentally change the traditional factory into a smart factory (Siepmann 2016): Today's factories are strongly horizontally dissected in means of organization as well as vertically-hierarchically structured. As a consequence, the communicational effort is very large. The basic idea for the implementation of cyber-physical product systems (CPPS) is to create self-organizing units that work independently and autonomously and therefore simplify the control of the company hierarchy. The groundwork for this are cyber-physical systems (CPS).

This phylogenetic view of Industry 4.0 clearly shows that the demands of technological development are indeed very high. However, it appears that something fundamentally new came into existence:

- The plentiful application of intelligent objects (digitalization) permanently generates data (big data). This data is – hereby differing from materials and energies – not limited and is as a matter of principle available as an infinite resource.
- A new industry emerged from the data collection and data processing: a data processing industry.
- The customers of this data processing industry are users of intelligent objects. Whether these users are companies – or even producing companies – or just smartphone users, is initially of no importance.

Cyber-Physical Systems (CPS): Features and Fields of Application

Digital replication, the virtualization of the real world, and the option of "intelligent" products as well as the integration of technological processes and business operations are all in the focus of Industry 4.0 (Manzei et al. 2016). Cyber-physical products hereby represent the key element as they connect the real world with the virtual world. CPS are technological systems (Fig. 2) that combine the following subsystems (Vogel-Heuser 2014):

- Sensors for data collection
- Actuators for operating physical processes
- Embedded computing for collecting data and controlling actuators
- Connection to the local area network (LAN) or wireless local area network (WLAN)
- Using local or worldwide accessible data and services
- Man-machine interface (e.g., language, gestures, keyboard, data goggles)

Draht (2014) distinguishes between three connected levels: On level 1 (physical objects), he places intelligent objects from which data is collected and returned to control data. On level 2 (data storage), data is memorized and passed on to level 3 for processing. On level 3 (service systems), data is processed with help of analyzing algorithms and evaluation programs. The processed data is then transferred to level 1 through level 2 for controlling.

Currently the basic principle of CPS is implemented in many fields of application: health care/medical (e.g., health check, blood pressure meter), sports fitness (e.g., sneaker, motorbike computer), car electronics, home security (baby care sensor, surveillance camera), home automation (e.g., air conditioner, lighting device), entertainment (e.g., camera, remote control, toys), wearable devices (e.g., watches, shirts), and industrial devices (cf. http://www.yuden.co.jp/ut/solutions/healthcare/product/3/).

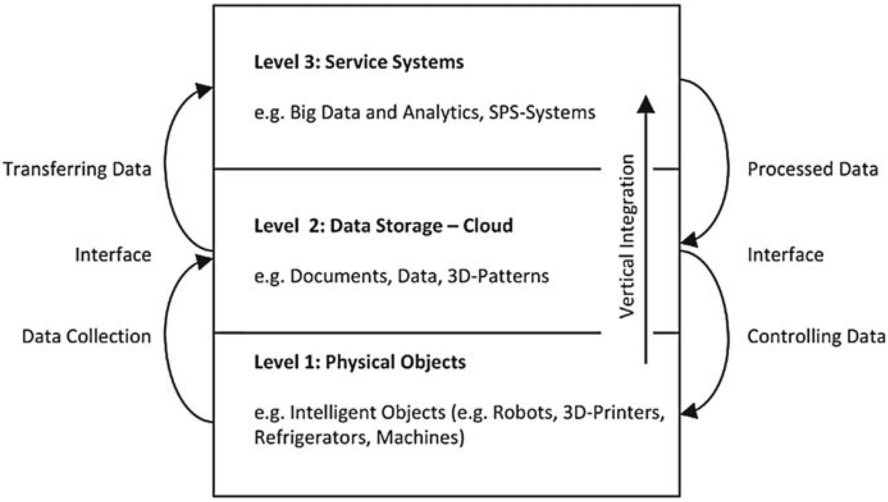


Fig. 2 CPS: cyber-physical system (cf. Draht 2014, p. 51)

Industrial applications thus are just one field of application out of many. Here again the production is only a section in which one can speak of cyber-physical-production systems (CPPS) and mean the third stage of development in Industry 4.0. In addition to this, CPS are, for instance, used for facility management (e.g., air conditioning management, lighting control) or in the security sector (e.g., open/close control) by the industry.

If consumers are asked for their ideas of further development in the field of digitalization, it becomes clear that they have great expectations for the functionality of intelligent products, connections, and services on the internet (Ericsson 2015). These range from voice control of household appliances up to implants for improving human performance (e.g., vision, memory, hearing). But such digital activities need digital skills and competencies. Thus, fears of a herewith linked digital pressure on developing such competencies are also expressed (Zweck et al. 2015).

Industry 4.0 as a Social Revolution

Industry 4.0 is, within a narrow understanding, a vision of a consistently digitalized production in which all actors in the entire value chain are linked and therefore render a high variety in products with a simultaneous automatization possible. In an extended understanding, Industry 4.0 is more than an individualized product from a smart factory, making the user a creator. The combination of intelligent products with efficient networks and services leads to a digital, agile space lattice in which everything becomes connectable and is able to communicate with each other. This affects all areas of social life. Herewith the term of socio-technology receives an entirely new dimension. Instead of Industry 4.0, one should rather speak of socio-technology 4.0 as it is more appropriate.

The design and development of subsystems of CPS require the inclusion of information technology and communication technology in each application domain. Hereby information technology and communication technology become interdisciplinary fields in processes of research and development. This inclusion should – modelled after the term interdisciplinary – be called digiplinarity.

In the following, these phenomena will be discussed against the background of education and the participation of industry in such educational processes.

Technology Education as a Mission of Industry

The Human in the Socio-Technological Framework of the Digital World

In an extended understanding, technology always contains technological as well as social subsystems that refer to each other, support each other, and require each other. People develop technological systems that are used by them or other humans. Thus, one can initially distinguish between two social roles: technology developer and technology operator. These two roles will be differentiated further for the above described CPS system in the following.

The role of developing is a crucial role because it determines the functionality of technological IT systems and their purpose in the social framework. This includes ICT professionals, software developers, programmers and administrators. They define data transformation through programs and are the "lords" to the raw material called data. They decide which and whose data is collected, which data is stored in which place, which data is processed in which way, who has access to the data, and who does not have access. Their performance includes the writing of programs and their adjustment to specific requirements. Hereby they define the occurrence of big data as well as the exploitation and utilization of this new "raw material." In the CPS model, they are placed on levels 2 (data storage and networks) and 3 (service systems).

Apart from these players, there are hardware developers who develop ICT subsystems in a physical shape (CPS level 1: physical objects, CPS level 2: data storage, networks). This includes computers, computer components, sensors, actuators, embedded systems, man-machine interface, and networks. The performance of hardware developers includes the construction of physical-technical subsystems which work as auxiliary systems for the extraction, the transfer, and the processing of data.

The role of the operator can be assigned to anyone who uses IT systems and serve as the operator at the human-machine interface. In other words, they get IT systems going. These systems can communicate autonomously with other technological systems and act independently from their intended purpose. Therefore, through the use of these systems, data evolves that is requested and intended by the user. But there is also a variety of data that is launched by backdropped programs. This process is normally not transparent for the user. Through his action the user becomes – aware or unaware – a producer of data. Herewith something new was called to life: operating becomes a source of big data.

In addition to these social roles that are characterized by activity and taking action, the human also has a technical role – a passive role – in the technological subsystem. A technological subsystem should initially transform an operand from its original state into a defined final state. If now the human himself is the holder of intelligent systems, he becomes an "embedded system." Health care/medical care are already now sectors in which this is practiced (e.g., cardiac pacemakers). And as users can imagine implants for increasing cognitive abilities (Zweck et al. 2015), it becomes even clearer which position the human has and can have. The human becomes part of a technological transformation system in which he incorporates sensors and actuators. Thus, he becomes a data source and data receiver. But he also becomes and operand, an object of work, which should be transferred from an original state into a defined state with the help of this data.

Following Marx's term of "asset," one might describe CPS generally as "data proliferating systems" or with regard to the "perpetuum mobile" also "perpetuum informatio." In addition to material resources (raw materials) and energetic resources (energy sources), another resource attracts the attention of technological development through the evolving data room. It generates through the use of technical subsystems and cannot be depleted – big data.

If machines communicate with each other and humans communicate with each other through ICT, communication, following Luhmann (2011), leads to a new quality in the gluing of social systems. The possibilities in information and communication are hereby not only a question of an interface between man and machine, but they also affect the nature of social systems. It is all about communication, information, thirst for knowledge, or also curiosity. This explains the pull and the fascination of and for technological systems. Through the penetration and networking of ICT in a variety of societal and personal sections, the tool character of this technology fades more and more into the background, and the system character gains importance. In the context of this understanding, one can speak of a digital society in which it seems impossible for the individual to escape these technologies even if people avoid technical artefacts.

Socio-technology 4.0 thus becomes a synonym for a tight network of human and mechanical actors which does not only develop and use technology but also generates data which can be industrially extracted and used for entirely new purposes.

The Aim of Education

The understanding of education is scrutinized and discussed again and again. Today the idea of education as the acquisition of defined curricula is rejected just as much as reducing the term "education" to training that aims for skills and direct usefulness. Especially against the background of experience from the twentieth century, it became clear that maturity and moral autonomy should be thought of as the outcome and aim of educational processes (cf. Jörissen and Marotzki 2009). They develop, continuing, and taking up Humboldt and Klafki's ideas, an understanding of education that is not based on a determined content but asks the question for the "place of the human in the overall structure of current socio-technological systems" (Jörissen and Marotzki 2009, p. 15).

Especially in the surplus of technological choices they see a necessity for the ability of orientation and for flexibility of individuals in order to be able to shape society in a responsible way. Therefore, with regard to self-determination, a reflection of the technological development and a reflection of one's own place in the socio-technological framework is needed. Hereby, education can be described as the acquisition of a differentiated societal problem awareness that may lead to an "increase in flexibility regarding self-reference and world-reference" (Marotzki 2009).

As Jörissen and Marotzki (2009) see education as the question for the "human's place within the overall structure of current socio-technological systems," it needs to be asked against the background of the shown developments whether and how the individual can succeed in orientating himself in the overflow of technological choices, in reflecting changes, in questioning positions and developments, and finally in shaping society responsibly. These are the criteria by which education will be judged.

Industry Involvement in Technology Education

Against the background of the phenomenon, Industry 4.0 education policy distinguished the necessity of appropriate education. Thus, campaigns for better STEM education have been postulated in many countries (Mammes and Graube 2016). Offering appropriate learning opportunities provides challenges for schools. On the one hand, they often do not have the financial capacities to offer adequate learning environments with latest learning tools and technologies (e.g., computer, 3D printer), and on the other hand, they do not have the technical know-how to educate with quality (Mammes et al. 2012). The problem of funding latest tools and technology for modern technology education can often be solved by donations or grants from organizations or industrial partners while the lack of knowledge and self-efficacy is more difficult to solve.

According to Shulman (1986), teaching knowledge encompasses three different forms of knowledge, the content knowledge, the pedagogical one, and the pedagogical-content knowledge. Content knowledge includes subject knowledge, justification of subject knowledge, and knowledge of relationships between subjects. Pedagogical knowledge is the knowledge of educational context while pedagogical content knowledge means the practical knowledge used by teachers to guide their action in classroom settings.

STEM teachers often do not hold the correlate content knowledge to teach a digital-oriented technology education. One reason may be that their teacher training dates back several years and content knowledge often cannot be developed in just one advanced training (Fischer et al. 2001). Also STEM teachers are often teaching outside their subject area. They are skilled in biology, chemistry, or physics and should teach technology but do not possess the appropriate teaching knowledge. That might be an obstacle to implement modern technology education (Graube and Mammes 2015). To avoid the lack of content knowledge, industrial partners could take part in technology education and impart important subject knowledge.

According to the BMWi (2014), e.g., in Germany, there are more than 15,000 STEM initiatives as extracurricular activities addressed to children and adolescents organized by universities, technology centers, as well as industrial enterprises (Graube and Mammes 2016). In particular, industrial enterprises with high research intensity offer well-equipped laboratories where students can gather experience with engineering and technology. In doing so, they should get insights into the business processes right from the ideation to the completed product and should also develop interest as well as skills. In such ways, skilled personnel as well as young scientists and engineers could be developed (Haupt et al. 2013). The "Baylabs" funded by the Bayer group are one example for the organization of such extracurricular learning settings. In appropriate equipped learning environments, students can deal with experiments of life sciences (biology, medicine, chemistry physics, and technology) guided by experts for 1 day in addition to everyday education.

Another example to bring technology education into schools through experts is the "Making Science Make Sense" project which is also funded by the Bayer group. Skilled employees are going into primary schools and work on experiments from natural sciences and/or technology together with the pupils. Founded in the USA in 1995, this project is now established in Brazil, Denmark, France, Great Britain, India, Ireland, Italy, Japan, Columbia, Singapore, and Taiwan (http://www.baylab.bayer.de/de/standort-berlin.aspx). Thus, industrial enterprises are willing to support an adequate technology education not only by providing appropriate environments but also adequate knowledge. However, it still has to be said that this expertise often simply consists of content knowledge and disregards pedagogical content knowledge as well as pedagogical knowledge. Ignoring pedagogical theories (e.g., the development of interest) could lead to an unbreakable disinterest of the students and let them avoid technology and career choices in technology fields (Mammes 2004).

To eliminate the aspects of adequate pedagogy in technology education as well as the lack of content knowledge and low budgets of the schools a cooperation between different kinds of expertise would be helpful. Such bridging is attempted by student labs. Their task is to let the students get distinct experience by self-dependent experiments and thereby develop interest and self-efficacy for dealing with technology also in their occupational choice (http://www.lernortlabor.de).

These projects are almost joint projects between economy, science, schools, and policy with cooperation agreements. This constellation ensures the integration of different perspectives in one conception:

– Schools are enabled to educate adequate technology education in addition to the school curricula.

– Industrial partners can contribute to educational objectives but also promote urgently required junior employees.
– Science and policy can ensure the implementation of desired educational objectives.

This may be an operating approach for a win-win-situation. Unfortunately there is less evidence of the effects of these learning settings so that we cannot draw any generalized conclusions.

Summary and Prospect

Industry 4.0 can be used as a synonym in order to show that technology and society change fundamentally. Behind digitalization, there is more than just the industrial production and its renunciation from mass production. It is about a network of human and mechanical actors in which not only technology is developed and used but in which also data is generated and industrially extracted and used for entirely new purposes. In this respect, one should rather speak of a socio-technological revolution than of an industrial revolution. Education systems now have to find an answer to the question of how this change needs to be positioned.

Modern technology education is understood as the ability to orientate within the overflow of choices and constant changes in the field of ICT as well as students being able to explain their own position/role, to reflect changes, to question positions and developments, and to finally be able to responsibly shape society. The challenge with shaping appropriate teaching/learning scenarios lies in focusing on developing technology as well as on critically questioning the digital society. Multidisciplinary teaching/learning concepts, such as "researching and developing" (Graube and Mammes 2015), represent an excellent starting point in order to on the one hand sharpen the developer role and on the other hand expand the concept to the key position of ICT.

For instance 3D printing has the potential to introduce learners to the developer role. Here, learners can easily experience an entire product life cycle by using ICT systems: by starting with the problem and own ideas, over the 3D construction on a computer and the production through the 3D printer and finally using the products, learning can actively participate in the process. Hereby, critically reflecting on their own actions should always be part of education processes. Herewith, digital education becomes, through ICT, "induced structural change in patterns of world-reference and self-reference" (Zorn 2014, p. 103) following Jörissen and Marotzki's term of media education.

The example of 3D printing also shows that digital education is always to be understood as a subfield of technology education which indeed primarily focuses on the category of information but always includes the categories of energy and material. Through developing constructive activity technology can be explored in all categories, showing respect to the world and self. In this way, learners experience themselves as being highly effective and thus edge away from the degrading status of being only a data source.

The debate on a future educational and competence canon in school, university, training, and further education which includes the challenges of a digital society has already started. It should be conducted openly as it offers the chance of finally assigning technology education the position that technology deserves due to its socio-technological character. In order to achieve this, a thorough theoretical and empirical enlightenment needs to take place.

Nevertheless, formal education in schools can often not fulfil this educational mission. Low school budgets do not offer the possibility of ordering latest tools and modern technology on the one hand, while on the other hand, teachers are often not well trained and do not have the teaching knowledge to teach modern technology. Inevitably the question of integrating industry partners in the educational mission has to be scrutinized. A cooperation between industrial partners, schools, educational policy, as well as scholarships seems to be meaningful in order to ensure the achievement of technology education objectives. Thus, an important task for future development work of technology education seems to be the investigating of such relationships to get evidence and to generate advice for future learning settings.

References

Bauerhansl, Thomas; Hompel, Michael; Vogel-Heuser, Birgit (Hg.) (2014): Industrie 4.0 in Produktion, Automatisierung und Logistik. Anwendung, Technologien, Migration. Wiesbaden: Springer Vieweg. Available online at http://dx.doi.org/10.1007/978-3-658-04682-8.

bitkom. (2016). *Industrie 4.0 – Status und Perspektiven*. Berlin: Studie.

Draht, R. (2014). Industrie 4.0 – eine Einführung. In B. Vogel-Heuser (Ed.), *Agenten im Umfeld von Industrie 4.0 [6. Expertenforum "Agenten im Umfeld von Industrie 4.0", 07./ 08. Mai 2014]*, *Tagungen und Berichte Universität München* (Vol. 4, 1st ed., pp. 47–56). Göttingen: Sierke.

Ericsson. (2015). *10 hot consumer trends 2016. An Ericsson consumer insight summary report*. Stockholm: Ericsson.

Fischer, H., Bos, W., Reyer, T., & Höllrich, N. (2001). Teachers' concepts and teaching strategies in Physicinstruction and their effects on instructional design and learning outcomes. In D. Psillos, P. Kariotoglou, V. Tselfes, G. Bsdikian, G. Fassoulopoulos, E. Hatzikraniotis, & M. Kallery (Eds.), *Proceedings of the third international conference on science education research in the knowledge based society* (pp. 220–222). Thessaloniki: Art of Text.

Graube, G., & Mammes, I. (2015). Forschen und Entwickeln als integrativer Lernbereich der Allgemeinbildung – eine Bildungsoffensive. In G. Graube & I. Mammes (Eds.), *Gesellschaft im Wandel. Konsequenzen für natur- und technikwissenschaftliche Bildung* (pp. 209–225). Bad Heilbrunn: Klinkhardt.

Graube, G., & Mammes, I. (2016). Pre-university engineering in Germany: Needs, possibilities and limits – A description. In M. J. de Vries, L. Gumaelius, & I.-B. Skogh (Eds.), *Pre-university engineering education*, *International technology education studies* (Vol. 1, pp. 47–64). Rotterdam, s.l.: SensePublisher.

Haupt, O. J., Domjahn, J., Martin, U., Skiebe-Corette, P., Vorst, S., Zehren, W., & Hempelmann, R. (2013). Schülerlabore – Begriffsschärfung und Kategorisierung. *MNU, 66*(6), 324–330.

Hirsch-Kreinsen, H. (2015). Einleitung: Digitalisierung industrieller Arbeit. In H. Hirsch-Kreinsen, P. Ittermann, & J. Niehaus (Eds.), *Digitalisierung industrieller Arbeit. Die Vision Industrie 4.0 und ihre sozialen Herausforderungen* (1st ed., pp. 9–1). Baden-Baden: Ed. Sigma.

Jörissen, B., & Marotzki, W. (2009). *Medienbildung – eine Einführung. Theorie - Methoden - Analysen*, *UTB Erziehungswissenschaft, Medienbildung* (Vol. 3189, 1st ed.). Bad Heilbrunn: Klinkhardt. Available online at http://www.utb-studi-e-book.de/9783838531892.

Luhmann, N. (2011). *Einführung in die Systemtheorie* (systemische Horizonte, 6th edn. Baecker, D., ed). Heidelberg: Carl-Auer-Verlag.

Mammes, I. (2004). Promotion girls' interest in technology through technology education: A research study. *International Journal of Technology and Design Education., 14*(14), 1–12.

Mammes, I., Schaper, N., & Johannes, S. (2012). Professionalism and teachers' beliefs in teaching technology education in primary schools in Germany – An area of conflict. In J. König (Ed.), *Pedagogical teachers beliefs and its relation to knowledge and performance* (pp. 91–109). Bad Heilbrunn: Klinkhardt.

König, J. (Ed.). *Pedagogical teachers' beliefs and its relation to knowledge and performance* (pp. 91–109). Bad Heilbrunn: Klinkhardt.

Manzei, C., Schleupner, L., & Heinze, R. (Eds.). (2016). *Industrie 4.0 im internationalen Kontext*. Berlin: VDE Verlag.

Roth, A. (Ed.). (2016). *Einführung und Umsetzung von Industrie 4.0. Vorgehensmodelle und Use Cases aus der Praxis* (1st ed.). Berlin/Heidelberg: Springer. Available online at http://www.gbv.eblib.com/patron/FullRecord.aspx?p=4398756.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*, 4–14.

Siepmann, D. (2016). Industrie 4.0 – Grundlagen und Gesamtzusammenhang. In A. Roth (Ed.), *Einführung und Umsetzung von Industrie 4.0. Vorgehensmodelle und Use Cases aus der Praxis* (1st ed., pp. 17–34). Berlin/Heidelberg: Springer.

Vogel-Heuser, B. (2014). Agent@PLC – Voraussetzungen und Konzepte für die Realisierung Cyber-Physical-Production-Systems. In B. Vogel-Heuser (Ed.), *Agenten im Umfeld von Industrie 4.0 [6. Expertenforum "Agenten im Umfeld von Industrie 4.0", 07./ 08. Mai 2014]*, *Tagungen und Berichte Universität München* (Vol. 4, 1st ed., pp. 63–70). Göttingen: Sierke.

Zorn, I. (2014). Selbst-, Welt- und Technologieverständnisse im Umgang mit Digitalen Medien. In W. Marotzki & N. Meder (Eds.), *Perspektiven der Medienbildung*, *Medienbildung und Gesellschaft* (Vol. 27, pp. 91–120). Wiesbaden: Springer VS.

Zweck, A., Holtmannspötter, D., Braun, M., Hirt, M., Kimpeler, S., & Warnke, P. (2015). *Gesellschaftliche Entwicklungen 2030. Ergebnisband 1 zur Suchphase von BMBF-Foresight Zyklus II*. Düsseldorf: VDI Technologiezentrum.

Online Sources

http://www.iiconsortium.org/
https://www.iv-i.org/en/
http://www.lernortlabor.de
http://www.baylab.bayer.de/de/standort-berlin.aspx

60 A Social Ecosystem of Distributed Learning Through the Braid of Technology Education and Communication

Maarten C. A. van der Sanden, Durdane Bayram-Jacobs, and Giovanni P. M. Stijnen

Abstract

We live with technology and we participate in innovation, as engineer, scientist, policy maker, business developer, pupil, university student, and citizen. Technology which enables and guides us at many stages in life, to formulate and achieve our goals, supports our social life, defines new horizons, and looks after our health and learning processes. People get acknowledged with technology individually, by their social network, formal education, media, and professional life. To better understanding of this socio-technical system, in which we all learn at various levels, in various contexts, and various moments of life, we elaborate in this chapter on the braid of technology education (TE) with technology communication (TC) and how they are interlinked through many micro connections in time. Furthermore, we state that if TE and TC are considered as elements in a social system of technology development, when they both are interconnected, then this TETC braid will sustain the societal challenge of responsible research and innovation. From a responsible or even ethical point of view, the contemporary societal context of responsible research and innovation (RRI) demands processes like social learning to which the TETC braid is fundamental, theoretically and practically. Therefore it is inevitable that scholars and professionals should develop a much more holistic view on TE and TC for the benefit of individual, society, and innovation alike.

M.C.A. van der Sanden (✉) • D. Bayram-Jacobs
Science Communication, Science Education and Communication, Delft University of Technology, Delft, The Netherlands
e-mail: m.c.a.vandersanden@tudelft.nl; d.bayram-Jacobs@tudelft.nl

G.P.M. Stijnen
NEMO Kennislink, Amsterdam, Netherlands
e-mail: stijnen@e-nemo.nl

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_59

Keywords
Technology education • Technology communication • Social system of technology development • Life long learning • Social learning • Social ecosystem • Innovation

Contents

Introduction

Innovation is simply described as new technological or social developments. This could mean an improvement of existing technology or services to meet new requirements, or it could mean so-called new and emerging technologies such as robotics and nano computing. Innovation, furthermore, is described as closed innovation (within a company or organization) or as open innovation (trans-organizational collaboration, Chesbrough 2006). Characteristics of innovation processes are described as incremental (step by step), radical (new technology and new context of application), or disruptive (new simple technology or services, with low service level, entering the market, improve themselves, and may become market leader due course).

Furthermore, technological innovation is considered as a socio-technical system in which many stakeholders are involved and which follows an uncertain pathway from fuzzy front end of development until the marketing back end of introduction to end users (Markard and Truffer 2008). This system of collaboration and interaction of professionals and end-users integrates the individual level (micro), the group organization level (meso), and the society (macro) level (Bailey 1994; Mitchell 2009; Schoeborn 2011; Cheung 2012; Van der Sanden and De Vries 2016). Moreover, innovation processes as, Markard and Truffer (2008) describe, could be seen as socio-technical system changes in which different levels such as niche (developments in physics education, developments in nanotechnology), regime (school system, start-ups), and landscape (educational beliefs, societal trends in entrepreneurship, leadership, political climate) all play a role. A niche is to be considered as actors, networks, and supportive institutions and is the least aggregated and mostly just refers to a single application context. A regime is to be seen as a set of rules carried out by different social groups in interlinked niches. And a patchwork of regimes is seen as a landscape of trends in innovation and other societal developments, e.g., individualization. Moreover, these three levels are dynamically interlinked (Geels and Schot 2007; Markard and Truffer 2008). Geels and Schot (2007), describe how the regime continuously absorbs changes in the niche and landscape, and from which bigger changes in innovation culture and regulations feedback to the landscape and niche, leading to both social changes in the collaborative network and changes in technology and/or its applications.

Social Learning

The dynamic interlinkages of the stakeholders at the various levels of innovation could be seen as a process of social learning. As Wenger (2000) states that the success of organizations depends on their ability to design themselves as social learning systems in which alignment between stakeholders, leverage of engagement, and shared imagination are necessities. Moreover, as Wenger (2000) describes these collaborative networks could be described from a community, identity, and boundary perspective. Meaning that identities of the stakeholders of innovation processes are shaped by their collaborative networks when they discuss differences in knowledge, behavior, and cultural and ethical viewpoints at various formal and informal meetings. The latter Wenger (2000) describes as boundary processes of boundary objects.

When we look at this process of collaborative social learning at the level of micro-social order (Fonseca 2002; Leeuwis and Aarts 2011; Verouden et al. 2016), we see how small interactions between stakeholders are the fundamentals of how spaces for innovation (Leeuwis and Aarts 2011) are created in which people can do and think, and where mutual trust and confidence is developed. Verouden et al. (2016), for example, state that the subtle differences in communication between vocational communication and listening and staying silent mean a lot to the conversation. Then silence is strategically used for the good and bad of collaboration. Team members may stay silent for the sake of the discussion or consciously hold back information for strategic reasons. Also interactions for innovation at the team level, such as team congruence (Pennington 2008) or shared motivation for mutuality (Vermeij 2016), are a prerequisite for effective innovations, at the niche and eventually at the regime and landscape level.

Seen from this perspective, technology communication can be considered as, among the network of stakeholders, a distributed aspect of social learning (Van der Sanden and Flipse 2015). Now one also understands that these insights in the micro-social order help in understanding and implementing, for example, responsible research and innovation (RRI) on a daily basis. As Stilgoe et al. (2013) describe (and as cited by Flipse and Bayram-Jacobs 2016), this could be done by focusing on:

1. The *anticipation* of possible effects of the innovation under development
2. *Reflexivity* by the actors involved in the innovation process about both the process and its implications

3. *Inclusion* of viewpoints of both experts and nonexperts, who may or may not be affected by the innovation
4. *Responsiveness*, which relates to establishing a capacity to change the innovation process direction to possibly further accommodate broader viewpoints and reflexive insights and to prevent negative anticipated effects

An important stakeholder of innovation and its accompanying micro-social order of social learning are the lay audience, people like all of us, who have a professional and a private life during which we are confronted with technological development from a practical and societal (i.e., RRI) perspective. Meaning that we use technology, and we live with and between technology and its development, and we develop knowledge and opinions upon such technological developments through formal and informal education and communication with our peers. And here we see how on this microlevel of our social lives TE and TC is mutually linked.

In the remainder of this chapter, we will first focus on technology communication, followed by the classical connection between TE and TC, informal learning. Then we will describe a TE case in which pupils learn about the connections between what the media say about technological developments and how to reflect on this. Eventually, this process of mutual reflection between teachers and pupils leads, or partly leads, to collaboration between pupils, teachers, scientists, and institutions of informal technology education. We then describe a TC case in which a lay audience is invited to cocreate or codesign new technology or new services concerning, e.g., smart cities. We conclude by conceptually connecting these two TE and TC initiatives in order to show how this TETC braid will sustain the societal challenge of responsible research and innovation. We conclude by saying that from a professional, responsible, or even ethical point of view, the contemporary societal context of responsible research and innovation (RRI) demands processes like social learning to which the TETC braid is fundamental, theoretically and practically. Therefore it is inevitable that scholars and professionals should develop a much more holistic view on TE and TC for the individual, society, and innovation alike.

Technology Communication

Van der Sanden and De Vries (2016) mentioned earlier that the four "classical" models of science communication as Lewenstein (2003) describes are a comprehensive overview of what science communication, and for that matter technology communication, is: the deficit, contextual, lay expertise and the public participation model. The deficit model is about the lack/deficit of scientific literacy; this acknowledges, as Lewenstein writes, that individuals do not simply respond as empty containers to information but rather process information according to social and psychological schemas that have been shaped by their previous experiences, cultural context, and personal circumstances. The contextual model emphasizes that the same information can have different meaning for a different audience. The lay expertise model, begins with local knowledge, is based in the lives and histories of real communities. About the fourth model, Lewenstein explains that because of the importance of social trust as it is an issue in policy disputes about scientific and technical issues, a "public participation" or "public engagement" model has emerged, focusing on a series of activities intended to enhance public participation and hence trust in science policy.

From a socio-technical system point of view, we know that these models are neither exclusive nor is there a best predictable fit with reality (Van der Sanden and Meijman 2008; Trench 2008). Also Lewenstein (2003) explains that these models provide only a schematic tool for understanding public communication of science activities. In practice, many activities combine elements of the different models, for example, by including information about basic scientific issues in the background materials for public engagement activities such as consensus conferences.

As the process of technology development becomes more dependent on collaboration in multidisciplinary networks in which new (innovative) ideas are codeveloped, technological development is also seen as a complex "socio-technical system" (Bailey 1994), a system in which scientists, industry, government, and the public coexist, collaborate, and cocreate, while their goals, values, and needs are intertwined. In such collaborations communication plays a crucial role to overcome potential social boundaries, e.g., dilemmas in cooperation if one wants to reach, as aforementioned, goal congruence in teams (Pennington 2008, 2011) or social learning between stakeholders (Wenger 2000). Thereby, the role of a technology communication officer can change to that of a broker (Meyer 2010) or coach (Van der Sanden and Osseweijer 2011). From this distributed perspective, TC becomes a distributed system element in a socio-technical system of technology development in which each actor has a communicative role, function, and tasks that need to be stimulated, supported, and trained, for real-world complex and dynamic multidisciplinary collaboration in all stages of science and innovation (Van der Sanden and Flipse 2015).

Classical Connections

There is "classical" linking pin between TE and TC, namely: informal TE and/or citizen science. TE programs at science centers and science events empower youngsters and adults to consider a higher education program on science and technology or to reflect on new research and design in their own professional life (McKinnon and Vos 2016; Schiele 2008). They may even participate in a citizen science program as lay audience or as a lay researcher doing research together with a lay audience. People learn about the content and process of science and technology developments by participating in research, and execute small, easy-to-elaborate experiments, or they simply count birds.

Informal technology education and citizen science are to a certain extent well researched (Bonney et al. 2009). Critiques on these events are that these engagement and dialogue processes and citizen science projects are often developed as single time interventions, most of the time isolated interventions, not connected in a (n) (inter)national overarching program (Van der Sanden and Flipse 2015, 2016). Of course, there are overarching thematic approaches such as for robotics or nanotechnology, but on the level of actions and events – TC process level – they are often not coordinated or connected as such. So, despite measured positive effects on awareness of technology developments (Jensen 2015), there is much potential in a more precise connection between single events, such as citizenship projects and science center exhibitions on a TC level, in such a way that they at least enhance each other. Then TC generates a comprehensive program for a lay audience interested in, for example, the technical challenges of engineering robots and the safety aspects concerning societal implementation seen from a health care perspective. Such overarching programs at the process level of TE and TC start from the formal TE program at primary and secondary schools.

Nowadays once children or adults have become ambassadors of technology or at least have some interest in technology, it gets more difficult to keep track of diffusion of the (informal) education and communication effort taken (Van der Sanden and De Vries 2016). Their beliefs, thoughts, enthusiasm, critique, and knowledge about how technology diffuses fade away throughout society in the absence of a supporting grid of connected TE and TC processes. This entails that a single dialogue, or science café or any other science and technology communication event, is of course useful, but from a socio-technical process point of view, it should be integrated in the whole in which connecting details of interaction – based on that system technology education and communication perspective – become prescriptive.

Distributed Ideas, Beliefs, and Learning

This brings us to the idea of TE and TC as a social network of interactions, in which pupils, students, and adults move in time and learn and communicate about technology development. Meaning that we start to design small or smaller interlinked TE and TC interfaces that have (1) a close fit with private daily life and (2) connections with professional processes of high-tech innovations in companies and organizations. Then stakeholders in both formal and informal TE processes, and stakeholders in TC processes, such as open innovations, develop a network of interlinked events on various levels of interest and beliefs that start at secondary schools and carry further throughout someone's personal and professional life. However, these networks are to be seen as ill-defined and ill-structured education and communication problems that are in need of system- and subsequently design-thinking to be understood in the first place and designed from a social learning perspective in the second place (Van der Sanden and De Vries 2016; Tromp 2013; Wenger 2000). In the next sections, we will first focus on the above described challenge from a TE perspective followed by a TC perspective.

ENGAGE

ENGAGE is a project (Grant No: 612269), which is funded under European Commission's 7th framework program, under the "science in society" call. The project aims at developing responsible research and innovation (RRI) inquiry skills of pupils to engage them in socio-scientific issues as responsive citizens of today's and tomorrow's society. Therefore, ENGAGE aims to change how teachers teach science as well as how pupils participate in science lessons. The project claims that to engage the young generation in scientific issues, how science and technology (STE) is taught at schools should be changed (Sherborne 2014). In fact, there is a consensus among the STE researchers about the need to change the way of technology teaching and the focus of STE (Aikenhead 2006; DeBoer 2000; Osborne 2007; Trigwell and Prosser 1996). In many education systems, STE is mainly content based (Aikenhead 2006; Bayram-Jacobs and Henze 2016; Deboer 2000; Hodson 1992). It means that STE focuses on knowledge acquisition, and it deals with a body of content. However, in the ENGAGE project by training teachers about group discussion, using dilemmas, and other participative skills, a perspective change is brought into STE, and abilities and skills to search for the broader perspective are developed.

The ENGAGE project operates in 11 countries (the UK, Greece, Germany, France, Romania, Israel, Spain, Norway, Switzerland, Lithuania, and Cyprus) where it aims to involve 12,000 teachers and 300,000 students. In this way, the project aims to bring change in STE on a broad scale. In this project, science educators, science communicators, formal and informal STE institutions, and scientists collaborate to engage young people in scientific argumentation, debate, and discussion processes. These interconnected events, as in SIL (Societal Interface Lab, see next section) principally make children think and talk about science. To be part of such processes, students need to have certain RRI inquiry skills. These skills as seen and discussed in a different way in the SIL section are shown in Fig. 1.

By focusing on these skills, ENGAGE desires to change traditional content-based and teacher-centered science lessons with student-centered science lessons where students are motivated to think and talk about science (Sherborne 2014). Moreover, the innovative education materials were developed by using the science in the news, which also contribute on shifting to student-centered lessons. Additionally, the pupils need to improve these RRI inquiry skills to participate in the discussions related to new technology, to reflect on societal implications of technology, and, in general, to be responsive citizens. In this way, science education has a key role in preparing the pupils, as future professionals, to collaborate and have dialogue with different stakeholders, and as lay public, to get engaged and involved in socio-scientific discussions.

ENGAGE has a three-stage continuous professional development (CPD) model to train teachers who will lead the desired change in STE. These stages are called "adopt," "adapt," and "transform" in the CPD framework of the project (see Fig. 2).

Adopt is the starting stage where teachers use ready-to-use ENGAGE materials. Although the materials are ready to use, some editing and adapting are expected from teachers to make the materials appropriate to their students. At this stage, teachers also learn the two pedagogical tools of ENGAGE which are "dilemma" and "group discussion" tools (Shwartz and Evagorou 2015). Moreover, teachers' further development is supported by workshops and online courses.

Adapt is the middle step of this CPD framework. Teachers at this stage are more expert in using materials. Therefore, ENGAGE provides them sequential materials which are longer (2–3 lessons), includes more RRI inquiry skills, and offers also extension and adaption opportunities. At this stage, teachers learn other two pedagogical tools such as "problem solving sequence tool" and "class discussions tool" (Shwartz and Evagorou 2015). "Problem solving sequence tool" fosters students' understanding about responsible decision making process on research and innovation, whereas with the help of "class discussions tool," the teacher teaches students how to be involved in the process of RRI.

Fig. 1 RRI inquiry skills in the ENGAGE framework (Okada and Bayram-Jacobs 2016, p. 4)

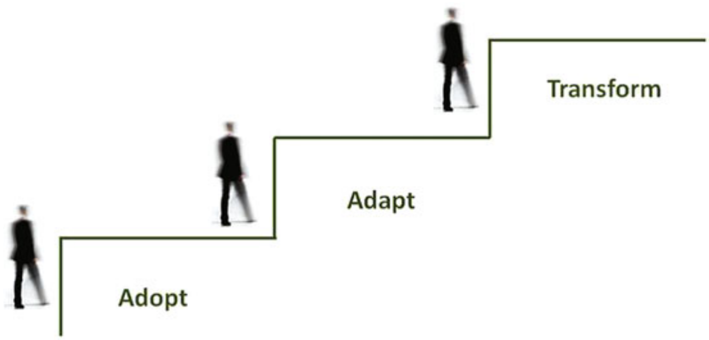


Fig. 2 Three-step transformational CPD model of the ENGAGE project (Sherborne 2014)

Transform is the last stage of this model, which aims that teachers and students set up their own projects rather than using ready materials. The main aim is to make students and teachers work with scientists and informal TE institutions. Therefore, bringing different stakeholders together is the core of the activities of this stage. When using such a key focus, technology communication plays a key role, and education strategies such as flipping the classroom (in which instructions are online and practice is done in the class room) gain more importance.

Early results of the ENGAGE's evaluation by Bayram-Jacobs and Henze (2016) indicate that science teachers' development of practical content knowledge (PCK) has improved in authentic lessons, where they applied innovative, RRI support materials and different teaching strategies based on ENGAGE material. Since many science teachers are used to content-based lessons, the findings of this study are encouraging and will be useful to develop training programs for improving RRI inquiry skills of students which are not covered in science lessons' content. These training programs may lead to the empowerment of science teachers, especially on aspects of new teaching strategies and assessment of students' skills.

The "ENGAGE Tree" (see Fig. 3 below) shows that at the start of a technology education course, the teacher kicks off with established PCK. However, by using ENGAGE the content starts to "branch out" in detailed knowledge fragments/branches/twigs due to the many angles discussed among the teacher and the pupils. So, for example, physics class starts with the basics on energy and thermodynamics. While the children discuss this content in the light of the development of smart cities, teachers together with pupils start to reflect and interact (direct or indirect) with other professional stakeholders (e.g., media). Figure 3 shows how the technology education program branches out in various topics, skills, and means of communicating and learning about new technology.

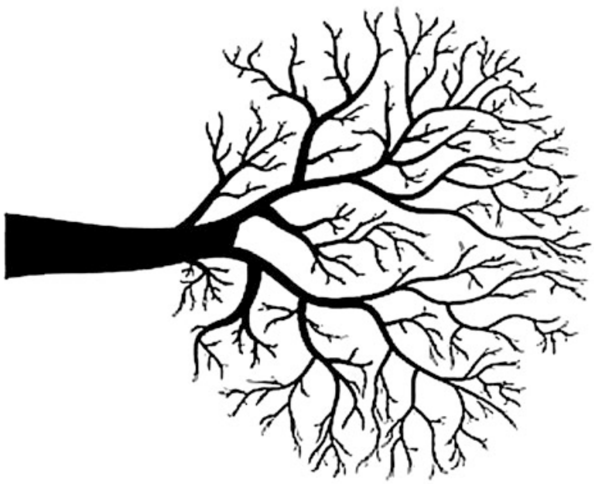


Fig. 3 ENGAGE Tree in which the interface with society is much more distributed (See text for further explanation)

Societal Interface Lab

NEMO Kennislink in a coalition with several regional partners in science, culture, and creative sector in Amsterdam, the Netherlands, have taken the initiative to develop a *Societal Interface Lab* (SIL) program (a program that is currently (2016) under construction). This idea emerges from the coalition's wish to be a forum for dialogue and hub for technology development. This means that NEMO Kennislink's mission is next to making people aware of and learn about new technological developments; they feed the ability to reflect on societal implications of technology by engaging in dialogue with different stakeholders. The idea is that this multi-stakeholder engagement process that is loosely orchestrated by moderators leads to new insights that are beneficial to all participants: it will hopefully lead to more socially robust technology development to form an opinion on technology and take part in debates. Theoretical foundations for this kind of processes are discussed with the engagement literature (Gilbert and Stocklmayer 2013), social learning (Wenger 2000), and cocreation and codesign (Tromp 2013; Stenfert 2016). The latter, for example, already is at place in many cities including Amsterdam in which the De Waag Society involves the lay audience to cocreate smart cities.

NEMO Kennislink wants to improve technology and make its developments by gathering, engaging, and empowering citizens, technology entrepreneurs, scientists, and policy makers in the early stages of technology development. In this way NEMO Kennislink not only has a societal role at the back end of developments but also takes responsibility at the fuzzy front end of development during which the aforementioned stakeholders need to collaborate. For example, scientists or start-up companies could share their ideas with a wide range of stakeholders concerning the responsible research and innovation (RRI) aspects in the early development stages at an SIL event. Subsequently, policy makers and business developers from industry could do the same. These team-up events are not exclusively located at NEMO Science Museum but might take place at universities, industry, and other many pop-up locations starting with the locations of coalition partners. For example, it might become a network of small interventions connected with each other on various topics concerning various aspects of RRI regarding technology at quite different stages of development. In itself any SIL event could be regarded as a temporary representation of the actual socio-technical innovation system for specific topics such as renewable energy or smart cities. The setting foreseen allows for direct interactions, and therefore you might call any SIL event a living scale model of the actual ecosystem in which people interact.

The basic idea for SIL originates from a "manifest way of thinking" (StudioLab 2017) in which the potential of new and emerging technology, positive or negative, is developed and displayed by artists. This is the way artists, for example, display complex and abstract technological development by using analogies, metaphors, and science and technology fictions, i.e., tissue-engineered leather purses. This may also be comparable with Fritz Lang's classical movie *Metropolis*, indicating an endless ocean of things to see, touch, and taste when it comes to technology development and innovations. Massimiamo Bucchi (1998) has written extensively about this, and he also mentions the "aesthetic" means of science and technology communication.

Artefacts such as tissue-engineered leather purses could be seen as a boundary object in which certain affective and cognitive aspects of technology surface, leading to astonishment, enthusiasm, hope, and fear. Roeser (2010) has extensively written about this subject of emotions connected to daily life and risky technologies. She writes that in moral decision making under uncertainty, people follow (that not only holds the lay audience, authors) their initial intuitions and "gut feelings." More in general this idea of biased decision making is extensively studied by Kahneman (2003) researching consumer behavior.

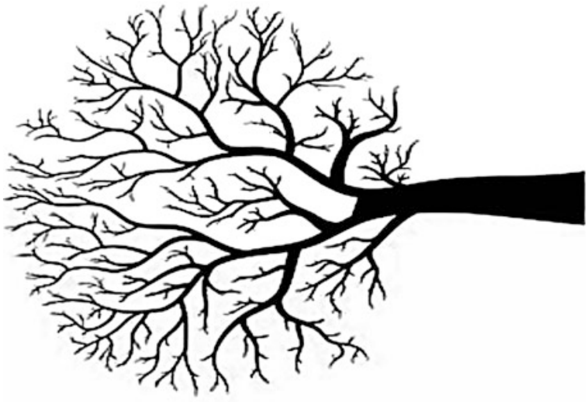
Then what is the added value of SIL? In science communication engagement and dialogue with the lay audience are central strategies to get citizens involved (Gilbert and Stocklmayer 2013). This of course is carried out in many different ways, e.g., citizen science projects, debates, science cafés, etc. However, all these events are loose or not coupled except from overarching technological themes such as robotics or nanotechnology, but there is no substantial integration between the input and output of these events; the processes designed, other than various reports, media attention, and various professionals; and science communication researchers meeting at national and international conferences such as ECSITE (2016) and PCST (2016).

The Societal Interface Lab NEMO Kennislink foresees and brings together various stakeholders in a multiple interactional environments in which people discuss, feel, and see technology developments. This is, so to speak, a "laboratory environment" in which technology is tried out, discussed, tested, and experimented with in different ways. This for the future happens at various places throughout the city at various times, concerning various partners/stakeholders. Meaning that small interventions in movie theatres, debate centers, museums, and the like on, for example, design fictions of nanofood (by M.C. Rozendaal 2017) or energy-generating cycle pathways (by D. Roosegaarde 2017) and small exhibitions about smart cities in railway stations lead to deep(er) learning processes for all stakeholders not only concerning the cognitive, rational aspects of new technology (single-loop learning) but also the affective emotional aspects of technology development (double-loop learning). This idea is partly based on, e.g., Kolb's (1983) pedagogical theories on various strategies of learning. From a socio-technical communication perspective, the rhythm of small interventions, with various stakeholders, concerning different new technologies has a closer fit to the rhythm of daily private life (Van der Sanden and Meijman 2012). So in an ideal world, various stakeholders will meet at various places in various situations during quite short and quite specific meetings and at various stages of innovations. So this is not about one big science communication event but about an interlinked small gatherings of stakeholders brainstorming or experiment, test, or play, with, new technology.

This less "sterile" environment in which emotions next to rational aspects surface might also lead to enhanced cocreation and open innovation since discussions can be held on different emotional and cognitive levels with all kinds of partners at the same time.

Earlier forms of the SIL-like ideas, such as the Societal Interface Group (SIG) in plant genomics (Hanssen and Gremmen 2012), proved to be successful. As the authors write*: analysis of the SIG sessions revealed that the input of public expertise*

Fig. 4 SIL Tree (See text for further explanation)



is not threatening or irrational, but provides the opportunity to harness the creative potential of future users highly relevant for the development of societal practices in which plant genomics play a role. However, SIL takes this idea further by moving up to the more fuzzy front end of innovations in which technological developments are about to take off.

The figure above shows how the various branches of the early technological development lead to robust and responsible introduction of new technology for and with society during SIL events, based on fuzzy front end gatherings, events, discussions, reflections, and anticipations on new and emerging technology in which knowledge, emotions, and beliefs are discussed by various people at various times but this time linked. Institutions as NEMO Kennislink, de Waag Society Amsterdam and technology teachers at various secondary schools, but also at applied universities and universities, may function as loosely coordinated hubs that keep interactions going and monitor and enhance this "movement." Since professionals such as engineers, scientists, business developers, and policy makers are involved in the many interactions whether by forming ideas, preparation, or implementation and execution, ideas about responsible implementation and improvement of the technology itself hopefully enter the core process of innovation, leading to responsible technology development at the level of the stem of the SIL Tree (see Fig. 4 above). In the following section, we will describe how TE processes connect with the various branches of the "SIL Tree."

A Social System Perspective: An "Ecosystem" of Technology Education and Communication

The word ecosystem is often (partially) used as an analogy of all kinds of interactive networks (technical, social, or socio-technical). Sometimes these analogies include details on, for example, waste recycling and energy flows (as is the case in industrial ecology, Korevaar 2004), and sometimes, as we learn from the literature on collaboration, "biodiversity" refers to, e.g., group diversity (Pennington 2011). Also cities are seen as ecosystems in which citizens and their built environment coexist. In this section we will merely focus on the idea of coupling "actions and emotions" connected to the development of new technology.

If we bring the two trees together, we see how the micro-interaction of ENGAGE connects with SIL micro-interactions in the, i.e., movie theatre discussed earlier. From SIL and from ENGAGE, it already became clear that TE and TC are about small interventions, based on the sociopsychological details of learning and interaction, in which emotions, precise rhythm of learning, and other elements of pedagogical and communication strategies are touched upon. And from the above, we learn that those details are also distributed and interlinked at various levels in a social network and stages of technological development. Meaning that, in an ideal world, pupils first learn through ENGAGE and then that evening take part in an SIL event. However, the change that happens here is rather small, let alone the a-synchronicity between individual learning processes and events organized. Hence, from a lifelong learning perspective, these connections in the socio-technical ecosystem may make sense. And in reality loosely in time-coupled grid of the ENGAGE Tree and the SIL Tree hopefully make people see how learning about technology, formal and informal, and hear and feel technology later on in one's life through technology communication is actually connected. These connections hopefully enable one to lifelong learn how to be reflective about new technology, be responsible, and be able to anticipate (see Fig. 5 below).

This tree analogy makes clear that interactions in the socio-technical system are no longer considered to stand alone or be isolated in time, target audience, or topic. Such an analogy may also help teachers, pupils, scientists, engineers, policy makers, and the lay audience to see the bigger picture of innovation while they learn, interact, cocreate, codesign, debate, discuss, or have a dialogue on new and emerging technologies.

Ethical Considerations

A current discussion in technology communication specific and in communication in general is the question if this kind of developments is strategic or nonstrategic. The problem is that many scholars in science and technology communication still find that, for example, science marketing should not be part of the science communication domain because of its aims of "convince" and "seduce" (Van der Sanden and Osseweijer 2011; Bud 2016). To compare the discussion on nudging (help people to take small steps in behavior change by positive feedback and not by forbidding certain behavior) in the Netherlands, the normative question is if the government can legitimately "manipulate" people in such a sophisticated way as is tried by nudging (Pol and Swankhuijsen 2015). That is not a discussion that is easily solved (if ever!); however we might use the same principles of RRI as they are used within ENGAGE and SIL: reflexivity, anticipation, and responsiveness. These should be design criteria for the kinds of close coupling of interactions of TE and TC. Meaning that the aims are explicitly articulated and clear, that all participants are not forced to participate in

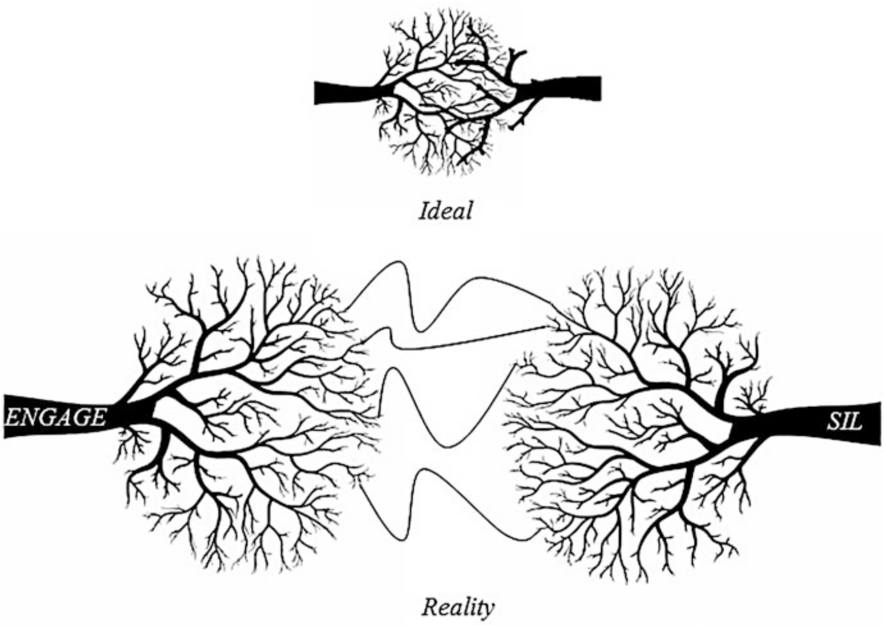


Fig. 5 Socio-technical ecosystem analogy. On the *right side*, you see the ENGAGE Tree and on the *left side*, the SIL Tree. Ideally they are closely interconnected physically and in time. In reality one sees loosely connected but nevertheless important connections between the ENGAGE Tree and the SIL Tree (See text for further explanation)

certain ways, and that connections and overarching themes are known. This kind of value sensitive design of ecosystems of distributed learning, in which TE and TC are connected, not only automatically leads to intended outcomes but is also transparent. Key performance indicators should be developed to keep track of these RRI keys during the process of lifelong learning. SIL therefore is a striking analogy, it is transparent and open, and failure of connection and learning is an option.

Next to transparency, we would like to emphasize that from a professional, responsible, or even ethical point of view, the contemporary societal context of responsible research and innovation (RRI) demands processes like social learning to which the TETC braid is fundamental, theoretically and practically. Therefore it is inevitable that scholars and professionals in TE and TC should develop a much more holistic view on TE and TC for individual, society, and innovation sake as ENGAGE and SIL do or attempt to do.

Conclusion and Future Directions

Technology education and technology communication could be considered as two different domains practically and theoretically from a deterministic perspective. Even informal science education can be seen from just a technology education and technology communication perspective. From a technology education and technology communication research point of view, we even might need to develop a new language practically and theoretically to describe the overlap or integration of technology education and technology communication as a topic on its own. But foremost, when they are considered as elements in the social system of technology development and as an ecosystem of distributed learning, they are interconnected, leading to mutual enhancement in a technology development ecosystem in which education and communication intertwine, supporting lifelong learning by having the ability and the opportunity and motivation to share ideas, knowledge, beliefs, and emotions. After all this TETC braid will sustain responsible research and innovation.

References

Aikenhead, G. S. (2006). *Science education for everyday life: Evidence-based practice*. New York: Teachers College Press.

Bailey, K. H. (1994). *Sociology and the new systems theory: Toward a theoretical synthesis*. New York: State University of New York Press.

Bayram-Jacobs, D., & Henze-Rietveld, I. (2016). *The influence of innovative, RRI support materials on teachers' practical knowledge*. National Association for Research in Science Teaching (NARST), 14–17 April, Baltimore.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *Bioscience, 59*(11), 977–984.

Bucchi, M. (1998). *Science and the media. Alternative routes in scientific communication*. Milan: Routledge.

Bud, R. (2016). Science, brands and the museum. *Journal of Science Communication, 15*(6), C03.

Chesbrough, H. (2006). *Open innovation the new imperative for creating and profiting from technology*. Boston: Harvard Business School Press.

Cheung, M. (2012). When mind, heart, and hands meet: Communication design and designers. *International Journal of Technology and Design Education, 22*, 489–511.

Deboer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37* (37), 582–601.

ECSITE (2016). Retrieved from: http://www.ecsite.eu/activities-and-services/ecsite-events/annual-conferences/ecsite-annual-conference-2015

Flipse, S. M., & Bayram-Jacobs, D. (2016). RRI bridges science education and communication. The innovator's perspective. In M. C. A. van der Sanden & M. J. de Vries (Eds.), *Science and technology education and communication. Seeking synergy.* Rotterdam: Sense Publishers.

Fonseca, J. (2002). *Complexity and innovation in organizations*. London: Routledge.

Geels, F. W., & Schot, J. (2007). Typology of societal transition pathways. *Research Policy, 36*(3), 399–417.

Gilbert, J. K., & Stocklmayer, S. M. (2013). *Communication and engagement with science and technology. Issues and dilemmas*. New York: Routledge.

Hanssen, J., & Gremmen, B. (2012). Influencing governance of a public-private partnership in plant genomics: The societal interface group as a new instrument for public involvement. *Public Understanding of Science, 22*(6), 718–729.

Hodson, D. (1992). In search of a meaningful relationship: An exploration of some issues relating to integration in science and science education. *International Journal of Science Education, 14*, 541–562.

Jensen, E. A. (2015). Evaluating impact and quality of experience in the 21st century: Using technology to narrow the gap between science communication research and practice. *Journal of Science Communication, 14*(3), C05.

Kahneman, D. (2003). Maps of bounded rationality: Psychology for behavioral economics. *The American Economic Review, 93*(5), 1449–1475.

Korevaar, G. (2004). *Sustainable chemical processes and products. New design methodology and design tools*. Delft: Eburon.

Kolb, D. A. (1983). Experiential learning: Experience as the source of learning and development. Englewood Cliffs, N.J.: Prentice Hall.

Leeuwis, C., & Aarts, N. (2011). Rethinking communication in innovation processes: Creating space for change in complex systems. *The Journal of Agricultural Education and Extension, 17* (1), 21–36. doi:10.1080/1389224X.2011.536344.

Lewenstein, B. V. (2003). Models of public communication of science and technology. *Public Understanding of Science, 16*, 1–11.

Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy, 37*, 596–615.

McKinnon, M., & Vos, J. (2016). Crossing a threshold. In M. C. A. van der Sanden & M. J. de Vries (Eds.), *Science and technology education and communication. Seeking synergy*. Rotterdam: Sense Publishers.

Meyer, M. (2010). The rise of knowledge broker. *Science Communication, 32*, 118–127.

Mitchell, M. (2009). *Complexity: A guided tour*. New York: Oxford University Press.

Okada, A., & Bayram-Jacobs, D. (2016, January). *Opportunities and challenges for equipping the next generation for responsible citizenship through the ENGAGE HUB*. Paper presented at International Conference on Responsible Research in Education and Management and its Impact, London.

Osborne, J. (2007). Science education for the twenty first century. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(3), 173–184.

PCST (2016). Retrieved from: http://pcst-2016.org/

Pennington, D. D. (2008). Cross-disciplinary collaboration and learning. *Ecology and Society*, *13* (2), 8, 55–68.

Pennington, D. D. (2011). Bridging the disciplinary divide: Co-creating research ideas in e-science teams. *Computer Supported Cooperative Work, 20*, 165–196.

Pol, B., & Swankhuijsen, C. (2015). Please don't nudge we're Dutch. *Magazine-C*.

Roeser, S. (Ed.). (2010). *Emotions and risky technologies*. Dordrecht: Springer.

Roosegaarde, D. (2017, February). Retrieved from: https://www.studioroosegaarde.net/info/

Rozendaal, M. C. (2017, February). Retrieved from: http://www.io.tudelft.nl/over-de-faculteit/persoonlijke-profielen/universitair-docenten/rozendaal-mc/

Schiele, B. (2008). Science museums and science centres. In M. Bucchi & B. Trench (Eds.), *Handbook of public communication of science and technology*. New York: Routledge.

Schoeborn, D. (2011). Organization as communication: A Luhmannian perspective. *Management Communication Quarterly, 25*(4), 663–689.

Sherborne T. (2014). *ENGAGE: Equipping the next generation for active engagement in science.* Retrieved July 1, 2014, from http://cordis.europa.eu/project/rcn/111469_en.html

Shwartz, Y., & Evagorou, M. (2015). Group Discussion Tool [Engage Project Documents]. Retrieved from Engage Project Shared Repository, https://docs.google.com/document/d/1YmBMyIecH4g8j1pXof9_4T9fWdA09hIsK0T3oxc0Ojo/edit#heading=h.d8qtd9gjm98g

Stenfert, H. (2016). *Co-creation in housing design: An exploration of the concept of co-creation, the co-creative design process and the practice of the co-creative architect*. Thesis, Delft University of Technology.

Stilgoe, J., Owen, R., & Macnaghten, P. (2013). Developing a framework for responsible innovation. *Research Policy, 42*(9), 1568–1580.

StudioLab (2017, February). Retrieved from: http://studiolabproject.eu/

Trench, B. (2008). Towards an analytical framework of science communication models. In D. Cheng, M. Cleassens, T. Cascoigne, J. Metcalfe, B. Schiele, & S. Shi (Eds.), *Communicating science in social contexts: New models, new practices*. New York: Springer.

Trigwell, K., & Prosser, M. (1996). Changing approaches to teaching: A relational perspective. *Studies in Higher Education, 21*(3), 275–284.

Tromp, N. (2013). *Social design: How products and services can help us act in ways that benefit society.* Thesis, Delft University of Technology.

Van der Sanden, M. C. A., & De Vries, M. J. (2016). Innovation in science and technology education and communication through design thinking. In M. C. A. van der Sanden & M. J. de Vries (Eds.), *Science and technology education and communication. Seeking synergy.* Rotterdam: Sense Publishers.

Van der Sanden, M. C. A., & Flipse, S. M. (2015). A cybernetic dream: How a crisis in social sciences leads us to a communication for innovation-laboratory. *Journal of Science Communication, 14*(01), Y01.

Van der Sanden, M. C. A., & Flipse, S. M. (2016). Science communication for uncertain science and innovation. *Journal of Science Communication, 15*(06), C05.

Van der Sanden, M. C. A., & Meijman, F. J. (2008). Dialogue guides awareness and understanding of science: An essay on different goals of dialogue leading to different science communication approaches. *Public Understanding of Science, 17*(1), 89–103.

Van der Sanden, M. C. A., & Meijman, F. J. (2012). A step-by-step approach for science communication practitioners: A design perspective. *Journal of Science Communication, 11* (02), A03.

Van der Sanden, M. C. A., & Osseweijer, P. (2011). Effectively embedding science communication in academia: A second paradigm shift? In D. J. Bennett & R. C. Jennings (Eds.), *Successful science communication: Telling like it is*. New York: Cambridge University Press.

Vermeij, R. (2016). *Reciprocity in wind farm development. An applied and theoretical approach*. Thesis, Delft University of Technology.

Verouden, N. W., Van der Sanden, M. C. A., & Aarts, N. (2016). Silence in interdisciplinary research collaboration: Not everything said is relevant, not everything relevant is said. *Science as Culture, 25*(4), 264–288.

Wenger, E. (2000). Communities of practice and social learning systems. *Organization, 7*(2), 225–246.

Gender and Technology Education 61

Sonja Niiranen

Abstract

Technology-oriented fields are still mostly male dominated. Increasing the number of women in natural science and technology careers remains an elusive goal in EU countries. Although gender equality and nondiscrimination have been critical, longtime concerns in education, gender-related divisions continue to occur in the field of technology and the subjects that pupils decide to study. Also, significant variations between girls' and boys' interest and behavior have been documented in technology education. In today's society, technology education plays an important role in providing children with opportunities and in improving their ability to interact with everyday technologies. Technology education also equips children with the necessary knowledge to perform a wide variety of jobs. In order to introduce a more equitable gender balance in higher education, technology-oriented fields, and, consequently, in the corresponding labor market, we must continue to expand our knowledge on the impact of current technology education and focus on gender-related issues. This chapter aims to discuss gender-related topics in technology education and careers. Could technology education have an impact on women and girls or potentially influence their advancement in technology-oriented fields? With the goal of achieving greater gender equality in technology fields, this chapter concludes with further directions for research and suggestions for new ways of thinking.

Keywords

Career aspiration • Gender • Gendered process • Interest • Technology education

S. Niiranen (✉)
Department of Teacher Education, University of Jyväskylä, Jyväskylä, Finland
e-mail: sonja.k.niiranen@jyu.fi

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_61

Contents

Introduction

In today's society, technology is playing an increasingly important role in most people's lives, and knowledge of technology and related abilities are vital for all citizens (Ardies 2015; Banks and Barlex 2014; Ritz and Fan 2015). However, technology has a deeply gendered history, and the discourses relating to gender and technology used to reflect this fact, labelling it as "masculine" or "not a place for a woman" (Layton 1993, 35 in Murphy 2006). Concern has been expressed for many years that relatively few women enter occupations in the natural sciences, yet the underrepresentation of women is even more striking in engineering and technology (e.g., Klapwijk and Rommes 2009; Mammes 2004; Sander 2012; European Commission 2013b). The low level of women in these fields deprives them of the opportunity to contribute toward research and innovation on an equal footing; given the different perspectives that women offer, the quality of research and innovation suffers as well (European Commission 2013b, 3). In order to introduce a more equitable gender balance, especially in technology-oriented fields, and, consequently, in the labor market, our knowledge of technology education and gender-related issues should continue to expand and to receive attention.

Gender can be seen as resulting from a complex cascade of biological and social-environmental factors (Lippa 2005, 259). Furthermore, gender is an important factor that influences speech, mannerisms, behavior, and our use of products and services that signal who we are in addition to establishing rules for interaction (European Commission 2013a). Murphy (2007, 240) states that gender is central to the way that life is organized and constructed and, therefore, is a significant element that influences our embedded thinking patterns and routines. Moreover, gender norms refer to the attitudes about the behaviors, preferences, products, professions, and knowledge that are appropriate for women and/or men (European Commission 2013a). These norms draw upon and reinforce gender stereotypes, which are widely held, idealized beliefs about women and men and the meaning of femininity and masculinity. Gender norms are produced through social institutions, such as families, schools, workplaces, and universities, and throughout wider cultural spheres via textbooks, literature, films, and video games (European Commission 2013a).

Gender, as a social construct, has been conceptualized in several different ways. The European Commission (2013a, 9), for example, defines gender as a sociocultural process that encompasses the cultural and social attitudes of a particular society. Together, such processes either shape or sanction "feminine" and "masculine" behaviors, products, technologies, environments, and knowledge (European Commission 2013a, 9). Thus, gender is not a static identity but rather a learned capacity to absorb and provide depictions of masculinity and femininity (McDermott 1996, citing Goffman in Murphy 2007, 240). Murphy (2007, 240) adds that representations of masculinity and femininity are often placed in opposition; in other words, what one is, the other is not. Blaine (2007) argues that even if gender categories help to organize cognitive resources through the development of stereotypes, there is a risk of discarding a great deal of information. Although few would disagree that the two sexes are physically different, scholars continually disagree over the related questions: Are the two sexes psychologically different? and do biological factors lead to sex differences in human behavior? (Lippa 2005, 85). Therefore, the influence of sex on gender remains an open question.

In terms of acquiring understanding and knowledge of technology, today's society places high demands on individuals as the technologies that mediate our lives become more complex (Elvstrand et al. 2012, 163; Dakers 2011). Technology education has been developed to help people understand technology and provide them with the tools and skills they need to utilize it. Banks and Barlex (2014, 75) reiterate the question posed by Layton (1993, 3): What do pupils learn from technological design and activity or through technology education that cannot be learned in any other way? They highlight the most general answer to this question in terms of capability: Technology education enables us to operate effectively and creatively in a human-made world. Thus, the goal is then to increase "competencies in the indeterminate zones of practice." (Layton 1993, 3 in Banks and Barlex 2014, 75.) Particularly, technology education enables students to actively engage and participate in practical and meaningful experiences and opportunities that also improve their technological knowledge and working skills (Järvinen and Rasinen 2015; Martin 2012). Furthermore, the hands-on nature of the subject helps students to better conceptualize scientific and technological concepts and their relationship to real-world uses (Ritz and Fan 2015). Meanwhile, Dakers (2011) notes that technology education curricula have also begun to emphasize other issues related to values and attitudes, such as ethics, sustainability, social, and moral impact, with the goal of providing a better framework to understand the modern technological world. As relevant to the implementation of technology education, the experience of children with technology is a matter of equal opportunities: All children should have the opportunity to gain technological literacy. Thus, technology education must be an important element of the overall educational system (Elvstrand et al. 2012). One challenge to achieving this goal is that technological literacy may be defined in several ways, and no consensus exists on the meaning of the term "technological literacy" (Dakers 2011). Although some countries have national standards for technology education at all educational levels, its specific subject status varies, and internationally, no common framework currently exists for teaching technology in primary and secondary schools (Cross 2011; de Vries 2005).

Technology Education

Attitudes toward technology are influenced from a young age. Research has shown that people's attitudes develop slowly over a long period and are influenced by many sources, such as parental perceptions, peers, and media (Ardies 2015; Lippa 2005; Volk 2007). From a young age, children experience social processes that expose them to ideas of what it means to be a girl or a boy in their society; they start to construct their identities through observation of others and participation in communities, such as peer groups (Paechter 2007). Other people, such as parents and educators, also have an influence during early childhood development via their reinforcement of attitudes and behaviors or their punishment of those that contradict gender norms (Turja et al. 2009). Children's toys and play were identified in the early 1980s as one major influence on the learning of gendered behavior patterns (Francis 2010). On average, boys prefer blocks, transportation toys, and construction toys (e.g., tool sets and construction sets) in addition to action-oriented or mock aggression toys (e.g., guns and swords), whereas girls play more with domestic toys (e.g., tea sets and play houses), dolls, and telephones (Lippa 2005, 158). Another study indicated that technology in the form of toys helps children to construct their gender identity at a very early age (Hallström et al. 2015). Children are also often directed toward certain types of play that afford opportunities for girls to develop communication skills and emotional literacy and for boys to develop technical knowledge and skills (Francis 2010). Thus, it can be pondered that since girls have less experience than boys in playing with technological toys, might they have difficulty in building a relationship with technology or an interest in technological careers and activities (Mammes 2004)? Research has also revealed that girls use technology in different ways compared to boys. When constructing something during play, girls often have a specific purpose in mind (to create an object for use); boys, on the other hand, often see the process of construction itself as play or as the main purpose of the playing (Elvstrand et al. 2012).

Girls and Boys in Technology Education

Hallström, Elvstrand, and Hellberg (2015) point out that gender-related behaviors in relation to technology are also obvious when children grow older; however, they involve several contradictions that cannot be reduced only to gender differences. Even so, significant variations in how girls and boys experience technology education have been documented (Ardies 2015b; Virtanen et al. 2015). Several studies have evidenced that girls generally tend to have lower self-efficacy or lack of self-confidence in relation to technology compared with boys, as early as primary school (Endepohls-Ulpe et al. 2012; Hallström et al. 2015; Virtanen et al. 2015). Despite boys' and girls' equal or near-equal achievement in mathematics and science, girls were shown to need more encouragement and support for their competencies in technological subjects (Endepohls-Ulpe 2012; Murphy 2007; Virtanen et al. 2015). Another study of the influence of teachers on students' self-efficacy and attitudes toward science studies found similar evidence: Perceived attention from a teacher was more closely related to self-efficacy in girls than in boys (de Weerd and Rommes 2012). Mammes (2004) notes that girls' lack of interest may result in a low level of attention or even a refusal to deal with technology, thereby leading to technological incompetence. In contrast, compared with girls, boys feel more self-confident and more eager to test and try something new, especially in relation to technological activities (Hallström et al. 2015; Virtanen et al. 2015). A study by Ardies (2015) also revealed that boys find technology less boring than girls and aspire to careers in a technical field to a greater extent than their female peers. This difference in interest becomes even greater with age, with boys demonstrating much greater interest in technology (Ardies et al. 2015). However, other evidence has shown that students will exhibit interest in technological fields and subjects if they have positive experiences with technology, are confident in their technical skills, have developed certain skills and experience in the area, and feel that a technical profession matches their self-image (Eccles 1987; Niiranen 2016).

Upon considering the motivational differences in girls and boys with respect to technology, girls have been found to be more interested than boys in studying environment-related issues (Virtanen et al. 2015). In Germany, for example, the number of women in environmental and chemistry studies and professions is higher than in other areas of science, technology, engineering, and mathematics (Quaiser-Pohl 2012). It has also been shown that girls, in particular, enjoy creating meaningful and useful projects when these have connections with their everyday life (Virtanen et al. 2015). Snape and Fox-Thurnbull (2013) noted that learners who consider the connections of technology with their own views, experiences, and understandings will be more motivated to engage with technology and participate in real and legitimate exercises. Would the implementation of authentic pedagogy and focus on applications of technology help girls to engage better with technology?

It can be only wondered to what extent childhood experiences set the stage for future interactions with technology. If girls tend to come into contact with technology less frequently than boys (at schools and in their free time), thus acquiring fewer experiences and knowledge of technology, one could ask what kind of effect this would have on their motivation to engage with technology as adults. The aforementioned studies have demonstrated the importance of conducting technical activities in class and that teachers can be influential in supporting pupils' motivation. Therefore, activities should be planned and presented in such a way that both genders would be interested in them. If pupils are engaged with meaningful activities, they might see technology as more relevant to their everyday lives and future careers.

Gendered Processes in Technology Education

All organizations have inequality regimes that can be loosely defined as interrelated practices, processes, actions, and meanings that maintain class, gender, and race inequality (Acker 2006). Acker (1990) argues that an organization or any other analytic unit, for example, a family or a school, has gendered patterns based on distinctions between the masculine and the feminine. These patterns include advantages and disadvantages, exploitation and control, action and emotion, and meaning and identity (Acker 1990, 146). Acker further describes how such social processes are often complex and how gendering occurs across distinct interactions that in reality form part of a similar practice, although analytically distinct (Acker 1990). As described previously, children's perceptions and valuation of technology are substantially shaped by a variety of experiences at school and at home.

Researchers have focused on the contribution of technology education to the development of young people by providing them with a wide range of knowledge and skills to participate in the rapidly changing societies of the future (Banks and Barlex 2014; Murphy 2007). If gender is seen as a social construction that emerges as pupils commit to certain meanings and positions based on their interaction with technology, then we can suppose that this construction is also malleable (Murphy 2007; van Aalderen-Smeets and van der Molen 2016). The main challenge is that gendered processes, i.e., interactions, symbols, and images, are often invisible. The reality remains that the extent to which pupils are prepared to participate in future technologies differs considerably depending on whether they are male or female (Murphy 2007; Virtanen et al. 2015). An example of gendered processes can be seen in the gender divisions between crafts, textile, and technical craft studies in some countries as well as in the entry trends in technology education that shows pupils' decision to study different technological subjects (Murphy 2007; Virtanen et al. 2015). Girls mainly study textile crafts/technology, while boys focus on technical crafts such as resistant materials or electronics. One might ask whether girls need encouragement to pursue a wider range of technical subjects, rather than those defined by the role of a traditional homemaker. And what about boys? Is it not equally important for boys to learn skills that are needed when using soft materials?

The image of technology as a masculine domain has been striking due to the fact that technology is remarkably male-dominated field and in technology education, the tendency has been that mostly male teachers are teaching it. Acker (1990) describes in her theory how "social interaction between women and men" is seen as a one type of the set of gendered processes. Research on experiences of females who chose to study technical craft and technology education and who were also working as teachers in basic education evidenced these processes (Niiranen and Hilmola 2016). All seven participants had experienced gendered patterns involving the enactment of dominance, submission, questioning, or wondering from male teachers, colleagues, technical support staff at school, or from boys at school (Niiranen and Hilmola 2016). In a similar vein, the Ministry of Education in Finland has advised that equality should be practiced with children even during small, fleeting moments, expressions, and gestures, which may unwittingly communicate gender bias or seem insignificant from the perspective of adults. However, small processes compose larger cultural structures (Committee on Alleviation of Segregation 2015). I argue that we must all, as part of the technology education community, reflect on our attitudes regarding gender and how we reflect these in our speech, gestures, actions, and behaviors. It is very important to be aware of what and how we as adults communicate with our pupils (see Murphy 2007). Negative communication and encounters should be replaced with positive and encouraging communication that supports the growth and development of pupils' identity and self-esteem. In order to achieve this, we should understand that there are individual differences as well as group differences between the needs, behaviors, and attitudes of girls and boys or women and men. Furthermore, attention should be placed on dismantling assumptions about what girls and boys can and want to do, and pupils should be offered the support needed to develop new learning habits (Murphy 2007).

Women in Technology-Oriented Fields

The opportunities women have to shape their own lives have dramatically increased in the past few decades (Quaiser-Pohl and Endepohls-Ulpe 2012). One of the main characteristics of contemporary labor markets is the remarkable increase in women's education. However, technology-oriented fields are still rather male dominated, and an effective approach for increasing the number of women in technology careers has not yet been achieved in EU countries (e.g., Klapwijk and Rommes 2009; Mammes 2004; Quaiser-Pohl 2012; Sander 2012; European Commission 2013b, 2016). Based on the European Commission "She Figures 2012" statistics, the share of women among highly educated people working as professionals or technicians is 53%, but the proportion drops to 32% among those employed specifically as scientists and engineers, a narrower category of employment (European Commission 2013b, 18). The new "She Figures 2015" statistics show that in recent years, some of these gender gaps have slowly been shrinking. Interestingly most progress has been made in the category of scientists and engineers (European Commission 2016). However, despite advances that have been made with regards to the proportion of women among tertiary education graduates, nevertheless inequalities persist, and a gender imbalance in favor of men still exists (European Commission 2016).

There are some clear differences between European countries in terms of women pursuing careers in science and technology – for example, the number of women in STEM fields in Eastern European countries, i.e., Bulgaria, Croatia, Latvia, Lithuania, and Romania, is notably higher than in other European countries (European Commission 2016; Quaiser-Pohl 2012). Quaiser-Pohl (2012, 54) reflects that the differences between countries could lie in various factors and their political and social structures, e.g., the educational system of a country, its economic situation, and its public and private institutions. In contrast, within the UK, many professions still seem to remain gender segregated. Many jobs are either male or female dominated, and most children and young people continue to prefer gender-appropriate jobs dominated by their own sex (Miller and Hayward 2006).

Gender-Related Career Aspirations

Factors that influence career development are broad and are often distinguished as being intrapersonal and contextual (van Tuijl and van der Molen 2016). The choices that men and women make are influenced by the options available to them, by their individual goals, attitudes, motivation, and self-definition and by the balance between the value of attainment and the perceived costs of various options (Endepohls-Ulpe et al. 2012; van Aalderen-Smeets and van der Molen 2016). Lippa (2005) has shown that sex differences in occupational preferences and interests are evident; men prefer realistic, "thing-oriented" occupations (e.g., mechanic, carpenter, engineer, and computer scientist), and in contrast, women prefer social and artistic "people-oriented" occupations, such as teacher, social worker, counselor, painter, and writer (Lippa 2005). Interestingly, however, in occupations that require creative and intellectual effort, there is virtually no sex difference (Lippa 2005). Van Tuijl and van der Molen (2016) also add that motivational forces such as interest, enjoyment, value, and perceived competence or self-efficacy are important aspects of career development. In conclusion, although the numbers show overall sex differences in occupational preferences, the low interest of women in technology-oriented fields is a complex problem and requires more research to explain the variety of factors that contribute to this lack of interest.

The most influential career anchor identified by women studying at university level and working in technology-oriented fields was their high level of competence in their chosen field (Engström 2015; Niiranen and Niiranen 2015). Also, higher self-efficacy and intellectual or practical interests in technical themes were reported to be motivational factors for pursuing a career in a technological field (Endepohls-Ulpe et al. 2012). Another key factor that influences occupational choices, especially in relation to technical careers, is family (Beauregard 2007; Sander 2012). Children who have a father and/or mother with a technological profession have greater ambitions to pursue a technological job themselves and are more interested in and less anxious about technology (Ardies 2015; Engström 2015; Niiranen and Niiranen 2015; Sander 2012).

The presence of women in technological fields is desirable since diversity fosters excellence in research and innovation (European Commission 2013a). This is also an issue of gender equality and the need to provide a sufficient number of qualified personnel in technology and engineering fields (Endepohls-Ulpe et al. 2012). This leads to the question what are the main challenges in advancing women in technological fields? One way to answer to this call would be to provide all students equal opportunities to obtain experience with and information about technology. In addition, teachers in technology-related subjects should focus on showing the relationship of technology and related skills and knowledge to practical applications and other areas of life, including work life. This is most important for girls who do not have first-hand examples of technological professionals in their families, who do not see the relevance of technology, or who otherwise would not imagine pursuing technology education and careers (Niiranen and Niiranen 2015). Research also evidences that students' implicit beliefs about their abilities and career aspirations can be changed through interventions directed at students or through the feedback of teachers and parents (van Aalderen-Smeets and van der Molen 2016). It also seems that girls often tend to be less confident in their abilities related to technology, and therefore it is highly important that they would receive support and encouragement from their teachers (Virtanen et al. 2015; Endepohls-Ulpe et al. 2012).

Advancing Equality in Technology Education

Education has an important impact on preparing children and young adults to participate in future society by providing them with the abilities and knowledge necessary to perform a wide variety of jobs (van Tuijl and van der Molen 2016). There is increasing evidence of the importance of career-related decisions made during the primary school years (Auger et al. 2005). Thus, technology education should be disseminated from the start of formal education, as effective learning is founded in childhood (Dagan 2015). Fausto-Sterling (2012) points out that research should focus on examining how different traits come into being over time by means of investigating the processes and factors (cultural and historical) that influence them (Fausto-Sterling 2012). In relation to the lack of women in technology-oriented fields or the state of technology education in schools, it seems that in spite of many years of development work focused on gender equality, technology education still appears to have gender-related issues. For example, girls mainly choose to study textiles and/or food technology with a female teacher, while boys study technical content (resistant materials) with a male teacher (Murphy 2007; Niiranen and Niiranen 2015). Also, gendered interactions between females and males appear to be present in technology education (Niiranen and Hilmola 2016). Might these gender-related factors affect girls when they are planning their futures? Can we afford to waste this potential talent?

Teachers play a key role in dismantling gendered practices and renewing the image of technology education because they are well placed to alter pupils' perceptions and indeed their whole identity (Murphy 2007). Numerous research studies on technology education have indicated the importance of how technological activities are conducted in class and how teachers can influence pupils' motivation through the application of different pedagogical approaches (Ardies et al. 2015a; Snape and Fox-Thurnbull 2013; Murphy 2007; Virtanen et al. 2015). Thus, it is important that activities in technology education lessons are planned and presented in such a way that all pupils would be interested in them. Hence, pupils can begin to see technology education as something valuable to them and become more motivated to study a technological field. This support is especially important for girls. In addition, the encouragement offered by teachers and their effort appear to influence girls in their studies and to motivate them to pursue male-dominated fields.

Several challenges in technology education have already been identified in previous international research. One of them is that in some countries technology education does not have a discrete status in basic education, and therefore it is not considered to be an independent subject (Rasinen et al. 2009). Thus its aims are very general in nature, or on the other hand, very subject related, i.e., technology is taught during the craft lessons. Another concern is that technology education might not receive proper attention given the busy school environment. The lack of curriculum guidelines and teachers' experience in technology education, particularly if resources or materials are inaccessible, are thus influential (Rasinen et al. 2009). Regardless of whether the aims of technology education are general or specific in nature, it is difficult for teachers to teach content that they are not familiar with. However, the importance of competencies in the field of technology for several areas of life – advancement in education included – should be emphasized. In order to help pupils to develop a positive attitude about and relationship to technology, educational practices should include a broader view of technology and embrace future-oriented conceptions of technology and related careers (Murphy 2007, 250). This reveals a great challenge for school teachers and also teacher education institutions.

Innovation lies at the heart of the strategy identified by Europe 2020 to achieve smart growth. The Innovation Union aims to make Europe a global leader in solving societal challenges (European Commission 2013a). If innovation skills are to be taught at school, whose responsibility will it be to ensure that this happens and is implemented well? Technology education is evidently relevant to this topic, as it has the potential to develop students' skills in many ways, to raise their awareness of the various dimensions of technology, and to enhance the creativity and innovativeness of young people (Elshof 2011). Could technology education also impact the potential and the advancement of women in technology-oriented fields? Even so, innovative ways of thinking are needed to achieve this goal in the future. Firstly, girls should be provided with equal opportunities to experience technology, but this would be only a start. New and improved practices and activities should be planned and presented in such a way that all pupils would be stimulated by them and thus see technology education as valuable. Also, schools should take on more responsibility for providing pupils with greater opportunities to obtain practical experience and information about career options in technology-oriented fields. Experienced teachers of technology-related subjects are crucial in order to support the development of the technology skills and knowledge that students will require in their working lives.

Conclusion and Future Directions

An increase in the number of women in technical careers has not yet been achieved in EU countries. The reluctance of women to enter occupations in the natural sciences or technology is still a challenge that many educators confront all over the world (e.g., Klapwijk and Rommes 2009; Mammes 2004; Sander 2012; European Commission 2013b, 2016). Hence, it is important to explore this challenge and to make interventions that would create equal opportunities for both girls and boys. Technology education has an important impact on today's society as it provides children with the possibilities and abilities to participate in the everyday technologies that they encounter and the knowledge necessary to perform a wide variety of jobs. To answer the call of advancing women in technology-oriented fields, girls should be provided equal opportunities in order to develop a positive relationship with technology and to obtain greater experiences with and information about technology. Also, new and improved practices and activities should be planned and presented in such a way that would foster girls' interest and allow them to see value in technology and thereby motivate more girls to study technology-related topics.

We should embrace the difference and diversity between men and women. Technology education can develop students' skills in a variety of ways. It raises their awareness of the various dimensions of technology, improves their technological literacy, and also enhances creativity and innovation. Thus, technology education has the potential to foster technological literacy in ways that respond equitably to human needs now and into the future.

References

Acker, J. (1990). Hierarchies, jobs, bodies: A theory of gendered organizations. *Gender and Society, 4*(2), 139–158.

Acker, J. (2006). Inequality regimes. Gender, class, and race in organizations. *Gender and Society, 20*(4), 441–464.

Ardies, J. (2015). Students' attitudes towards technology. *A cross-sectional and longitudinal study in secondary education*. Doctoral dissertation. Antwerpen: Universiteit Antwerpen.

Ardies, J., De Maeyer, S., & Gijbels, D. (2015a). The effect of classroom activities on students' interest and career aspirations towards technology. *Australasian Journal of Technology Education, 2*.

Ardies, J., De Maeyer, S., Gijbels, D., & van Keulen, H. (2015b). Students' attitudes towards technology. *International Journal of Technology and Design Education, 25*(1), 43–65. doi:10.1007/s10798-014-9268-x.

Auger, R. W., Blackhurst, A. E., & Wahl, K. H. (2005). The development of elementary-aged children's career aspirations and expectations. *Professional School Counseling, 8*(4), 322–329.

Banks, F., & Barlex, D. (2014). *Teaching STEM in the secondary school: Helping teachers meet the challenge*. New York: Routledge.

Beauregard, T. A. (2007). Family influences on the career life cycle. In M. Ozbilgin & A. Malach-Pines (Eds.), *Career choice in management and entrepreneurship: A research companion* (pp. 101–126). London: Edward Elgar Press.

Blaine, B. E. (2007). *Understanding the psychology of diversity*. California: Sage.

Committee on Alleviation of Segregation. (2015). *Tasa-arvotyö on taitolaji.* [The work at equality takes skill]. Ministry of Education and Culture Working Group suggestions. Oppaat ja käsikirjat 2015:5.

Cross, A. (2011). In search of a pedagogy for primary design and technology. In C. Benson & J. Lunt (Eds.), *International handbook of primary technology education: Reviewing the past twenty years* (pp. 167–180). London: Sense Publishers.

Dagan, O. (2015). Kindergarten student teachers' attitudes towards and perceptions of technology: The impact of a one year pre-service course. In M. Chatoney (Ed.), *Plurality and complementary of approaches in design & technology education. PATT29 conference* (pp. 98–105). Marseille: Presses Universitaires de Provence.

Dakers, J. R. (2011). The rise of technological literacy in primary education. In C. Benson & J. Lunt (Eds.), *International handbook of primary technology education. Reviewing the past twenty years* (pp. 181–193). Rotterdam: Sense Publishers.

de Vries, M. J. (2005). *Teaching about technology: An introduction to the philosophy of technology for non-philosophers*. Dordrecht: Springer.

de Weerd, J., & Rommes, E. (2012). To beta or not to beta? The role of teachers in the gendered choice of science and technology by secondary school students. In C. Quaiser-Pohl & M. Endepohls-Ulpe (Eds.), *Women's choices in Europe: Influence of gender on education, occupational career and family development* (pp. 63–78). Münster: Waxmann.

Eccles, J. S. (1987). Gender roles and women's achievement-related decisions. *Psychology of Women Quarterly, 11*(2), 135–172.

Elshof, L. (2011). Technology education: Overcoming the general motors syndrome. In M. de Vries (Ed.), *Positioning technology education in the curriculum* (pp. 145–162). Rotterdam: Sense Publishers.

Elvstrand, H., Hellberg, K., & Hallström, J. (2012). Technology and gender in early childhood education: How girls and boys explore and learn technology in free play in Swedish preschools. In T. Ginner, J. Hallström, & M. Hultén (Eds.), *Technology education in the 21st century. The PATT 26 conference* (pp. 163–171). Stockholm: Linköping University/CETIS/KTH.

Endepohls-Ulpe, M. (2012). Are females or males disadvantaged in contemporary educational systems? In C. Quaiser-Pohl & M. Endepohls-Ulpe (Eds.), *Women's choices in Europe: Influence of gender on education, occupational career and family development* (pp. 15–28). Münster: Waxmann.

Endepohls-Ulpe, M., Ebach, J., Seiter, J., & Kaul, N. (2012). Barriers and motivational factors for taking up a career in a technological field in Germany and Austria. In C. Quaiser-Pohl & M. Endepohls-Ulpe (Eds.), *Women's choices in Europe: Influence of gender on education, occupational career and family development* (pp. 79–93). Münster: Waxmann.

Engström, S. (2015). The females who succeed within higher technical education: Why do they choose and who are they? Four profiles emerge through the use of cluster analysis. In M. Chatoney (Ed.), *Plurality and complementary of approaches in design & technology education. PATT29 conference* (pp. 120–125). Marseille: Presses Universitaires de Provence.

European Commission. (2013a). Gendered innovations. How gender analysis contributes to research. Research and innovation. Report of the expert group 'innovation through gender'. European Commission. Luxenbourg: Publications Office of the European Union.

European Commission. (2013b). She Figures 2012. Gender in research and innovation. Statistics and indicators. European Commission. Luxenbourg: Publications Office of the European Union.

European Commission. (2016). She Figures 2015. Gender in research and innovation. European Commission. Luxenbourg: Publications Office of the European Union.

Fausto-Sterling, A. (2012). *Sex/gender: Biology in a social world*. New York: Routledge.

Francis, B. (2010). Gender, toys and learning. *Oxford Review of Education, 36*(3), 325–344.

Hallström, J., Elvstrand, H., & Hellberg, K. (2015). Gender and technology in free play in Swedish early childhood education. *International Journal of Technology and Design Education, 25*(2), 137–149. doi:10.1007/s10798-014-9274-z.

Järvinen, E.-M., & Rasinen, A. (2015). Implementing technology education in Finnish general education schools: Studying the cross-curricular theme 'human being and technology'. *International Journal of Technology and Design Education, 25*(1), 67–84. doi:10.1007/s10798-014-9270-3.

Klapwijk, R., & Rommes, E. (2009). Career orientation of secondary school students (m/f) in the Netherlands. *International Journal of Technology and Design Education, 19*(4), 403–418. doi:10.1007/s10798-009-9095-7.

Layton, D. (1993). *Technology's challenge to science education: cathedral, quarry, or company store?* Buckingham/Philadelphia: Open University Press.

Lippa, R. A. (2005). *Gender, nature, and nurture* (2nd ed.). Mahwah: Lawrence Erlbaum Associates.

Mammes, I. (2004). Promoting girls' interest in technology through technology education: A research study. *International Journal of Technology and Design Education, 14*(2), 89–100.

Martin, M. (2012). Values in design and technology education: Past, present and future. In T. Ginner, J. Hallström, & M. Hultén (Eds.), *Technology education in the 21st century. The PATT 26 conference* (pp. 309–315). Stockholm: Linköping University/CETIS/KTH.
McDermott, R. P. (1996). The acquisition of a child by a learning disability. In S. Chaiklin & J. Lave (Eds.), *Understanding practice - Perspectives on activity and context*. Cambridge: Cambridge University Press.
Miller, L., & Hayward, R. (2006). New jobs, old occupational stereotypes: Gender and jobs in the new economy. *Journal of Education and Work, 19*(1), 67–93.
Murphy, P. (2006). Gender and technology. Gender mediation in school knowledge construction. In J. R. Dakers (Ed.), *Defining technological literacy: Towards an epistemological framework* (pp. 219–237). New York: Palgrave MacMillan.
Murphy, P. (2007). Gender and pedagogy. In D. Barlex (Ed.), *Design and technology: For the next generation* (pp. 236–251). Shropshire: Cliffeco Communications.
Niiranen, S. (2016). *Increasing girls' interest in technology education as a way to advance women in technology.* Doctoral dissertation. Jyväskylä: University of Jyväskylä.
Niiranen, S., & Hilmola, A. (2016). Female technology education teachers' experiences of Finnish craft education. *Technology and Design Education: An International Journal, 21*(2), 41–48.
Niiranen, S., & Niiranen, S. (2015). Women in technology-oriented fields. *Australasian Journal of Technology Education, 2*.
Paechter, F. (2007). *Being boys, being girls: Learning masculinities and femininities*. London: Open University Press.
Quaiser-Pohl, C. (2012). Women's choices in STEM – Statistical data and theoretical approaches explaining the gender gap. In C. Quaiser-Pohl & M. Endepohls-Ulpe (Eds.), *Women's choices in Europe: Influence of gender on education, occupational career and family development* (pp. 53–61). Münster: Waxmann.
Quaiser-Pohl, C., & Endepohls-Ulpe, M. (2012). Education, occupational career and family work – Similarities and differences in women's choices in Europe (Editorial). In C. Quaiser-Pohl & M. Endepohls-Ulpe (Eds.), *Women's choices in Europe: Influence of gender on education, occupational career and family development* (pp. 7–13). Münster: Waxmann.
Rasinen, A., Virtanen, S., Endepohls-Ulpe, M., Ikonen, P., Ebach, J., & Stahl-von Zabern, J. (2009). Technology education for children in primary schools in Finland and Germany: Different school systems, similar problems and how to overcome them. *International Journal of Technology and Design Education, 19*(4), 368–379. doi:10.1007/s10798-009-9097-5.
Ritz, J. M., & Fan, S.-C. (2015). STEM and technology education: International state-of-the-art. *International Journal of Technology and Design Education, 25*(4), 429–451. doi:10.1007/s10798-014-9290-z.
Sander, E. (2012). Biographies of female scientists in Austria: Results of an interview study. In C. Quaiser-Pohl & M. Endepohls-Ulpe (Eds.), *Women's choices in Europe: Influence of gender on education, occupational career and family development* (pp. 107–122). Münster: Waxmann.
Snape, P., & Fox-Thurnbull, W. (2013). Perspectives on authenticity: Implementation in technology education. *International Journal of Technology and Design Education, 23*(1), 51–68. doi:10.1007/s10798-011-9168-2.
Turja, L., Endepohls-Ulpe, M., & Chatoney, M. (2009). A conceptual framework for developing the curriculum and delivery of technology education in early childhood. *International Journal of Technology and Design Education, 19*(4), 353–365. doi:10.1007/s10798-009-9093-9.
van Aalderen-Smeets, S. I., & van der Molen, J. H. (2016). Modeling the relation between students' implicit beliefs about their abilities and their educational STEM choises. *International Journal of Technology and Design Education,* Published online: 18 Nov 2016. doi:10.1007/s10798-016-9387-7.
van Tuijl, C., & van der Molen, J. H. (2016). Study choise and career development in STEM fields: An overview and integration of the research. *International Journal of Technology and Design Education, 26*(2), 159–183. doi:10.1007/s10798-015-9308-1.

Virtanen, S., Räikkönen, E., & Ikonen, P. (2015). Gender-based motivational differences in technology education. *International Journal of Technology and Design Education, 25*(2), 197–211. doi:10.1007/s10798-014-9278-8.
Volk, K. S. (2007). Attitudes. In M. de Vries, R. Custer, J. Dakers, & G. Martin (Eds.), *Analyzing best practices in technology education* (pp. 191–202). Rotterdam: Sense Publishers.

Part VIII

Media

Media in Technology Education: Section Introduction

62

Marc J. de Vries

Abstract

The section on media is a relatively small one. This indicates the current state of technology education research: there is not enough substance in several topics to allow for a survey type of chapter in accordance with the nature of a handbook. There chapters that are included show an interesting variety, as they do not only refer to new media (internet, mobile phones, and social media) but also to media like children's books.

This final section of the *International Handbook of Technology Education* deals with the use of media for teaching about technology. One would be tempted to use the term "educational technology" for that, but the scope of this section is wider. Educational technology is the use of modern electronic media for educational purposes. Examples of this are internet, mobile phones, and social media. One would expect technology educators to be experts in using such media. That expectation is in contract with the size of this final section: it is the smallest one of the whole handbook. In spite of the efforts that were made to find authors that have done research into certain topics in this domain, only very few were found and even fewer that could write about the use of modern electronic media. This raises the question: why so few available research studies in this domain?

It is fair to say that we have to distinguish here between educational technologies and technologies that are the content of technology education. These two are continuously confused by many who are not directly involved in technology education. Many articles on educational technology are submitted to the *International Journal of Technology and Design Education* without any connection to the teaching of technology. They deal with, for instance, online language courses or computer

M.J. de Vries (✉)
Department of Science Education and Communication, Delft University of Technology, Delft, The Netherlands
e-mail: m.j.devries@tudelft.nl

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_75

software for classroom management. This final section of the handbook is only about educational technologies (and some other media). Other sections in the *Handbook of Technology Education* deal with technologies that are in the content of technology education. Examples of those can be found in the chapters by Fislake and Ginestié. In the chapter by Stables, we find an example of how electronic media can be used for assessment purposes in technology education. That chapter, in fact, could also have been part of this section, as it is an example of technology being used not as content of education, but as a means to support it.

Media are not just electronic media. Books, newspapers, and movies are media too. They can also be used for teaching about technology, as some of the chapters in this section show. In a high-tech era, we sometimes forget that. Even when not used deliberately for the purpose of teaching about technology, novels and children's books provide an image of technology that can have an impact on the way we think about technology. Knowing that, we can, of course, use such media on purpose. It is important, then, that they present the sort of image of technology we want people to have. If children's books suggest that technology has only positive sides, this may cause a great naivety toward technology and a lack of critical skills in dealing with technology. If, on the other hand, such books create an image of technology in which it is the cause of all evil and disasters, this does not do justice to technology either. In her chapter, Axell describes the different types of images of technology that fictional books for children can convey. Such insights give hints and clues as to how to use such media in technology education properly.

Likewise, movies present images of technology. A genre, in which technology plays a particular role, is science fiction. In fact, that term is not correct in most cases. It is not so much science that is made visible in the movies, but technology. For that reason, it would be more proper to talk about "technology fiction." The fact that that term is never used can be seen in a broader context: the term "science" is often used to comprise technology as well. This, however, does not do justice to technology as a human activity of its own right. In a way this terminology still assumes that technology is merely the application of (natural) science, in spite of the fact that philosophers have shown that this is not a correct conceptualization of technology (see also the first section in this handbook). Lin presents movies as a medium that can support teaching about technology in an often attractive way. Movies appeal to many young people and the use of movies in teaching can have a motivational effect on learning.

The only chapter in this section that deals with electronic media for teaching about technology is the one by Loveland. Social media and internet are the two foci in this chapter, and the author shows how they can be used in very effective ways for enriching technology education. The impression that the chapter leaves us with is that we do not yet fully employ the possibilities that these media offer. The number of applications to which computers and smartphones give access is rapidly increasing, and the variety of functions gets broader every year. As for all use of educational technologies, it is important to think carefully on how the technical and functional properties of these media and applications fit (or do not fit) with educational needs (e.g., the acquisition of certain knowledge, skills, and attitudes). In technology education, such reflections should be possible by nature, as reflection on technology belongs to the core business of technology education.

Why then was it so difficult to get content for this final section of the handbook? Is it because our abilities to reflect critically on technology have made us shy away from the hypes that we can sometimes observe in other subjects? There are many cases, indeed, in which the use of educational technologies seems to be driven by an almost blind belief in the technologies themselves than by a careful analysis of the fit between technical functionality and educational needs. But the fact that there is perhaps a lot of unsophisticated use does not, of course, mean that proper use is not possible. It is worth asking ourselves the question: do we not leave many good opportunities unused for reasons that are not very strong (such as a fear to fall into the trap of an unbridled technology push)?

Another reason might be our history: technology education has emerged often from a craft-oriented tradition. In such a tradition, the experience of working with real tools and materials was valued higher than "virtual experiences," such as watching an instruction on a screen or using our hands only to type a text on a keyboard. For sure, this tradition still lingers on in much of contemporary technology education. But one would expect that in research, we have left this behind. The experience in putting together this section of the handbook does not confirm that. It seems, rather, that there is still a world to be won. Hopefully the *Second International Handbook of Technology Education* will have a media section with more substance than this current handbook. The chapters that are in this first handbook media section show clear enough that the use of media can make quite valuable contributions to the teaching of technology.

63 Technology and Children's Literature

Cecilia Axell

Abstract

The technology that mediates our lives today is complex. If we are to understand our modern technological world, technology education needs to place more emphasis on discussions and reflections about technology. A starting point for this chapter is that children's literature can be understood as a mediator of views and values about technology, which makes it an interesting subject matter for technology education. Children's fiction places technology in a context and could therefore serve as a pedagogical tool for broadening and expanding technology education. This chapter is an exploration of different views of technology found within a selection of children's books: an *anti-consumeristic* view of technology, technology as a *servant* to humans, a *nostalgic* view of technology, and technology as a *vehicle for adventure.* The books are all examples of stories which depict technology itself but also issues and problems relevant to the field of technology education. In general, the books present technology in a diverse way, and the messages in the stories reveal its multifaceted nature. This chapter concludes that fictional stories can make it possible to problematize the nature of technology in ways that textbooks seldom can. Children's fiction could therefore serve as a platform for open-ended enquiries and dialogues about the nature of technology and the effects of technology on individuals, society, and nature in the past and the present.

Keywords

Technology education • Children's fiction • Technology • Views of technology • Views of nature

C. Axell (✉)
Department of Social and Welfare Studies, Linköping University, Norrköping, Sweden
e-mail: cecilia.axell@liu.se

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_66

Contents

Introduction

"I am the Lorax. I speak for the trees.
I speak for the trees, for the trees have no tongues.
And I'm asking you, sir, at the top if my lungs"-
he was very upset as he shouted and puffed -
"*What's that THING you've made out of my Truffula tuft*?"
"Look, Lorax," I said. "There's no cause for alarm.
I chopped just one tree. I am doing no harm.
I'm being quite useful. This thing is aThneed [. . .]"
The Lorax said,
"Sir! You are crazy with greed.
There is no one on earth
Who would buy that fool Thneed!"
(Dr. Seuss 1971/2012:23–24)

In 1971, just as the environmental movement began to take hold, Dr. Seuss first published *The Lorax*, a tale about needless consumerism and environmental destruction. The story takes place in a dark and post-apocalyptic landscape which has been destroyed by the Once-ler's exploitation of nature. In the story, the Once-ler starts to cut down Truffula trees, and the Lorax, the caretaker of the Truffula forest, immediately appears and tries to convince the Once-ler to stop cutting down the trees. The Once-ler does not listen. Instead, he wants to develop his business which manufactures "Thneeds." The story illustrates the effects of reckless deforestation and cause and effect outcomes which can drive technological and societal change. The extreme consequences of excessive technological development, consumerism, and industrialization are clear.

Why involve children's literature in technology education? One reason is that, since technology is something which inescapably impinges on our lives, "[. . .] it also becomes a part of the environment within which literature works" (Greenberg and Schachterle 1992:16). The fact that technology is so prevalent in literature can also be linked to that it has been a natural part of our culture since the dawn of human history. Mumford (1967/70), for example, emphasizes the role of human beings' ability to communicate with each other. He argues that there are parallel developments between human tools and social organization through language and the human ability to create symbols to represent objects, experiences, and memories.

In a highly technological world, technology education cannot be expected to teach children how all modern technologies work, and technological literacy consequently implies more than just the ability to create objects or to understand the function of certain technologies (Dakers 2011). When technology is so pervasive in our lives, it is important to understand how it shapes society and which factors influence its development (Garmire and Pearson 2006). Discussions and reflections on technology should thus be regarded as an important part of technology education (de Vries 2006). Since a knowledge of technology is often a matter of decisions and preferences, it also involves people's values. Technology is not neutral; it is value laden and political in nature. To be able to create conditions of understanding for the modern technological world we live in, technology curricula should therefore place more emphasis on issues relating to values and attitudes in terms of technology, such as ethics, environmental impact, social impact, sustainability, and moral impact, i.e., a pedagogical framework which involves open-ended enquiry and dialogue (Dakers 2011).

As Fisher (1998) argues, the use of stories in the classroom provides us with metaphors of life, as our lives can be regarded as a narrative structure in which we all have a role. In science education, there seems to be a growing consensus among researchers that children's literature, including picture books and fiction, can be used to foster interest in, and positive attitudes toward learning science in early years (see e.g. Sackes et al. 2009; Monhardt and Monhardt 2006; Trundle and Troland 2005). Research on how technology is portrayed in children's fiction is still in its infancy, as is the use of fiction in technology classrooms (Axell 2015). However, there is research which highlights the importance of using narrative technology in education. Dakers (2011), for example, proposes the use of castaway stories as a springboard for bringing social aspects of technology into the technology classroom. A castaway theme can transfer children into a world in which they become responsible for creating the technologies they find essential, meaningful, and purposeful. Daugherty and Daugherty (2007) also highlight the importance of placing technology in a narrative context, and they advocate the use of oral histories to engage learners in exploring the historical, social, and cultural contexts involved in technology. Children's fiction is another narrative tool which can provide a basis for the technology classroom. It places technology in a context which can contribute to children's understanding of the technological world. Children's literature has also been a genre which responds affirmatively to our fascination with technology, and it often offers alternative views (Yaross Lee 1992). By using children's books as a base, aspects of technology and its application can be assessed in the technology classroom (Foster 2009; Axell 2015, 2017; Axell and Hallström 2011, 2015; Axell et al. 2013).

For many students, however, technology remains heavily associated with specific artifacts, i.e., objects made by humans. This is confirmed by previous research which indicates an emphasis on artifacts and making objects in technology education (Klasander 2010; Mawson 2007; Siu and Lam 2005). The artifact focus also tends to pervade many nonfiction children's books about technology, in particular books aimed at younger children (Axell and Boström 2015). However, by failing to place technology in a broader context, the connections between artifacts, human intentions, and the societal context are disregarded (Axell 2015; Klasander 2010; Mawson 2007; Siu and Lam 2005; Svensson 2011; Turja et al. 2009).

In this chapter, the discourse on technology is linked to children's fiction as a pedagogical tool in the technology classroom. The starting point is that children's fiction can be understood as a mediator of views and values in terms of technology, which makes it an interesting subject matter for technology education (Axell 2015). The aim is to suggest ways of reading and interpreting children's literature from the perspective of technology education, as well as to encourage a pedagogical discussion on technology and children's literature. The selection of stories is based on examples of different views of technology: an *anti-consumeristic* view, technology as a *servant*, a *nostalgic* view of technology, and technology as a *vehicle for adventure* (Axell 2015, 2017). Each section concludes with suggested questions relating to the story, which can serve as starting points for learners to explore the nature of technology and the technological world which surrounds them. This chapter will thus contribute to a pedagogical framework involving open-ended enquiries and dialogues.

The Anti-consumeristic View of Technology in The Lorax

As human beings, we expect technology to solve our problems, make our lives better, and help develop the future we want. At the same time, we are attuned to nature, a dependence which comes from millions of years of feeling at home with it (Arthur 2011). Consequently, discourse about technology not only deals with technology itself but is often connected to different views of nature (Applebaum 2010). Nature provides us with the natural resources we need to create our technology which, once created, has an effect on nature and the environment in one way or another. *Anthropocentric* and *biocentric* describe two divergent aspects of the human view of nature. An anthropocentric view of nature represents a human-centered view, where nature is for humans. This means that nature itself has no intrinsic value, and each impact on nature should be valued in terms of the effect it has on people (Sörlin 1991). Representatives of a biocentric view make the opposite argument, where everything in nature has an intrinsic value, and humans do not occupy a higher position in the hierarchy than other species; humans are part of nature (Sörlin 1991). The story of *The Lorax* (1971/2012) by Dr. Seuss can be interpreted as depicting the clash between these two approaches. The Lorax challenges the Once-ler's anthropocentrism and offers a biocentric defense in which nonhuman aspects of nature have as much right to exist as humanity (Lebduska 1994).

The story takes place in no particular time or place, which makes it universally accessible as a pedagogical tool in the technology classroom. It is set in a dark, post-apocalyptic landscape, destroyed by the Once-ler's excessive exploitation of natural resources. A boy, who is living in the polluted area, visits a strange man called the Once-ler, who lives alone in the "Street of the Lifted Lorax." The boy pays the Once-ler to tell him the legend of how the Lorax was "lifted" away.

When the Once-ler first comes to the valley, it is a magnificent forest studded with brightly colored, butterfly milk-scented Truffula trees. It has a clear lake and a host of different forest creatures. The Once-ler has been looking for a tree like the Truffula for a long time, and he chops one down and uses its woollike foliage to knit a "Thneed," a peculiar but versatile garment.

Suddenly, "a sort of man" emerges from the stump of the tree he has chopped down. This is the Lorax, who speaks for the trees ("as they have no tongue"). The Lorax expresses his disapproval of both the sacrifice of the tree and the Thneed itself. The Once-ler answers that there is "no cause for alarm" because he has only chopped down one tree, which has been "quite useful":

> This thing is a Thneed.
> A Thneed's a Fine-Something
> That-All-People-Need!
> It's a shirt. It's a sock.
> It's a glove. It's a hat.
> But it has other uses.
> Yes, far beyond that.
> You can use it for carpets.
> For pillows! For sheets!
> Or curtains! Or covers
> for bicycle seats! (Dr. Seuss 1971/2012:24)

The Lorax, however, finds the Once-ler greedy and believes that no one on Earth will want to buy anything like the "fool Thneed." Unfortunately, he turns out to be wrong. The first person to purchase the Thneed encourages the Once-ler to start a business to manufacture and sell them. As there is a chance of making the whole Once-ler family "mighty rich," the Once-ler builds a radiophone and calls his relatives to come and work for him. Soon the Once-ler finds that chopping down one tree at a time is too slow. He invents a "Super-Axe-Hacker," which can "whack off" four Truffula trees "at one smacker" and which makes it possible to make Thneeds four times faster. New vehicles and equipment are brought in to log the Truffula forest and ship out Thneeds, and the Once-ler's small shop has soon grown into a factory. Since the story makes connections between capitalism, greed, and environmental degradation, it also prompts a critique of consumer society and a dialogue about its consequences. The Lorax soon appears and reports that the small bear-like Bar-ba-loots, who eat Truffula fruits, are short of food and must be sent away to find more. The Once-ler is sad to see them go away but notes that "business is business, and business must grow. . ."

Like most innovations, the Thneed is not an isolated object or product. It can also be described as the result of a technological process. The Once-ler organizes a *technological system* to manufacture and distribute his Thneed. Like any other technological system, it has inputs and outputs (Hughes 1987). The foliage is delivered to the factory as an input into the system from the environment. Energy, knowledge, and material resources are supplied to the system, and the output is the finished Thneed. Important parts of the manufacturing process in the Once-ler's factory include raw materials, design, labor, an assembly line, energy, transportation, and profit/loss, but there are also unwanted outputs. The construction of the Once-ler's machine not only pollutes the air and the water but also produces unwanted by-products, and the Lorax returns to the Once-ler to complain about the by-products the machinery is making: "Gluppity Glup" and "Shloppity Shlop." These have been dumped into the ponds where the Humming Fish live. Consequently the Swomee Swans, the Humming Fish, and the other animals have been forced to migrate. The Once-ler, however, is unrepentant and refuses to listen; he will keep on "biggering" his business.

In accordance with Kranzberg's first law of technology, technological solutions very often have consequences which go far beyond their intended application (Kranzberg 1986). The messages in the story also relate to Winner (1989), who notes that if we simply see technology as a neutral tool which can be used for either good or evil, we fail to take into consideration any unintended consequences in its construction. The Once-ler, however, does not realize the consequences of his actions until the moment his machines harvest the very last Truffula tree, and without raw materials the factory and his business cannot go on. The factory shuts down and the Once-ler's relatives leave. The Once-ler is left to ponder the costs of not having a sustainable plan.

As the story encompasses the difficulty of controlling emerging technology, and can be interpreted as expressing the consequences of a *deterministic* or *autonomous* view of technology, the technological development in the story follows its own principles based on rationality and efficiency and takes place outside the control of human beings (Ellul 1964, 2010).

The Lorax disappears, and in his place is a small monument engraved with a single word: "UNLESS." When the Once-ler tells the boy his story, he suddenly realizes what the Lorax' message means: unless someone cares a great deal, the situation will never improve. The story ends with a glimmer of hope. A single Truffula seed is left behind. The Once-ler gives the seed to the boy and urges him to grow a forest from the seed and to "protect it from axes that hack." Then the Lorax and all the animals might return.

Pedagogical Implications

Exploring the story requires us to consider cause and effect, as well as the influence and effects of technology on society and the natural world. Businessmen like the Once-ler sometimes invent new machines and other systems to increase their profit. *What technology does the Once-ler invent to increase the production of Thneeds?*

The use of technology requires resources from nature, which often has an effect on the environment. *What effects did the production of Thneeds have on the environment? How could the Once-ler have manufactured Thneeds in a more sustainable way? Whose responsibility is it to ensure sustainability on Earth?*

The Once-ler organizes a system to manufacture and distribute his product. The manufacturing process involves raw materials, product/product design, workers, assembly lines, energy, transportation, and profits. *Draw a flowchart showing how*

Thneeds are produced. What in the story corresponds to the different components of a technological system? Choose a real industry and give examples of the components in the production process.

Technological production often creates by-products. Sometimes these are unwanted or dangerous for humans, as well as for the environment. *What are the by-products from making Thneeds? What effects do these by-products have? Compare the Once-ler's factory and a real industry. What are the by-products? What are the effects on the environment? Discuss possible solutions.*

Technology Which Serves Humans in the Story About Mike Mulligan and His Steam Shovel

Mike Mulligan and His Steam Shovel (1939/2005), written by Virginia Lee Burton, is a picture book about a man and his trusty steam shovel, Mary Anne, which he has cared for and worked with for many years. Mike is proud of Mary Anne, and they are a perfect team. They dig deep canals for boats to travel through, cut mountain passes for trains, and hollow out cellars for city skyscrapers.

> It was Mike Mulligan and Mary Anne and some others
> who cut through the high mountains so that trains could
> go through.
> It was Mike Mulligan and Mary Anne and some others
> who lowered the hills and straightened the curves
> (Lee Burton 1939:7–8)

In this story, technology is portrayed as serving humanity and as a powerful tool in helping human beings achieve their dreams and aspirations, which include a mastery of nature. The depiction of how humans use their technology to transform nature for their own needs can be tied to an anthropocentric view of nature. The story addresses enduring themes: the emotional bond between humans and machines, the transforming effects (for good and ill) of new technology, and the struggle against adversity.

Mary Anne is an *anthropomorphic object* which is ascribed human attributes, and the relationship between the steam shovel and Mike Mulligan is reminiscent of a marriage. One suggested reason for the use of anthropomorphic technology is that it helps the reader feel at ease with technology as part of the human world. If a form of technology is so complicated that it is hard to understand or grasp, depicting it as a living being is one way of bridging the barrier between this technology and human beings. Anthropomorphism also contributes to building an emotional bond between human and machine (Schwarcz 1967; Waytz et al. 2014).

The main message in the story is concerned with how modern technologies outperform and replace older ones. With progress come new machines like gasoline and electric shovels, and soon Mike Mulligan and Mary Anne are out of work. The steam shovels are sold off for scrap metal or left in gravel pits to rust and fall apart. The "good old days are gone," and no one wants or needs them anymore. Mike, however, is convinced that "Mary Anne can dig as much in a day as a hundred men can dig in a week," and the two have one last chance to prove themselves and save Mary Anne from the scrap heap. Mike Mulligan learns of a new town hall to be dug in a small town, Popperville, and decides that he and Mary Anne might have more success there than in the big city.

They get the job by promising that they will be able to dig the cellar in one day. Although the work is hard, Mike and Mary Anne work harder and faster as more and more people come to watch their progress. When the hole is ready at the end of the day, even the most skeptical man in Popperville is impressed. However, one problem remains – how will Mary Anne get out of the hole? They have succeeded in carrying out their task in one day, but they have forgotten to leave a way out from the bottom of the pit.

Finally, a little boy finds an ingenious solution by suggesting an alternative use for the steam shovel as a heating plant for the town hall, and they are given the important task of warming up the town hall meetings. Mary Anne's rescue lies in the fact that technology very rarely disappears once it has been created, and technology which may be rare in the modern urban world can be quite common in the developing rural world. The story also confirms that "new technology" is often a result of existing knowledge and of finding a new use for old technology (Edgerton 2006; Kelly 2010). The description of how the steam shovel is transformed from a shovel destined to dig, to a modern boiler, and what happens in Popperville, can be interpreted as a testament to old-fashioned hard work and ingenuity, as well as an illustration of how technology serves humankind. From a gender perspective, technology in the fable is portrayed as female in the form of Mary Anne. This paves the way for a more democratic development of society and, in the end, helps satisfy a basic human need for warmth when Mary Anne is installed in the basement of the town hall (Yaross Lee 1992).

Pedagogical Implications

The view of technology conveyed by *Mike Mulligan and His Steam Shovel* can serve as a starting point for highlighting a historical perspective as well as a sustainable one.

How can we tell that this story was written many years ago? How does the technology in Popperville differ from technology we use today?

Before the steam shovel was invented, it took many people with hand shovels several days to dig a large hole. The steam shovel was an invention that made it easier to dig the same hole in much less time, and with only one person operating the shovel. *Give examples of other inventions that have made work faster and easier. What kind of technology did we use before cell phones, computers, freezers, electric lights, microwaves, etc. to fulfill the same human needs and desires? What are the advantages and disadvantages of the different technological solutions?*

Mike Mulligan takes good care of his steam shovel, and, although it is outdated, he does not want it to end up rusting away in a gravel pit. *What happens to our devices and objects like cell phones, computers, cars, and refrigerators when we stop using them? Which items are recycled at home or at school? How does recycling benefit* *sustainability? How can artifacts which are routinely thrown out be used in a new way?*

The little boy's suggestion at the end of the story is the answer to Mike and Mary Anne's problem in terms of getting out of the pit they have dug: she is recycled as a furnace for the new town hall. *What alternative solutions to Mike and Mary Anne's problem might have been possible? What happens to outdated equipment when it is replaced by new inventions? What happens to people who operate older technology when it is replaced by new machines? Compare!*

We sometimes create an emotional relationship with our objects and devices, such as giving them names. *Give examples of items we often give names to. Why is the steam shovel portrayed as a female, not as a male? Why are some objects portrayed as feminine rather than masculine?*

The Nostalgic View of Technology in the Harry Potter Series

According to Ellul, there is a historical relationship between magic and technology. Technology (or *technique*, as Ellul terms it) has evolved along two distinct paths. One is the concrete technology created by *homo faber,* a maker who poses problems and usually studies them. However, Ellul suggests there is also a form of technology connected to a more or less spiritual order, which we sometimes call *magic*. Magic developed along with other technology and was an expression of the human desire to obtain results of a spiritual order. For example, humans performed rituals using masks, prayer wheels, mystical drugs, etc. These rituals, including magic artifacts, were passed on to the next generation, very often without any kind of evolution or change (Ellul 1964). Magical technological solutions are also common in children's literature.

The Harry Potter books by JK Rowling take place in a magical world beyond time and space and can be read as a celebration of an older technology. In Harry's wizarding world, modern technology is what non-magic people, or Muggles, use as a substitute for magic powers. The problems Harry and his friends face are often solved with the help of "magic technology," one which originated far back in time. In the world of wizards and witches, there is no need for mundane domestic artifacts such as dishwashers, vacuum cleaners, the Internet, or mobile phones. An emphasis on ancient knowledge in the books promotes a nostalgic view, which is intended to be passed on to future generations and live on forever through schools like Hogwarts. The school's task is to teach young wizards and witches how to harness and employ magical powers.

There is thus an explicit distinction between the technology used in the Muggle world and the technology in Harry's magical world, where modern technology serves as a symbol of the Muggles and their lives. Harry's very unpleasant uncle, Vernon Dursley, is director of a firm that makes drills, and his son (Harry's materialistic and greedy cousin Dudley) is never satisfied with anything he receives on his birthday, even when it includes a new computer, a second television, a racing bike, a cine-camera, a remote-control airplane, 16 new computer games, and a video recorder

(Rowling 1997). In the wizarding world, Muggle technology is mainly replaced by older or magic technology.

Muggle technology	Magic technology
Electric light	Firelight and candles
Paper	Parchment
Internet	Library books, newspapers with moving pictures
Pen and pencil	Quill and ink
Mobile phones and the postal system	Owl post
Video games	Quidditch and wizard chess
Cars, bicycles, motorbikes, and airplanes	Flying broomsticks, a flying car (an antique model), and a flying motorbike
Electric trains	A scarlet steam train
Central heating	Open fireplaces
A cashless system	Golden coins stored in vaults
Drone	A winged Snitch

Magic is often tied to a specific ethnic group (Ellul 1964), and in the Harry Potter books this is represented by “the ethnic group” of wizards and witches. Although the technologies in the two different worlds very often meet the same kind of needs, their history is different; the magic technology rarely follows the same evolutionary curve as the modern and materialistic technology. The emphasis instead is on the application of old means, or as Ellul expresses it: “There is not a progression of discoveries built one upon the other; rather, discoveries remain side by side and do not affect one another” (Ellul 1964:26). Moreover, the technology used in the wizarding world is attributed a higher value than the technology in the Muggle world. There is even a *Misuse of Muggle Artefacts Office*, which regulates the use of magic on Muggle objects and has the job of keeping items that have been bewitched away from Muggles.

Another aspect of technology highlighted in the Harry Potter stories is the dual nature of artifacts. They are physical objects of a certain size, shape, color, weight, etc., but at the same time they have a certain functional dimension (de Vries 2006). Flying broomsticks, a talking hat, and moving staircases indicate that many of the technological solutions the wizards use have their origin in the Muggle world, but in the wizarding world they are given a different function, or function in a different way. Unlike most Muggle technology, it can be difficult to determine the function of magic artifacts simply on the basis of their design. Norman (2013) uses the terms “affordance” and “signifier” to describe the relationship between a designed object and the interacting agent (human, animal, or machine). Affordances are the possible interactions between people and the environment, while signifiers signal the possible actions and how they should be carried out. Affordances determine possible actions, while signifiers communicate where these actions should take place. The design of a broomstick, for example, is consistent with its function in the Muggle world; they are for sweeping. In the wizard’s world, on the other hand, the signifier is weak, while a plethora of affordances can be linked to a magic broomstick. Consequently, and in keeping with Dennett (1990), "[. . .] the inventor is not the final arbiter of what an artefact is, or is for; the *users* decide that" (Dennett 1990:186). In this way, it is the wizards and witches who decide what the artifacts should be used for. In the hands of a trained wizard or witch, magic technology works as reliably as the technology that makes a car work. What an education at Hogwarts cannot ensure, however, is that the pupils will only use their powers wisely, responsibly, and for the common good. When magic artifacts fall into the wrong hands, the consequences can be dire. The Philosopher's Stone, for example, is an artificial stone with magical properties. The stone is able to be used not only to create the Elixir of Life, it can also transform any metal into pure gold. It therefore becomes the target of the evil Lord Voldemort. Like many artifacts in the Muggle world, the stone is essentially neutral in terms of its value, because it is a tool in the service of the user, and tools can be used either well or badly (Pitt 2014).

However, very often the magic artifacts behave unpredictably and can therefore be perceived as *autonomous*. The Sorting Hat, for example, is an anthropomorphic object which can even respond to the thoughts of the wearer. Another example involves the Hogwarts Stairway, a massive structure in Hogwarts Castle which provides access to each floor of the castle. The stairs can suddenly turn around when the pupils are walking up them. There are also a number of trick stairs which they can sink through, and another student has to pull them out. Other examples of autonomous artifacts are the paintings, whose subjects are able to talk and move around from picture to picture, and even interact with the people looking at them. Equally, although the wizard's chess board is identical to ordinary chess and the rules are unchanged, the pieces move by themselves and can attack each other violently; the losing piece is smashed by the winning piece and dragged off the board. The winged Snitch is another unpredictable artifact – a small flying ball used in the wizarding game and reminiscent of a complex drone. It has an advanced memory and can hover, dart, and fly around the pitch by magic, avoiding capture yet remaining within the boundaries of the playing area. However, unlike the Snitch, drones in the Muggles' world are not autonomous. Remote pilots control their flight, and they use onboard cameras and other sensing equipment to detect and identify people.

Muggle technology can often be perceived as something which evolves beyond our control. Ellul suggests that contemporary technological development moves too quickly to integrate older traditions, and therefore it follows its own rules and principles based on rationality and efficiency (Ellul 1964, 2010). On the other hand, and in accordance with Winner, the concept of autonomous technology is related to the fact that today's technology is often highly specialized and largely incomprehensible. Hence, the idea that technology is autonomous often stems from a lack of understanding (Winner 1977).

However, there are also some representations of technological change in the wizarding world. The magic broomstick, for instance, is an artifact under constant evolution. The first time Harry sees the world-class broomstick "Firebolt" is in the window of his favorite shop. Curious about what the people in the shop are staring at, Harry squeezes into the crowd until he is able to read the sign next to the broom:

> This state-of-the-art racing broom sports a streamlined, superfine handle of ash, treated with a diamond-hand polish and hand-numbered with its own registration number. Each individually selected birch twig in the broomtail has been honed to aerodynamic perfection, giving the Firebolt unsurpassable balance and pinpoint precision. The Firebolt has an acceleration of 0–150 miles an hour in ten seconds and incorporates an unbreakable braking charm. Price on request. (Rowling 1999:43)

The "Firebolt" is the most magnificent broom Harry has ever seen, and he has never wanted anything so much in his whole life. It is depicted as the BMW of broomsticks and is marketed like any artifact in the Muggle world. The "Firebolt" is thus not just an artifact, it is also a status symbol. For instance, as noted by Kroes (2012), an artifact like a car is not simply an artifact in the sense of a means of transport. It may also be a status symbol or stand for a specific lifestyle.

Representations of more recent technology in the wizarding world include a flying motorbike and a flying car, as well as the fact that there is a sewage system. The first floor girls' lavatory, known as "Moaning Myrtle's Bathroom," is situated on the first floor of Hogwarts Castle. The ghost Myrtle, who lives there, says she sometimes ends up in the nearby lake when someone flushes a toilet in her bathroom, and this information can contribute to a discussion on sanitation practices in relation to environmental issues.

In summary, the magical world rests on a nostalgic vision that "it was better before."

Pedagogical Implications

Asking learners to make a comparison between magic technology and the technology in the Muggles' world allows them to investigate the nature of technology. *What technology is used in the magic world to satisfy specific needs and desires and to solve problems? What kind of technology is used in the Muggles' world to satisfy similar needs and desires and to solve problems? What are the advantages and disadvantages of the different magical solutions compared to Muggle technology*? *Which technological solutions are more or less the same in our world and the magical world?*

The Harry Potter books mainly take place in a world which is largely reminiscent of a bygone era. Using Hogwarts School as a setting, make a comparison. *In what way has our technological landscape changed over time? Give examples of different technologies which have evolved over time. What are the driving forces behind technological change?*

Harry and his friends use a flying car. This is an example of technology which has been predicted for more than a century, not least within the science fiction genre. *What are the advantages and disadvantages of a flying car compared to cars driven on land? This is not yet a reality, but driverless cars are already being tested in different parts of the world. What are the advantages of self-driving cars? What are the potential problems?*

In Harry Potter's magical world, many objects function and are used in different ways to those in the Muggles' world. *Identify as many ways as possible of using a broomstick or a hat. Examine different artifacts in your own world which are used differently to how they were originally intended.*

Technology as a Vehicle for Adventure in Moominpappa's Memoirs

In adventure fiction, technology is often a prerequisite for adventures and for discovering the unknown. Adventures which make use of technology, especially different kinds of air and marine vehicles, are particularly associated with Jules Verne and his heroes (Frängsmyr 1990). In the Harry Potter books, a fictitious train, the Hogwarts Express, takes Harry and his friends to their adventures at Hogwarts magic school. In Tove Jansson's book *Moominpappa's Memoires* (1968/2009), the amphibious ship *Haffsårkestern* takes Moominpappa and his friends on adventures, and technology is depicted as something which creates opportunities for adventure. In the story, different kinds of machines and inventions play a central role.

Before he had a family, Moominpappa lived a life of adventure and intrigue, but he has never told his story. When he has a bad cold, however, it is the perfect time for him to remember his youthful endeavors and to ponder the experiences which have made him the remarkable Moomin he is. In his memoirs, he tells the story of how he met the inventor Fredrikson, who becomes his friend and companion in their adventures on the boat "*Haffsårkestern*."

In the story, Moominpappa describes the first time he came in contact with a water wheel, technology which later proves to be an important component of the *Haffsårkestern*. He describes the water wheel as "beautiful" and commends anyone who suffers from "a restless heart" to watch a well-made water wheel spinning in a stream. The art of constructing a water wheel is a skill Moominpappa later passes on to his son Moomintroll. Through the description of the water wheel, technology is given an artistic role in conveying a sense of peace.

Moominpappa's view of technology rests on the fact that he never ceases to be amazed by Fredrikson's "deep affection for machines." He himself finds machines "creepy." Water wheels, however, are "nice," as they are "understandable," while he is suspicious of zippers, which "are approaching the machine world." What Moominpappa is expressing can be interpreted as a preference for what Mumford (1963) labels *democratic technology*, or small-scale systems related to arts and crafts which have their roots far back in time. This relates to the idea that older technologies are in some ways more democratic, since they are used in contexts where humans have a closer relationship with the technology. Moominpappa prefers technology he understands and is able to create himself. On the other hand, the more complex the technology, the more *authoritarian* (Mumford 1963) it is considered, being perceived as something "magic" and difficult to understand.

Haffsårkestern turns out to be a vessel designed to manage difficult situations and take Moominpappa and his friends on exciting adventures. Once the friends are on board, they are soon hovering away over the treetops. Fredrikson has a surprise for his friends. He suddenly takes *Haffsårkestern* straight down into the sea. A garland of lights appears amidships and shines into the dark sea. They slide deeper and deeper into the bottom of the darkness and see living sea creatures like fishes and sea serpents. It turns out that *Haffsårkestern* is not only able to walk on the seabed but also on land, as she is equipped with caterpillar tracks. Fredrikson has managed to transform *Haffsårkestern* into a hybrid vehicle, viable in the air, on land, and on and under the water. The description of *Haffsårkestern* therefore conforms to Arthur's (2011) notion that technological evolution often occurs when components are improved and used in other applications and that technologies come into being as fresh combinations of what already exists.

Haffsårkestern is initially reminiscent of Captain Nemo's vessel, *Nautilus*, in Jules Verne's famous adventure story *Twenty Thousands Leagues Under the Sea* (1870), but she is developed by Fredrikson to be more like the "*Terror*," a machine constructed by the inventor Robur in *Master of the World* (1904). The *Terror* can be used as a car, boat, submarine, and aircraft, i.e., a vehicle which can "defeat" all elements. However, in Verne's stories there is also a critical aspect. Captain Nemo is a technological genius who suffers from megalomania, which leads to his downfall. Technology itself is not "evil," but humans can choose to use it in a good or bad way (Pitt 2014). Like Verne's inventors, Fredrikson is an eccentric character whose inventions come before friendship. He likes to invent things, but he seems to be neither concerned nor interested in the impact they have; he is driven by hubris and a will to defeat the forces of nature.

As Hård and Jamison (2005) point out, fictional stories often reflect the ambivalent character of technology. On the one hand, they show how humans have opened up new possibilities for humankind. On the other hand, they indicate that we need to tame or control this hubris if we are to find appropriate uses for the technology we create.

In this way, Fredrikson also bears some similarity to the inventor in Mary Shelley's story *Frankenstein or The Modern Prometheus* (1818). Victor Frankenstein is an inventor who refuses to consider the implications of his invention (Winner 1977). Paramount for Fredrikson is to explore what inventions are possible, not what their consequences might be.

The view of nature which pervades the story is nevertheless ambiguous. Nature is anthropomorphic; human feelings are attributed to talking animals, and the sea "goes to bed." On the one hand, the characters live in a kind of symbiosis with nature. On the other hand, nature is depicted as something which needs to be mastered with the help of technology. Technology is expressed as the result of creative processes and a desire to create. *Haffsårkestern* can thus be interpreted as a metaphor of the driving forces behind technology. It represents how technology evolves to satisfy our curiosity and our need for adventure, and how innovations are often a result of existing technology utilized in a new and alternative way.

Pedagogical Implications

Technology is often described as something humans create and use to satisfy basic needs and desires or to solve problems. It functions as a prerequisite for adventure in the story. *Give examples of where technology is important for the adventures Moominpappa is involved in. Give examples of other stories where technology plays an important role. In real life, how do we use technology to experience different kinds of adventure?*

In the design of *Haffsårkestern*, a cogwheel, a propeller, and a water wheel are important components. *What functions do these different components have in the* *construction of the boat? In what other kinds of technology do these components play an important role? Give examples.*

Haffsårkestern is a hybrid of an aerial vehicle and a submarine, which shows that new technology is often a result of combinations of existing technology. *Give examples of other technological solutions which are the result of an evolution of previous, existing technology.*

Conclusion and Future Directions

An analysis of a selection of children's literature shows that the messages about technology and technological progress are often ambiguous. The ambivalent messages in the stories reveal the complexity and multifaceted nature of technology in ways that textbooks or nonfiction books seldom do. The stories have a built-in duality, since they describe how technology is not only capable of solving problems and meeting basic needs, but how it can also have unintended consequences. A conclusion is that children's fiction can contribute to broadening and expanding technology education. By incorporating books which are of interest for children, thoughts and ideas about technology can be presented as part of the world they perceive, one where they feel at home. The stories could thus act as springboards in the technology classroom for creative discussions about the nature of technology and the driving forces behind technological change, as well as its impact on people, society, and nature in the present and the past. By placing technology in a context, fictional stories can make it more comprehensible and visible for learners. There are therefore implications for future research studies which explore how children's literature can be used in the classroom to contribute to fulfilling the aims of technology education.

References

Applebaum, N. (2010). *Representations of technology in science fiction for young people*. New York: Routledge.

Arthur, W. B. (2011). *The nature of technology: What it is and how it evolves*. London: Allen Lane.

Axell, C. (2015). *Technology landscapes in children's literature. A didactic journey from Nils Holgersson to Pettson and Findus* (Dissertation). Linköping: Linköping University.

Axell, C. (2017). *Upptäck tekniken i barnlitteraturen*. Natur och Kultur: Stockholm.

Axell, C., & Boström, J. (2015). Facts for youngsters – Contextualised technology or fragmented artefacts? A study on portrayals of technology in picture books from a gender perspective. In M. Chatoney (Ed.), *PATT 29 plurality and complementarity of approaches in design and technology education*. Marseille Aix: Marseille University.

Axell, C., & Hallström, J. (2011). Representations of technology in educational children's fiction in Sweden in the early 20th century: The example of The Wonderful Adventures of Nils. In K. Stables, C. Benson, M. J. de Vries (Eds.), *PATT 25: Cript 8: Perspectives on learning in design & technology education*. London: Goldsmiths, University of London.

Axell, C., & Hallström, J. (2015). Technology and the shaping of a Swedish national identity in the educational work of Selma Lagerlöf, 1900–1907. *History of Education & Children's Literature, 10*(1), 299–344.

Axell, C., Hallström, J., & Hagberg, J.-E. (2013). Technology for a sustainable life. Images in Swedish children's literature. In J. P. Williams & D. Gedera (Eds.), *PATT 27: Technology education for the future: A play on sustainability.* Christchurch/New Zealand/ Hamilton/New Zealand: University of Waikato.

Burton, V. L. (1939/2005). *Mike Mulligan and his steam shovel*. London: Frances Lincoln.

Dakers, J. R. (2011). The rise of technological literacy in primary education. In C. Benson & J. Lunt (Eds.), *International handbook of primary technology education: Reviewing the past twenty years*. Rotterdam: Sense.

Daugherty, J., & Daugherty, M. (2007). Thinking in time: Affecting technological literacy through oral history research. In J. R. Dakers, W. Dow, & M. J. de Vries (Eds.), *PATT 18: Teaching and learning technological literacy in the classroom*. Glasgow: Faculty of Education, University of Glasgow.

de Vries, M. (2006). Technological knowledge and artifacts: An analytical view. In J. R. Dakers (Ed.), *Defining technological literacy: Towards an epistemological framework*. New York: Palgrave Macmillan.

Dennett, D. C. (1990). The interpretation of texts, people and other artifacts. *Philosophy and Phenomenological Research, 50*(S), 177–194.

Edgerton, D. (2006). *The shock of the old: Technology and global history since 1900*. London: Profile Books.

Ellul, J. (1964). *The technological society.* New York: Vintage Books.

Ellul, J. (2010). The autonomy of technology. In C. Hanks (Ed.), *Technology and values: Essential readings*. Malden: Wiley-Blackwell.

Fisher, R. (1998). *Teaching thinking: Philosophical enquiry in the classroom*. London: Continuum.

Foster, P. N. (2009). An analysis of children's literature featured in the "Books to briefs" column of technology and children, 1998–2008. *Journal of Technology Education, 21*(1), 25–43.

Frängsmyr, T. (1990). *Framsteg eller förfall: framtidsbilder och utopier i västerländsk tanketradition* (2nd ed.). Stockholm: Allmänna förlaget.

Garmire, E., & Pearson, G. (2006). *Tech tally: Approaches to assessing technological literacy.* Washington, DC: National Academy of Science.

Greenberg, M. L., & Schachterle, L. (1992). Introduction: Literature and technology. In M. L. Greenberg & L. Schachterle (Eds.), *Literature and technology.* Bethlehem: Lehigh University Press.

Hård, M., & Jamison, A. (2005). *Hubris and hybrids: A cultural history of technology and science*. New York: Routledge.

Hughes, T. P. (1987). The evolution of large technological systems. In W. E. Bijker, T. P. Hughes, & T. J. Pinch (Eds.), *The social construction of technological systems: New directions in the sociology and history of technology.* Cambridge, MA: MIT Press.

Jansson, T. (2009). *Muminpappans memoarer* (New ed.). Stockholm: Alfabeta.

Kelly, K. (2010). *What technology wants*. New York: Viking.

Klasander C. *Talet om tekniska system: Förväntningar, traditioner och skolverkligheter* (Dissertation). Linköping: Linköping University; 2010.

Kranzberg, M. (1986). Technology and history: 'Kranzberg's Laws'. *Technology and Culture, 27*(3), 544–560.

Kroes, P. (2012). *Technical artefacts: Creations of mind and matter: A philosophy of engineering design*. Dordrecht: Springer Netherlands.

Lebduska, L. (1994). Rethinking human need: Seuss's The Lorax. *Children's Literature Association Quarterly, 19*(4), 170–176. Project MUSE.

Lee, J. Y. (1992). The feminization of technology: Mechanical characters in picture books. In M. L. Greenberg & L. Schachterle (Eds.), *Literature and technology.* Bethlehem: Lehigh University Press.

Mawson, B. (2007). Factors affecting learning in technology in the early years at school. *International Journal of Technology & Design Education, 17*(3), 253–269.
Monhardt, L., & Monhardt, R. (2006). Creating a context for the learning of science process skills through picture books. *Early Childhood Education Journal, 34*(1), 67–71.
Mumford, L. (1963). Authoritarian and democratic technics. *Technology & Culture, 5*(1), 1–8.
Mumford, L. (1967/1970). *The myth of the machine*. New York: Harcourt Brace Jovanovich.
Norman, D. A. (2013). *The design of everyday things* (Revised and expanded ed.). New York: Basic Books.
Pitt, J. C. (2014). 'Guns don't kill, people kill'; Values in and/or around technologies. In P. Kroes & P.-P. Verbeek (Eds.), *The moral status of technical artefacts*. Dortrecht: Springer.
Rowling, J. K. (1997). *Harry Potter and the philosopher's stone*. London: Bloomsbury.
Rowling, J. K. (1999). *Harry Potter and the prisoner of Azkaban*. London: Bloomsbury.
Sackes, M., Trundle, K. C., & Flevares, L. M. (2009). Using children's literature to teach standard-based science concepts in early years. *Early Childhood Education Journal, 36*(5), 415–422.
Schwarcz, H. J. (1967). Machine animism in modern children's literature. *The Library Quarterly, 37*(1), 78–95.
Seuss, D. (1971/2012). *The Lorax*. London: HarperCollins Children's.
Siu, K. W. M., & Lam, M. S. (2005). Early childhood technology education: A sociocultural perspective. *Early Childhood Education Journal, 32*(6), 353–358.
Sörlin, S. (1991). *Naturkontraktet: Om naturumgängets idéhistoria*. Carlsson: Stockholm.
Svensson, M. (2011). *Att urskilja tekniska system: didaktiska dimensioner i grundskolan* (Dissertation). Linköping: Linköping University.
Trundle, K. C., & Troland, T. H. (2005). The moon in children's literature. *Science and Children, 43*(2), 40–43.
Turja, L., Endepohls-Ulpe, M., & Chatoney, M. (2009). A conceptual framework for developing the curriculum and delivery of technology education in early childhood. *International Journal of Design and Technology Education, 19*(4), 353–336.
Waytz, A., Heafner, J., & Epley, N. (2014). The mind in the machine: Anthropomorphism increases trust in an autonomous vehicle. *Journal of Experimental Social Psychology, 52*(3), 113–117.
Winner, L. (1977). *Autonomous technology: Technics-out-of-control as a theme in political thought*. Cambridge, MA: MIT Press.
Winner, L. (1989). *The whale and the reactor: A search of limits in an age of high technology* (5th ed.). Chicago: The University of Chicago Press.

Use of Films in Technology Education 64

Kuen-Yi Lin

Abstract

This chapter mainly focuses on exploring the use of film in technology education. The main content includes current research into using film, an exploratory study of how film is used in teaching, and suggestions for using film in technology education, based on previous discussion and the development direction of this manuscript. In consideration of the previous discussion, this chapter presents the following conclusions: (1) to effectively use films in teaching, one should consider the film selection, as well as activities and discussion related to the film; (2) in the field of technology education, teaching activities covering knowledge, skills, design, and reflection can all be incorporated into the classroom by using film. In the future, the following subjects should be considered: (1) most science fiction films' themes are not easily integrated into technology education for developing students' technological creativity. To select appropriate films requires technology teachers to use proper planning and consideration in the topic of hands-on activity. (2) In the future, researchers in the field of technology education can consider how to use film to help students build technological knowledge, develop an interest in technology education, and develop creativity and critical thinking.

Keywords

Creativity • Film • Imagination • Science fiction films • Technology education

K.-Y. Lin (✉)
National Taiwan Normal University, Taipei City, Taiwan
e-mail: linkuenyi@ntnu.edu.tw

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_64

Contents

Introduction

Images are among the most influential media in today's society. The newer generation of students has difficulty separating their concerns from images (Prensky 2001). Therefore, the integration of images and learning can have a great impact. Film is a representation of images. Films can seem to present the reality of historical and cultural material using sound and light effects. Not only do films convey emotional meaning, they also include the audience in the emotional experience (Wang 2012). Films are often thought by students to be a natural part of their lives and culture. Film is the entertainment medium that students are most connected to, it is most shared with peers, and students are most interested in it (Marshall 2003; Tobolowsky 2007). Therefore, if films and education are properly integrated, this should be able to draw students' attention and guide students to appreciate films for different purposes and learn to consider other aspects of their surroundings to achieve their educational goals.

The integration of film and education is a usual practice. In Murray's discussion of film research and education (1973), he mentions that films can inspire students to read more and better stories, and when the content of textbooks was difficult, then film could be considered an alternative means of educating. Therefore, the use of film in education is indeed feasible and worthy of further discussion. From the perspective of cognitive style, cognitive style is comprised of personal preferences and habits related to processing and organizing information (Riding and Rayner 1998). Childers et al. (1985) categorized students' cognitive style as either verbal or image oriented. With the use of information and communication, technology has gained popularity among new-generation students. Learners' cognitive styles are greatly inclined toward the image oriented, and learners who are inclined to use a verbal-oriented cognitive style have become fewer and fewer (Lin et al. 2013). Recognizing this, how to properly use films to help students learn is something on which educators should be concentrating. Although past trends have focused on electrical or mobile learning, many learning programs are gradually moving into using films. For example, in recent years, Taiwan has promoted Massive Open Online Courses, known as MOOCs, where universities offer special courses for international students to learn. These prominently feature films in the course curriculum (Chen and Chen 2015). In addition, the rise in the flipped classroom strategy allows teachers to fully use film resources from the Internet more and more, moving away from the traditional lecture. This provides students an opportunity for active learning and participation in classroom discussion.

At present, the research into using films mostly focuses on knowledge of scientific interest in the field of science education. As for the field of technology education, the use of films has also become more and more popular. Some researchers believe that science fiction film is more interesting as a cultural expression in developing students' attitude toward technology (Murphie and Potts 2003). Some technology teachers use teaching films on machines to help students acquire the concepts of operational safety. Some technology teachers use science fiction film clips to stimulate students' imaginations and generate more creative ideas in the design phase. The researchers in technology should consider ways to use films to help students build technological knowledge and to develop an interest in technology. The main purpose of this chapter is first to discuss the current research on film usage and then explore further the use of film in the teaching field. Finally, this chapter will conclude with suggestions for using film in technology education.

Related Studies on the Use of Film

The influence of film on people can be surmised by the frequency of viewing. For example, Rideout et al. (2010) found that an average American spent 4 h and 29 min watching television and 25 min watching movies in a typical day between the ages of 8 and 18. The director may have simply filmed a script and sometimes led the audience to reflect upon it, but with the help of current film technology, films also allow viewers to experience alternate realities (Tucker 1993). In order to consider current research into film usage, the following explains such concepts as cognitive domain and affective domain, in order to better understand the substantial benefits of film in education.

Cognitive Domain

Before children start going to school, many parents teach them patterns of thinking and emotional experiences through stories. Storytelling is the easiest way to connect people (von Franz 1986), and film is a type of storytelling. Through this type of storytelling, one is presented with the relationship between cultural tradition and historical culture. Films help students to build a deeper understanding of the social culture and history of a time period (Walker 2006; Wineburg et al. 2007). Films can allow one to imagine a future world of technology and give audiences more space to imagine (Larson 2008). Damasio (2000) believed that through the integration of film and education, the learners' brain usage would expand; meaning, through the arrangement of the stories in films, they could integrate their thinking and emotions and use their knowledge to validate their understanding.

The use of films in education is not a new concept (Barnett and Kafka 2007). Many scholars have tried to teach students concepts of science through science fiction (Barnett and Kafka 2007; Efthimiou and Lewellyn 2004; Freedman and Little 1980), and research has presented positive (Liberko 2004) and negative (Barnett et al. 2006) results of its effectiveness. Researchers do believe that the impact of science fiction films on audiences comes from the sense of being entertained in a relaxed manner and then carrying away an ability to construct scientific ideas, even if the science presented is not true science (Kirby 2003). In fact, films can create plausible images of scientific phenomena that lead audience members to wonder whether what they have just viewed could be true (Rose 2003). Logan (2001) believed that films were not useful for conveying true scientific concepts but were useful for creating interesting scientific images. Frank (2003) believed that films often caused audience members to change their understanding or ability to accept science or scientific phenomenon, even if they knew what they had viewed was mainly entertainment. Many studies have also shown that films help change the public's understanding of scientific concepts. Mainly this is because films can stimulate an interest in science, can reduce people's fear of technology, can present positive images of science and scientists, etc. (Cavanaugh and Cavanaugh 1996; Long and Steinke 1996).

Affective Domain

In addition to the aforementioned applications in the cognitive domain, many researchers use films to stimulate learners' interests in the affective domain. Taking science as an example, films can be used to help students learn concepts and also to stimulate students' interest in science. Most of the research showed positive results at these (Brake and Thornton 2003; Laprise and Winrich 2010). For example, Brake and Thornton (2003) thought that using film clips in science classes could intensify students' interest in science, and this is mainly because film clips are often closely related to the students' daily living. Laprise and Winrich (2010) also tried to use science fiction to stimulate students' interest in learning science, and according to their research data, such films stimulated interest in studying science among students who were not majoring in science. In other words, using films to help students in learning science concepts might produce positive or negative effects, but if films were used to motivate students and stimulate an interest in learning, then the outcome was mostly positive. The main reason is because film is often considered a part of the culture, and it is the most commonly shared medium of entertainment (Marshall 2003; Tobolowsky 2007). Hence, when films and learning are joined, this can stimulate students' interest.

Other Domains

In addition to using films in science courses, some researchers have started analyzing the content of science fiction films and exploring their ability to stimulate students' imaginations. For example, Blythe and Wright (2006) believe that science fiction films could be used as an important source for user-centered design. For instance, 50 years before Bill Gates started living in his smart house, Isaac Asimov had already proposed the idea. Twenty years after Arthur C. Clarke proposed the concept of satellite communication, the technology of satellite communication was common. Although Blythe and Wright (2006) consider science fiction films to stimulate creative ideas, Larson's analysis of ten popular sci-fi films (2008) showed that the development trend or imagination of future technology described in them was actually very limited. Although what was imagined in the ten sci-fi films that Larson (2008) analyzed was very limited, it did not necessarily follow that this limited content could not stimulate the learner's imagination. Besides, subsequent films, made after these ten films, have shown more imagination.

Aside from using films to stimulate learners' imaginations, many scholars have also tried to use films to cultivate students' critical thinking abilities. For example, Walker (2006) believed that guiding students to identify film content that is related to the course material was the first step in training the students in critical analysis. Students should view the film with a questioning and critical attitude, and they should consider the possibilities and diverse ways of historical development. Through analysis, students can compare past and current social and political issues. Moreover, films stimulate students' reflection and critical thinking, allowing them to reexamine their views of historical reality by seeing what is latent under the surface of history, while helping them to differentiate between the actual and the imagined (Stoddard and Marcus 2010; Walker 2006; Woelders 2007).

In summary, the study of film usage shows that the integration of film and education promotes students' learning in science and technology, as well as their interest, imagination, and critical thinking skills. This is an important idea for future use.

The Application of Using Films in Teaching

With this understanding of the use of film in teaching, this section is mainly an in-depth discussion of teaching methods using films. According to the concept of constructivism, knowledge building cannot be independent of context (Brown et al. 1989) because learning occurs within the knowledge context (Spiro et al. 1992), and film is the most effective medium for providing knowledge context. Using films in teaching has received much support. For instance, Wang thought that the teaching by using films was relatively low cost, was more convenient, and was reflective of students' interests and the pulse of society (2012). Wang also asserts that films match the learning style of today's young students. In addition, using films in teaching enhances students' interest in learning. Discussion sessions after viewing a film also help students to cultivate critical thinking and self-reflection. The following section mainly focuses on teaching practice and the effectiveness of teaching using films. Lastly, the potential applications of teaching with film in technology education are provided; these may be used as reference for technology teachers and researchers.

Methods of Using Films in Teaching

When it is mentioned to the methods of using films in teaching, the film selection, activity planning, and discussion planning are three important aspects and the should be noticed in teaching.

Film Selection

When choosing films, teachers must have a clear understanding of their subjects and of the learning content. Films should be chosen that connect to students' prior experiences, rather than those based on the teacher's personal preferences (Marshall 2003; Stoddard and Marcus 2010). Krueger et al. (2004) created an online video database that enables instructor trainers to select appropriate instructional videos and use them in methodology classes. The results show that the teachers involved were very pleased with this method. In addition, Tobolowsky (2007) found in his study that using instructional videos allowed students to choose films themselves, and the students welcomed this. Through the selection exercise, students received learning experience in analytical thinking. Therefore, choosing their own selections becomes an effective strategy for increasing students' critical thinking and analytic abilities, and teachers are able to determine students' learning needs and preferences for their own professional development.

Activity Planning

If teachers play films without considering the students' thinking, then the benefit of film for students is very limited. Many researchers believe that when the film watched reflects students' real-world situations, then the film is able to create a learning environment that facilitates students' thinking, helping them to cross-reference their actual situations with the film's plot and thereby resulting in a deeper understanding. This also leads students into a process of self-reflection. This type of study atmosphere and effect cannot be produced in lectures given by teachers (Marshall 2003; Wang 2012). In addition, Weerts (2005) pointed out that a teacher's questioning techniques are also important to increasing students' critical thinking. Therefore, in addition to proper planning that enhances students' thinking, teachers should also ask good questions to stimulate critical thinking in students.

Discussion Planning

In addition to the activity planning, discussion can also enhance the educational value of teaching using films, making this a major factor in learning. Conducting proper discussions beforehand is a critical element in encouraging students to think (Wang 2012). Tobolowsky (2007) also pointed out that when instructors are carrying on classroom discussion, they must allow different viewpoints, interpretations, and critiques, letting all viewpoints be heard. For instance, artificial intelligence, or AI, raises ethical concerns for students to think about. If videos are just played in the classroom and are not used to create room for discussion and thinking, then even the best films are just entertainment without much educational value (Stoddard and

Marcus 2010; Wang 2012). Barnett (2006) integrated classroom teaching using films with Internet discussion and then set up a website to conduct discussions with experts about the important issues presented in the films in order to broaden the understanding of the issues raised.

In addition to the activities mentioned above, some researchers use a case method of teaching through film to plan learning activities. The implementation process consists mainly of case studies, discussion, and reflection (Cannings and Talley 2002; Chang and Hsu 2010). In this process, teachers play a supporting role to encourage students to actively learn, and through deep discussions centered on the students, the students acquire meaningful knowledge and learning experience using analysis, discussion, and reflection. In addition, students develop self-concepts, improve their communication and listening skills, learn to appreciate others' opinions, and increase their critical thinking, reflective thinking, and problem-solving skills (Ertmer and Russell 1995; Jennings 2002; Merseth 1994; Wassermann 1995).

The Practical Approach to Using Film in Technology Education

Having discussed general methods of teaching using films, this section will explore how to use films in technology education. There are many feasible methods; the following suggestions for knowledge, skills, design, and reflection are provided for reference.

Knowledge Aspect

The knowledge aspect mainly refers to using films to stimulate reflection on the nature of technology and social critique and to teach technological knowledge that is difficult and hard to understand. When teaching engineering graphics, films can be used to explain three-dimensional graphs or drawings (e.g., Introduction to Engineering Drawing from https://www.youtube.com/watch?v=z4xZmBpXIzQ). In teaching Mechanics and its structures, films can be used to explain mechanical structure and the actual operations (e.g., How pinwheel calculators work from https://www.youtube.com/watch?v=YXMuJco8onQ). Thus, this way of teaching gives students a more thorough understanding of the technological knowledge being taught.

Skills Aspect

The skills aspect is one of the important teaching goals of technology education. It trains students for hands-on operation of machines. Students often must learn how to use manual tools or mechanical equipment during machine operation (e.g., How to use a power drill from https://www.youtube.com/watch?v=r59gnrhiCrw). In order for students to fully learn correct operating skills, the technology teachers may consider using films first to teach preliminary concepts of operational safety before the teachers personally carry out a demonstration. This avoids accidents caused by any unfamiliarity with safe operating techniques. For instance, when teaching how to use circular saws, films such as "How to Use a Table Saw" can be used to help students understand safe operation of circular saws beforehand (https://www.youtube.com/watch?V=F8kUMwluwMk).

Design Aspect

In hands-on activities, students often need to go through a design and production stage. Many students often design with intuition. However, due to the lack of relevant stimuli to assist their imaginations, many scholars attempt to use films to stimulate their students' imagination or to enhance their students' creative expression in technological products. Lin (2012) compared the stimulating effects of science fiction books and science fiction films on the design creativity of eighth grade middle school students, and the results showed that the effective use of science fiction films stimulated students' design creativity more than did science fiction reading. According to Lin's (2012) research results, Lin et al. (2013) used science fiction films to stimulate technological creativity in junior high students and found that the use of these films actually helped stimulate technological creativity. In addition, Lin (2014) also used science fiction films to promote a creative atmosphere and then to explore the films' impact on creative ideas and creative products in junior high school students. The research results indicated that a learning environment using science fiction films helped stimulate ideas in junior high school students. However, from the perspective of creative product, although there was a good outcome, the effect did not reach a statistically significant level. If the technology teachers can properly select films to promote a creative atmosphere, this should help in stimulating students to develop more creative ideas and to cultivate technological creativity.

Reflection Aspect

Many science fiction films, such as "I am Legend" and "A.I. Artificial Intelligence," explore ethical issues concerning technology. If the technology teachers can properly provide space for students to discuss and think about such issues (Stoddard and Marcus 2010; Wang 2012), and guide students to reflect in a deep way, this would be helpful in cultivating students' critical thinking skills. In order to plan a good classroom discussion, Tobolowsky's (2007) suggestion should be noticed, that is, the technology teachers must allow students to express their different viewpoints, interpretations, and critiques to their teammates. Besides, the technology teachers should also stimulate their students in having complex-level thinking instead of just basic-level thinking when they are planning discussion about the technological issues.

Conclusions and Future Directions

Film is one of the most influential media in today's society. Due to the fact that film and students' lives are inseparable, using films to assist in the implementation of technology education is an important topic that is worth further thought. This chapter presents the following concrete conclusions: (1) teachers should consider the choice of films, as well as the thinking activities and discussion activities to avoid merely playing videos and not guiding students to think; (2) in the field of technology education, teaching activities regarding knowledge, skills, design, and reflection can all be included in by using films to teach. Especially in the area of design, there is research that indicates using science fiction films to promote a creative atmosphere is very effective (Lin 2014). For future research, the use of films in the classroom should consider the following subjects: (1) the theme of a film may present ethical issues in technology development or focus on the imagining of future scientific developments; therefore, it is not easy to integrate with technology education or actual hands-on activities. Selecting appropriate films requires technology teachers to use good planning. (2) At present, the research into using films mostly focuses on knowledge of scientific interest. In the future, researchers in technology should consider ways to use films to help students build technological knowledge and to develop an interest in technology or attitudes toward technology.

References

Barnett, M. (2006). Using a web-based professional development system to support pre-service teachers in examining authentic classroom practice. *Journal of Technology and Teacher Education, 14*(4), 701–729.

Barnett, M., & Kafka, A. (2007). Using science fiction movie scenes to support critical analysis of science. *Journal of College Science Teaching, 36*(4), 31–35.

Barnett, M., Wagner, H., Gatling, A., Anderson, J., Houle, M., & Kafka, A. (2006). The impact of science fiction film on student understanding of science. *Journal of Science Education and Technology, 15*(2), 179–191.

Blythe, M. A., & Wright, P. C. (2006). Pastiche scenarios: Fiction as a resource for user centered design. *Interacting with Computers, 18*(5), 1139–1164.

Brake, M., & Thornton, R. (2003). Science fiction in the classroom. *Physics Education, 38*(1), 31–34.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42.

Cannings, T. R., & Talley, S. (2002). Multimedia and online video case studies for pre-service teacher preparation. *Education and Information Technologies, 7*(4), 359–367.

Cavanaugh, T. W., & Cavanaugh, C. (1996). *Learning science with science fiction films*. Dubuque: Kendall/Hunt Publishing Company.

Chang, Y.-F., & Hsu, C.-L. (2010). The effects of applying a VCS system on pre-service teachers' competencies for technology integration. In Z. Abas et al. (Eds.), *Proceedings of global learn Asia Pacific 2010* (pp. 1394–1401). Chesapeake, VA: Association for the Advancement of Computing in Education.

Chen, Y.-H., & Chen, P.-J. (2015). MOOC study group: Facilitation strategies, influential factors, and student perceived gains. *Computers and Education, 86*, 55–70.

Childers, T. L., Houston, M. J., & Heckler, S. E. (1985). Measurement of individual differences in visual versus verbal information processing. *Journal of Consumer Research, 12*(2), 125–134.

Damasio, A. (2000). The feeling of what happens: Body and emotion in the making of consciousness. San Diego/New York/London: Harcourt.

Efthimiou, C., & Lewellyn, R. A. (2004). Cinema as a tool for science literacy. *Physics Education, 16*(1), 1–13.

Ertmer, P. A., & Russell, J. D. (1995). Using case studies to enhance instructional design education. *Educational Technology, 35*(4), 23–31.

Frank, S. (2003). Reel reality: Science consultants in Hollywood. *Science as Culture, 12*(4), 427–443.

Freedman, R. A., & Little, W. A. (1980). Physics 13: Teaching modern physics through science fiction. *American Journal of Physics, 48*(7), 548–551.

Jennings, D. (2002). Strategic management: An evaluation of the use of three learning methods. *Journal of Management Development, 21*(9), 655–665.

Kirby, D. A. (2003). Science consultants, fictional films, and scientific practice. *Social Studies of Science, 33*(2), 231–268.

Krueger, K., Boboc, M., Smaldino, S., Cornish, Y., & Callahan, W. (2004). In time: Impact report what was in time's effectiveness and impact on faculty and pre-service teachers? *Journal of Technology and Teacher Education, 12*(2), 185–210.

Laprise, S., & Winrich, C. (2010). The impact of science fiction films on student interest in science. *Journal of College Science Teaching, 40*(2), 45–49.

Larson, J. (2008). Limited imagination: Depictions of computers in science fiction film. *Futures, 40* (3), 293–299.

Liberko, C. A. (2004). Using science fiction to teach thermodynamics: Vonnegut, ice-nine, and global warming. *Journal of Chemical Education, 81*(4), 509–512.

Lin, K.-Y. (2012). The stimulating effects of science fiction books and films on the product-design creativity of middle school students. *Journal of Research in Education Science, 57*(3), 121–151.

Lin, K.-Y. (2014). Effects of science fiction films on junior high school students' creative processes and products. *Thinking Skills and Creativity, 14*, 87–97. doi:10.1016/j.tsc.2014.09.005.

Lin, K.-Y., Tsai, F.-H., Chien, H.-M., & Chang, L.-T. (2013). Effects of a science fiction film on the technological creativity of middle school students. *Eurasia Journal of Mathematics, Science & Technology Education, 9*(2), 191–200.

Logan, R. A. (2001). Science mass communication. *Science Communication, 23*(2), 135–163.

Long, M., & Steinke, J. (1996). The thrill of everyday science: Images of science and scientists on children's educational science programs in the United States. *Public Understanding of Science, 5*(2), 101–119.

Marshall, E. O. (2003). Making the most of a good story: Effective use of film as a teaching resource for ethics. *Teaching Theology and Religion, 6*(2), 93–98.

Merseth, K. K. (1994). *Cases, case methods, and the professional development of educators* (ERIC document reproduction service no. ED 401272).

Murphie, A., & Potts, J. (2003). *Culture and technology*. New York: Palgrave MacMillan.

Murray, J. C. (1973). Film study and education. *Melbourne Studies in Education, 15*(1), 145–162.

Prensky, M. (2001). *Digital game-based learning*. New York: McGraw-Hill.

Rideout, V. J., Foehr, U. G., & Roberts, D. F. (2010). *Generation M^2: Media in the lives of 8–18 year-olds*. Menlo Park: Henry J. Kaiser Family Foundation.

Riding, R., & Rayner, S. (1998). *Cognitive styles and learning strategies: Understanding style differences in learning and behavior*. London: David Fulton Publishers.

Rose, C. (2003). How to teach biology using the movie science of cloning people, resurrecting the dead, and combining flies and humans. *Public Understanding of Science, 12*, 289–296.

Spiro, R. J., Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (1992). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. In T. M. Duffy & D. H. Jonassen (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 57–75). Hillsdale: Lawrence Erlbaum.

Stoddard, J. D., & Marcus, A. S. (2010). More than "showing what happened": Exploring the potential of teaching history with film. *High School Journal, 93*(2), 83–90.

Tobolowsky, B. F. (2007). Thinking visually: Using visual media in the college classroom. *About Campus, 12*(1), 21–24.

Tucker, M. (1993). *Dreaming with open eyes*. San Francisco: Aquarian/Harper.

von Franz, M. L. (1986). *Interpretation of fairytales*. Munich: Kosel-Verlag.

Walker, T. R. (2006). Historical literacy: Reading history through film. *The Social Studies, 97*(1), 30–34.

Wang, C.-H. (2012). An exploratory study on learner-oriented movie-teaching approach for a life education course in teachers' education. *Journal of Educational Practice and Research, 25*(1), 163–188.
Wassermann, S. (1995). *Getting down to cases: Learning to teach with case studies*. New York: Teachers College Press.
Weerts, S. (2005). Use of films to teach critical thinking. *Journal of Nutrition Education and Behavior, 37*(2), 100–101.
Wineburg, S., Mosborg, S., Porat, D., & Duncan, A. (2007). Common belief and the cultural curriculum: An intergenerational study of historical consciousness. *American Educational Research Journal, 44*(1), 40–76.
Woelders, A. (2007). "It makes you think more when you watch things": Scaffolding for historical inquiry using film in the middle school classroom. *The Social Studies, 98*(4), 145–152.

Social Media and the Internet in Technology Education

65

Thomas Loveland

Abstract

Beginning in the 1980s with the introduction of computers and the Internet in the early 1990s, school systems took major steps to empower teachers with tools that increased their productivity and communications. With changing ideas about curriculum, expanded availability of computers, and higher speed Internet connectivity, schools are supporting student research and learning through real-time applications. The increasing use and evolution of educational technologies is having an impact on education systems. Technology used by teachers now include hardware and software collaborative tools, and social networking sites (ISTE 2008). Technology education student use of the Internet enhances both brainstorming and design steps of engineering design. The use of WebQuests, virtual reality applications, smartphones, and other applications provide technology teachers with flexible instructional options and encourage a collaborative learning environment for students. Social media applications are allowing for increased student collaboration via shared content development. Student communication and collaboration can expand beyond the traditional school boundaries to new global partners. Online applications such as Facebook, Edmodo, wikis, and blogging offer students an open source location to post, reexamine, edit, and communicate content to others globally in ways that are familiar to the millennial and Z generations. Research in technology education illustrates the numerous benefits to teachers who learn to adapt these new technologies. The increasing capabilities of these technologies is having an effect on technology teachers, classroom structures, instructional strategies, and students.

Keywords

Internet • Social media • Global collaboration • Connectivity

T. Loveland (✉)
University of Maryland Eastern Shore, Baltimore, MD, USA
e-mail: tloveland@umes.edu

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5_65

Contents

Introduction

Classrooms across the world have used educational technologies in one form or another for decades. Educational technology is "the use of technologies by teachers to support learning in their classrooms (Loveland 2012, p. 115). In the 1960s, the use of overhead projectors, film strip projectors, 16 mm film projectors, and foreign language stations were common. Students were passive recipients of these tools. Student research was conducted in school libraries through the use of file cards, hard copy books, publications, and microfiche files.

Beginning in the 1980s with the introduction of computers and the Internet in the early 1990s, educational technologies took a radical shift towards empowering students to support their own research and learning through real-time applications and peer collaboration. Technology used by teachers and students now include media, multimedia, hardware, software, electronic gradebooks, presentation graphics, online reference databases, communications, the creation of educational videos and video sharing sites, and social networking sites (ISTE 2008). This chapter will focus on an emerging area of educational technology in the field of technology education: the use of software applications and social media to support learning, increased global collaboration, and the impact of these evolving technologies on technology education classrooms.

The Internet and Schools

With its potential as a widely accessible and vast educational resource, the Internet is a natural fit for school districts trying to survive in a tight fiscal climate. Technology and the Internet have become prevalent in schools and universities worldwide, having transitioned from stand-alone computer labs in the 1980s to technology-integrated classrooms in most major subject areas. Kennedy (2016) reports that "as computer programs have become more sophisticated, devices more ubiquitous and costs more affordable, millions of students now have easy access inside and outside classrooms to resources of higher quality and in greater quantity than previous generations could have imagined" (p. 12). There has been an extraordinary level of recent development of Internet infrastructure, new applications, and user capabilities available to schools (Glassman and Burbidge 2014).

While technology infrastructure tends to be the focus of attention in school budgetary planning, Glassman and Burbidge (2014) report that schools should shift their attention to the social aspects of Internet use in schools. This shift accounts for the implications of the way the Internet changes society and how students relate to each other in the world around them. Schools should focus on the meaning of the implementation of the Internet as part of a natural integrated part of human activity. The possibility for instantaneous communication worldwide leads students to extend their learning and thinking by collaborating with others within and beyond the classroom. Students can broaden their learning into new realms through interconnected cooperation with other people, whether students, teachers, or experts.

> The ability to move back and forth easily between local and global contexts, and for knowledge of the Internet not only to influence place but be influenced by place, suggests that the Internet as a tool, separate from the processes of knowing and used simply as a way of promulgating and disseminating knowledge, is giving way to the idea of the Internet being integrated into the larger gestalt of our lived experience. (Glassman and Burbidge 2014, p. 21)

Impact on Students and Teachers

Turner (2015) describes the Generation Z as digital natives. Born on or after 2000, these individuals grew up with readily accessible technologies. Their smartphones are considered an all-in-one entertainment hub. They are used to being fully connected with no downtime. With multitasking the norm, Generation Z are often an *absent presence*, meaning that they may be physically in a place but are distracted by their technologies. Table 1 compares the school experiences of boomers, Generation X, millennials, and Generation Z.

Feiertag and Berge (2008) discuss the nature of teaching the millennial generation. Sometimes referred to as Generation N for *networking*, born between 1980 and 1999, they have many common attributes. Like Generation Z, millennials rely on the Internet for information. Many are graphically oriented, as opposed to text driven. Jones (2013) described millennials as tethered to their technology. They thrive in group settings with hands-on work. In schools, they prefer video lectures over in-person lectures (Bishop and Verleger 2013). Millennials take a cut and paste approach to completing assignments and often do not understand the repercussions of posting items on social media or the long-term impact of what they write in emails

Table 1 Secondary education experiences by four generations

	Boomers Born 1946–1964 **Generation X** Born 1965–1979	**Millennials** Born 1980–1999	**Generation Z** Born 2000+
Communication	No phone access in school Limited use of pagers later Typed or handwritten notes	Cell phones confiscated, email	Smartphones, tablets, instant messaging, SKYPE, Snapchat
Research means	Use file cards, microfiche, and hard copies	Use emailed PDFs and WWW search	Smartphone search, wikis, YouTube
Collaboration	Small face groups, competitive, task-oriented	Collaborative small groups, problem-solving oriented	Online collaborative, thinks globally, networking-oriented

(Jones 2013). The best teaching strategies for millennials and Generation Z is to have course resources online that include discussion forums, virtual group work, and engaging multimedia.

According to Freiertag and Berge (2008), many millennials feel that any information found on the Internet is in public domain and may be freely used. Jones (2013) states that millennials lack skills needed to perform educational research or identify reliable online resources. Soloway et al. (2000) state that student research on the Internet is generally inadequate due to limited attention spans, short class periods, lack of expertise, and lack of media center support. Other identified problems include irrelevant hits when browser searching and student access to inappropriate websites on the Internet.

The impact of the Internet and online education resources on teachers depends largely on their age and technological prowess. For older teachers, keeping up with technologies and applications may be beyond the teacher's expertise. Glassman and Burbidge (2014) report teachers, like society, may be in one of three stages in adopting technological innovations. Stage one is when the technology is seen as a threat, uncomfortable to one's wellbeing and an infringement on the norm. In stage two, teachers learn to accept the innovation although it is still seen as separate from one's core. In the third stage, individuals embrace new and evolving technologies and integrate them fully in their work and home life. Through technology innovations in teacher preparation programs younger teachers may be more likely to be in stage two or three, using technologies seamlessly in their classrooms.

Glassman and Burbidge (2014) report that the most ineffective application of the Internet and new technologies is to use it as the principal method of disseminating static knowledge. Teachers should not use the Internet as a primary tool of communication but make it an integrated aspect of the classroom community to reach beyond the classroom walls. Kennedy (2016) describes connected twenty-first century classrooms with virtual field trips, simulations, supplementary video lectures from YouTube, social media contact with global experts, and video teleconferences with other classrooms around the world. This use of the Internet allows students to go beyond traditional classroom walls in the process of exploring new information through nonlinear linked structures and global partners. This ability helps teachers to meet the ISTE National Educational Technology Standards and teacher performance indicator #4-d “develop and model cultural understanding and global awareness by engaging with colleagues and students of other cultures using digital-age communication and collaboration tools” (ISTE 2008).

Internet Applications and Technology Education

The Internet has proven to be a great resource for educators in general and technology education teachers in particular. In the engineering design process, initial steps common to Engineering by Design and Project Lead the Way include problem analysis, brainstorming and research, and generating ideas. Pieper and Mentzer (2013) report that digital-native students have problems in the research step, specifically with searching through Internet resources due to the overwhelming volume of resources available. Despite this problem, engineering students working on a design solution were found to have devoted nearly triple the amount of time searching on the Internet than in paper-based resources. Akers (2016) reported that high school students responded positively to the inclusion of Internet-based applications in the engineering design process. Pieper and Mentzers’ study highlighted equity issues in high schools regarding access to computers and the amount of class time available for research. The implication to technology teachers was to provide equitable access to the Internet in a computer lab to increase the amount of time students have to work on their hands-on designs.

WebQuests

Researchers at San Diego State University developed WebQuests in 1995 as a teacher resource for developing inquiry-based lesson plans on the Internet (WebQuest.org 2016). Technology education teachers may develop content-specific lesson plans in WebQuest for their students to open and work within the WebQuest environment. For example, a technology teacher in Florida used WebQuests in a transnational curriculum project with a Japanese class to design and construct a 1/20th scale model International Space Station (ISS) for teenagers. Four sections (control, experiment bay, living quarters, and power) of the ISS were developed by teams of two Japanese and two American students each. Plans were shared through a WebQuest project site. Extensive use of NASA educational websites were utilized by all four teams (Loveland 2012). Cook et al. (2016) referred to global collaboration when a class project involves students from around the world who are given the same challenge or curriculum within a given amount of time. “When this collaboration results in digital educational content shared globally, all boundaries of time, place, and space are removed” (Cook et al. 2016, p. 22).

WebQuests are effective lesson formats because they increase peer to peer communication between students regardless of geography. Talamentes (2006) reported on how WebQuests mediated the communication process, affected the meaning perspectives by students through language socialization, and increased student collaboration. This socialization guides the maintenance of continuity and coherence in projects through increased face-to-face work. WebQuest was crucial in providing a technology process and means in which students could demonstrate and construct the academic and social effectiveness within the groups formed.

Virtual Reality and Simulations

Virtual worlds and Internet-based simulations are instructional tools that are finding a place in technology education classrooms (Swinson et al. 2016; Wood et al. 2013; Downey 2014). According to Loveland (2012), they are "a means to allow students to explore and manipulate three dimensional multimedia environments, including gaming simulations, in real time" (p. 122). Virtual worlds, developed as a gaming entertainment, are being utilized for instruction and educational research (Downey 2014). Improved from early versions that were text-based and accessible by less than 250 users, third-generation virtual worlds are larger-scale graphical, high-resolution systems with 10,000 simultaneous users. One of the developers of this service, Second Life, has content including real-world buildings, towns, and scientific simulations, making it a popular choice for technology educators (Downey 2014).

Wyss et al. (2014) describes Second Life as a free, Internet-based 3D multiuse virtual world. Users create a virtual user bot that is then placed in a virtual world to explore. In technology education, teachers can use this to allow students to complete assignments at their own pace. One example virtual world, Cotton Island, includes supplemental resources embedded in the world for students to access. These resources include videos, PowerPoints, and scavenger hunts. Launched is 2003, Second Life helps students to develop collaborative skills in a highly immersive and social environment. Technology students demonstrate increased attention, relevance, confidence, and satisfaction, all resulting in greater learner motivation (Wyss et al. 2014).

Wood et al. (2013) report that virtual worlds are being used in education to make online coursework more engaging and personable for students. They are used in technology education to simulate hazardous conditions for training purposes and to test building stress points. Simulations allow students to modify inputs to mimic defects in materials and designs, thereby helping students to learn engineering skills while solving problems and improving systems, structures, and products (Swinson et al. 2016). The ability to virtually analyze designs can be equally applied to tower designs and computer finite elements analysis. Jones (2013) links simulations and virtual learning to three important twenty-first century learning skills: the ability to think critically, analyze information, and to collaborate. In technology education, best practice use included developing bots as a learning activity and use of chat bots in virtual space.

Educational simulations are enhanced by the use of bots or simulated figures who respond to prompts in complex manners. Bots are improving from low-resolution characters with limited movement to more complex and interactive capabilities that are more authentic to students. Wood et al. (2013) indicates that while bot use is not widespread now, educators have plans for expanded use of bots. A lack of technical expertise by teachers is hindering further implementation. Four benefits of using bots were identified:

- They enable greater realism and immersion with improved interactivity.
- They can be used to create learning situations that can't exist in real life.
- Bots are effective in teaching routine procedures.
- They also support soft skills development and understanding of content knowledge.

One final aspect of virtual education is the use of augmented reality (AR) applications. In augmented reality, three-dimensional virtual objects are superimposed on real worlds or objects. According to Thornton et al. (2012), AR can be utilized in technology education to model objects in engineering designs and provide nonconsumable demonstrations that can be repeated. This flexibility enhances the student's visual and spatial skills. Augmented reality has many benefits: teachers learn to adapt new technologies, clarity and understanding of examples is improved, it can be an effective tool for accommodating special needs and at-risk students, and it allows technology education students to examine engineering problems from different perspectives. Thornton et al. (2012) described a technology education lesson plan where students interacted with the Eiffel Tower by accessing Google Earth through ARSights, an augmented reality provider.

Smartphones

Wireless devices like cell phones, personal computers, tablets, and cameras are labeled by many educators as disruptive devices in schools (Nowell 2014). Some teachers and students believe that the benefits outweigh the risks of allowing their use in the classroom. With the introduction and mass acceptance of smartphones, their use by technology education teachers as instructional tools has increased. The improved functionality and location-aware content applications have transformed how teachers view the technology (Squire and Dikkers 2012). Five ways in which students benefit from using smartphones in classrooms include portability, social interaction ability, immediacy of content and data, connectivity in multiple networks, and unique scaffolding for individual's learning needs. Squire and Dikkers (2012) indicate that students use the mobile WiFi devices for gathering information and participating in social networks. Students valued their ability to quickly look up information or view video tutorials as needed. The phones make it possible for students to teach others what they have researched. Finally, enterprising students may find that time working with mobile technologies in the content fields of art, design, engineering, or technology could make them more productive learners in these areas (Squire and Dikkers 2012).

Nowell (2014) described how a technology education teacher allowed students to use smartphones in the class as organizers and instruments for employer-employee communications and to increase their media literacy skills. Technology teachers maximize their effectiveness by requiring students to understand that media messages are constructed and interpreted by different authors and audiences. A Korean technology education teacher uses tablet PCs and smartphones for in-class discussions and problem-based learning in team settings (Kim 2016).

A technology teacher in Anne Arundel County, Maryland, reports successful integration of smartphones in the classroom. The students are able to transfer information instantaneously and write reports more easily. Students can record via video or audio parts of their project and can even see what other people in their group are doing (Norris 2016). Rose et al. (2014) describe the mobile learning application *geocaching* to teach concepts of energy systems. Geocaching is an interactive gaming scenario where students use smartphones to scavenger hunt and discover information based on global positioning system coordinates. The information being sought meets learning objectives in the technology education course. In a case study on the use of GeoMobile to study nearby energy systems, Rose et al. (2014) reported improvements pre to post test in 75% of the sites being studied. Students indicated that geocaching was enjoyable and engaging. One main concern with the use of mobile WiFi phone technologies is how to equitably use them if they are student owned rather than universally provided by schools. Students whose families cannot afford smartphones or it is a lower priority will be at a disadvantage if phones are a required part of the curriculum.

Social Media and Web 2.0

Social media is described as “a technology of communication and for creating and exchanging user-generated content” (Herrera and Peters 2011, p. 364). Web 2.0 tools are utilized in social media for sharing content, collaborating, and interacting (Kovalik et al. 2014; Stevenson and Hedberg 2011). Herrera and Peters (2011) discuss how user-developed organization, distribution, and commentary of content contribute to a new mediascape where interactions are participatory. Specific Web 2.0 tools that are ubiquitous now include Facebook, Twitter, LinkedIn, Jing, Google, Pinterest, Wikispaces, Instagram, and more. Hsu (2007) referred to these systems as conversational technologies.

According to Herrera and Peters (2011), there are nine core principles that define social media as different from other forms of communication:

1. *Participation* by multiple groups of people simultaneously.
2. *Collective wisdom* from the shared work on content.
3. *Transparency* as every person has access to view, edit, and critique the shared content.

4. *Decentralization* as no one absolutely controls the content.
5. *Virtual community* where the work builds social relationships between users.
6. *Design is politics* How the site is structured is based on how people will use it.
7. *Emergence* describes the self-organizing structure that is based on democratization of all person's efforts.
8. *Revisability* means that all content can be continually altered.
9. *Ownership* of the content is free and completely accessible.

Social Media as an Educational Tool

Teachers are integrating Web 2.0 tools into their curriculum and sharing their ideas within teacher networks, blogs, and wikis (Kovalik et al. 2014). Web 2.0 is popular with teachers and school districts because they are free, easy to adapt, and can be structured within a teacher-controlled environment. Stevenson and Hedberg (2011) describe Web 2.0 as simple to adopt, learner-oriented, and effective at supporting out-of-school applications. Piotrowski (2015) cautions that K-12 educational systems have not fully embraced social media for instruction or staff use. Issues of concern to school districts are the uncertainty of public or private ownership, and the intellectual property rights of social media-developed content (Herrera and Peters 2011). Other challenges related to institutional acceptance of social media include the quality of professional development for teachers, lack of research on learning design, ineffective institutional leadership, security issues, and scalability (Stevenson and Hedberg 2011). Scalability refers to the ability of a system, network, or process to manage a growing amount of work. Social media does offer technology students the opportunity to quickly connect and collaborate with other students across the globe. The potential for connecting global education systems to new generations of digital-savvy students can transform education in ways not previously imagined.

Herrera and Peters (2011) discuss the impact of social media tools on student research in an educational context. First, there needs to be a virtual place that multiple stakeholders have access to. Second, there needs to be valuable artifacts grounded in practice and policy to work with. Finally, the social norms in the Web 2.0 tool must be supportive of academic rigor, empirical evidence, interpersonal respect, and ethical behavior. This last attribute is sometimes referred to as social media citizenship.

One effect on educational systems is that the digitalization of learning has increased the speed and dispersal of knowledge, thus leading to new digital literacies. The new technology-adapted pedagogies have the potential to disrupt traditional instructional strategies and learning. Hedberg (2010) states that social media technologies in general are more unifying of people generationally, geopolitically, and digitally. The new technologies may be disruptive to teaching pedagogies but it depends on the school system and abilities of the teachers. Stevenson and Hedberg (2011) conclude that:

"the development of skills that support newer modes of learning, cultural expression and collaboration arguably necessitate transformed relationships between pedagogies and technologies, allowing for multi-modal expression within participatory cultures to the point where collaboration and collective intelligence represent dominant discourses" (p. 330).

Applications of Social Media in Technology Education

Technology education teachers often find themselves in the role of technology and digital mentor to other teachers in their school. While some of this may be a perception that a technology education teacher is up to date on all new forms of technology, many technology educators are in fact technology integrators (Loveland 2012). Technology education teachers are likely to be early adopters of new technologies and the use of social media as an instructional strategy.

Facebook

Due to its' size and pervasiveness in culture, Facebook is the foremost application of social media in the world. According to Herrera and Peters (2011), Facebook had 800 million users worldwide communicating in 70 languages with 30 billion postings per month. The Facebook website reports that by 2015, they had reached 1 billion users (Facebook 2016). Facebook is a social networking platform where individuals can build social relationships through personal and professional interest affiliations. Interpersonal interactions in this knowledge-sharing network can foster communities of learners and teachers across the globe.

Aydin (2012) discussed research results showing that Facebook can positively impact classrooms if students are allowed to use it in class for academic activities. One American technology education teacher (Maser 2016) stated "This is a great place for the kids to create a page for their project or organization. They can advertise their work and even look for other people to collaborate with." Facebook can have a positive effect on the teaching of language in schools. This could include the technical language associated with technology education content.

Manca and Ranierti (2013) report that Facebook supports student learning based on content exploration, connections between students and outsider experts, and development of artifacts within networks that connect students, digital artifacts, and subject matter content, particularly when tied into real world applications. Positive student attitudes towards learning are enhanced when students use Facebook to identify and find resources, help friends to answer questions, and to share notes. Manca and Ranerti (2013) list educational uses for Facebook that include allowing students to have shared discussions with critical thinking exercises, develop multimedia content artifacts, share resources, expand curriculum and instructional strategies, and support self-directed learning by students.

Edmodo

Similar to Facebook, Edmodo is a closed educational social media community where students have unlimited access to a personalized learning environment (Nowell 2014). Teachers can assign work to students online and post class announcements. Students publish their assignments in Edmodo and communicate with teachers and peers. Nowell (2014) reported that a technology education teacher used Edmodo to teach students about job interviewing, writing skills, and tailoring messages to specific audiences.

American technology education teachers use Edmodo in multiple ways. One teacher uses it to stay in contact with students because it meets county computer use policies (Akers 2016). Another teacher reports:

> It's like Facebook in that students can create a profile, post messages and reply to my and other student's post. I use it for a variety of purposes from having students post to a question to taking a poll in order to get students' opinions. It can be used also to take quizzes in different formats and I can have students open documents from this webpage. Students like it because they can see what other students are thinking. I like that I can monitor student's activities in one easy location. (Koperski 2016)

A third technology education teacher suggests that social media is framing the way technology education is heading. The social media feel of Edmodo makes it a very valuable tool for this teacher who uses it for background research and training on computer programming (Evans 2016).

Microblogging

Gao et al. (2012) describe microblogging as a way for people to publish short (140 characters or less) information briefs for real or asynchronous communication. Two well-known instruments of microblogging are Twitter and Instagram. When used by educators, microblogging promotes a collaborative virtual learning setting where instructors can quickly exchange ideas with students. A key characteristic of blogs is it allows users to develop and maintain their own subject output (Hsu 2007). In a review of 21 research studies, Gao et al. (2012) summarize problems with using microblogging in schools: students' unfamiliarity with blogging, intimidation with the learning curve to use it, unwieldy flow and amount of information encountered, most postings are a waste of time, small number of participants compared to non-participants, and the inability of students to express complete ideas in only 140 characters. In order to maximize the use of microblogging, teachers should define clear expectations for students, model effective microblogging, include microblogging results in assessment, use hashtags and shorten links in postings, and weave important tweets into class discussion and lectures.

A technology education teacher from Baltimore County, Maryland, describes positive use of microblogging as "…active just for your project or team. They can communicate with each other or with the other groups competing. They can get their ideas out into the twitterverse and see if anyone else enjoys them. They are able to document in real time what they were doing and when" (Maser 2016). Micro-blogging and blogs support students meeting the twenty-first century skill of collaboration (Jones 2013).

Blogging

Kovalik et al. (2014) describes blogging as "a place to write, upload images and documents, create hyperlinks, and invite others, to comment on the content the blogger has provided" (p. 94). Google has a free Web 2.0 tool called Blogger that can be used by educators. Teachers use blogging to help students think deeply and critically, and to facilitate questions and responses to support learning. Two issues that teachers face are the amount of time it takes to create the blog for the students and restrictions placed by the administration on using the comment option.

Ramsay et al. (2012) report that educational systems are including online components in courses to stimulate student engagement and connect with millennials and Generation Z. Use of blogging by educators creates space for student reflection, exchange of ideas through student-authored postings, and share comments and feedback that is democratic and immediate. Blogs are difficult to incorporate though due to their complexity to design, implement, and maintain. Few faculty are creating blogs and most are unfamiliar with how blogs can support instructional objectives. In a study of 200 preservice Design and Technology teachers in Australia, Chandra and Chalmers (2010) report that the sharing of constructive comments through blogs was deemed useful to the design process by participants. The collaborative feedback had potential to shape the understanding of design and technology content in preservice teachers.

Wikis

Knobel and Lankshear (2009) define wikis as "a collection of webpages whose content is typically organized around a specific purpose or topic" (p. 631). They are an online space where multiple authors from across the globe collaborate to define a topic through reediting; posting of embedded links to other documents, photos, videos, or audio; and built-in discussion forums. Chandra and Chambers (2010) state that wikis represent a summary of a group's learning experience and research. Glassman and Burbidge (2014) define the most well-known wiki, Wikipedia, as a digital online encyclopedia. They caution about the validity of the content on Wikipedia because the information is crowd sourced, not expert driven.

In a technology education classroom, wikis can be utilized with student teams to prepare and communicate reports about any technological subject. Chandra and Chambers (2010) report that Design and Technology preservice teachers used wikis in their assignments. In a specific technology project, student teams used wikis to report on critical stages in the project related to investigating, designing, producing, evaluating, and reflection. Qualitative interviews with five students concluded that the use of wikis added value to the student work, were a useful tool for group work, and work continued unabated even when students were in remote locations or on asynchronous time. Jones (2013) stated that the use of wikis helps students to meet the twenty-first century learning skill of collaboration.

Conclusion and Future Directions

Due to an ever-expanding list of educational social media applications and the expected increase in bandwidth, processing speeds, storage capacity, and the imagination of tomorrow's digitally driven workforce, it can be expected that future educational applications of the Internet and social media will keep growing into evermore complex structures. Artificial intelligence and three-dimensional content will make targeted, authentic training more likely for future technology students. Learning will continue inside and outside of the classroom with greater opportunities for cooperation and collaboration between technology classrooms across the world. This expanding global connectivity will help our digital-savvy students learn through a process of constant unlearning and relearning. Technology education will not look like it did in the 1980s, 2000s, or even today. Educators are advised to hold on to their hats for a wild ride.

References

Akers, Ruth. Social media in the classroom [Internet]. Message to: Thomas Loveland. 2016 May 13 [Cited 2016 June 3].

Aydin, S. (2012). A review of research on Facebook as an educational environment. *Educational Technology Research & Development, 60*(6), 1093–1106.

Bishop J, Verleger M. The flipped classroom: a survey of the research. Proceedings of the 120th ASEE Annual Conference & Exposition; 2013 June 23-26; Atlanta, Georgia. American Society for Engineering Education, Paper ID #6219.

Chandra, V., & Chalmers, C. (2010). Blogs, wikis and podcasts–collaborative knowledge building tools in a design and technology course. *Journal of Learning Design, 3*(2), 35–49.

Cook, L., Bell, M., Nugent, J., & Smith, W. (2016). Global collaboration enhances technology literacy. *Technology and Engineering Teacher, 5*, 20–25.

Downey, S. (2014). History of the (virtual) worlds. *The Journal of Technology Studies, 40*(2), 54–66.

Evans, Charles. Social media in the classroom [Internet]. Message to: Thomas Loveland. 2016 May 5 [Cited 2016 June 15].

Facebook [Internet]. About Facebook. [cited 2016 June 6]. Available from www.facebook.com/facebook/info/?tab=milestone

Feiertag, J., & Berge, Z. (2008). Training generation n: How educators should approach the net generation. *Education & Training, 50*(6), 457–464.

Gao, F., Luo, T., & Zhang, K. (2012). Tweeting for learning: A critical analysis of research on microblogging in education published in 2008-2011. *British Journal of Educational Technology, 43*(5), 783–801.

Glassman, M., & Burbidge, J. (2014). The dialectical relationship between place and space in education: How the internet is changing our perceptions of teaching and learning. *Educational Theory, 64*(1), 15–32.
Hedberg, J. (2010). Towards a disputive pedagogy: Changing classroom practice with technologies and digital content. *Educational Media International, 48*(1), 1–16.
Herrera, L., & Peters, M. (2011). The educational and political significance of the new social media: A dialogue with Linda Herrera and Michael A Peters. *E-Learning and Digital Media, 8*(4), 364–374.
Hsu, J. (2007). Innovative technologies for education and learning: Education and knowledge-oriented applications of blogs, wikis, podcasts, and more. *International Journal of Information & Communication Technology Education, 3*(3), 70–89.
International Society for Technology in Education (ISTE) [Internet]. The ISTE national educational technology standards (nets-t) and performance indicators for teachers 2008 [cited 2016 May 31]. Available from https://www.iste.org/docs/pdfs/20-14_ISTE_Standards-T_PDF.pdf
Jones, V. (2013). Teaching, connecting & empowering learners. *Techniques, 88*(1), 16–17.
Kennedy, M. (2016). Keeping on the cutting edge. *American School & University, 88*(7), 12–15.
Kim, Jinsoo. Social media and Internet use in Korea [Internet]. Message to: Thomas Loveland. 2016 June 26 [Cited 2016 June 27].
Knobel, M., & Lankshear, C. (2009). Wikis, digital literacies, and professional growth. *Journal of Adolescent & Adult Literacy, 52*(7), 631–634.
Koperski, Kevin. Social media in the classroom [Internet]. Message to: Thomas Loveland. 2016 May 3 [Cited 2016 June 13].
Kovalik, C., Kuo, C., Cummins, M., Dipzinski, E., Joseph, P., & Laskey, S. (2014). Implementing web 2.0 tools in the classroom: Four teachers' accounts. *Techtrends: Linking Research & Practice to Improve Learning, 58*(5), 90–94.
Loveland, T. R. (2012). Educational technology and technology education. In J. Williams (Ed.), *Technology education for teachers*. Rotterdam: Sense.
Manca, S., & Ranieri, M. (2013). Is it a tool suitable for learning? a critical review of the literature on facebook as a technology-enhanced learning environment. *Journal of Computer Assisted Learning, 29*(6), 487–504.
Maser, Robert. Social media in the classroom [Internet]. Message to: Thomas Loveland. 2016 May 4 [Cited 2016 June 9].
Norris, Greg. Social media in the classroom [Internet]. Message to: Thomas Loveland. 2016 May 3 [Cited 2016 June 7].
Nowell, S. (2014). Using disruptive technologies to make digital connections: Stories of media use and digital literacy in secondary classrooms. *Educational Media International, 51*(2), 109–123.
Pieper, J., & Mentzer, N. (2013). High school students' use of paper-based and internet-based information sources in the engineering design process. *Journal of Technology Education, 24*(2), 78–95.
Piotrowski, C. (2015). Social media: Major topics in dissertation research. *Education, 135*(3), 299–302.
Ramsay, C., Aman, D., & Pursel, B. (2012). Blogging pragmatics and pedagogy: An adventure in faculty development. *Education and Information Technologies, 19*(2), 425–440.
Rose, A., Gosman, D., & Shoemaker, K. (2014). Mobile learning: Geocaching to learn about energy systems. *Technology and Engineering Teacher, 74*(1), 18–23.
Soloway, E., Norris, C., Marx, R., Blumenfeld, P., Krajcik, J., & Fishman, B. (2000). K-12 and the internet. *Communications of the ACM, 43*(1), 19–23.
Squire, K., & Dikkers, S. (2012). Amplifications of learning: Use of mobile media devices among youth. *Convergence: The Journal of Research Into New Media Technologies, 18*(4), 445.
Stevenson, M., & Hedberg, J. (2011). Head in the clouds: A review of current and future potential for cloud-enabled pedagogies. *Educational Media International, 48*(4), 321–333.

Swinson, R., Clark, A., Ernst, J., & Sutton, K. (2016). Design, test, redesign: Simulation in technology, engineering, and design education classrooms. *Technology and Engineering Teacher, 75*(7), 8–12.
Talamantes M. Computer use in context: looking through the lens of language socialization University of California, Riverside; 2006.
Thornton, T., Ernst, J., & Clark, A. (2012). Augmented reality as a visual and spatial learning tool in technology education. *The Technology Teacher, 71*(8), 18–21.
Turner, A. (2015). Generation z: Technology and social interest. *Journal of Individual Psychology, 71*(2), 103–113.
WebQuest.org [Internet]. [cited 2016 June 1]. Available from http://webquest.org/index.php
Wood, L., Reiners, T., & Bastieans, T. (2013). Design perspective on the role of advanced bots for self-guided learning. *International Journal of Technology, Knowledge & Society, 9*(4), 187–199.
Wyss, J., Lee, S., Domina, T., & MacGillivray, M. (2014). Cotton Island: Students' learning motivation using a virtual world. *Decision Sciences Journal of Innovative Education, 12*(3), 219–232.

Index

M.J. de Vries (ed.), *Handbook of Technology Education*, Springer International Handbooks of Education, DOI 10.1007/978-3-319-44687-5

D