INTERNATIONAL TECHNOLOGY EDUCATION SERIES

Fostering Human Development Through Engineering and Technology Education

Moshe Barak and Michael Hacker (Eds.)

SensePublishers

Fostering Human Development Through Engineering and Technology Education

INTERNATIONAL TECHNOLOGY EDUCATION STUDIES

Volume 6

Scope
Technology Education has gone through a lot of changes in the past decades. It has developed from a craft oriented school subject to a learning area in which the meaning of technology as an important part of our contemporary culture is explored, both by the learning of theoretical concepts and through practical activities. This development has been accompanied by educational research. The output of research studies is published mostly as articles in scholarly Technology Education and Science Education journals. There is a need, however, for more than that. The field still lacks an international book series that is entirely dedicated to Technology Education. *The International Technology Education Studies* aim at providing the opportunity to publish more extensive texts than in journal articles, or to publish coherent collections of articles/chapters that focus on a certain theme. In this book series monographs and edited volumes will be published. The books will be peer reviewed in order to assure the quality of the texts.

Fostering Human Development Through Engineering and Technology Education

Edited by

Moshe Barak
Ben-Gurion University of the Negev, Israel

Michael Hacker
Hofstra University on Long Island, New York, USA

SENSE PUBLISHERS
ROTTERDAM/BOSTON/TAIPEI

A C.I.P. record for this book is available from the Library of Congress.

ISBN: 978-94-6091-547-5 (paperback)
ISBN: 978-94-6091-548-2 (hardback)
ISBN: 978-94-6091-549-9 (e-book)

Published by: Sense Publishers,
P.O. Box 21858,
3001 AW Rotterdam,
The Netherlands
www.sensepublishers.com

Printed on acid-free paper

TABLE OF CONTENTS

MOSHE BARAK AND MICHAEL HACKER

INTRODUCTION

Human Development and Engineering and Technology Education

HUMAN DEVELOPMENT

The future of engineering and technology education (ETE) and its role in general education strongly depend on how educators, researchers, stakeholders and the general public conceptualize and understand the role of ETE in developing students' broad intellectual competencies, talents, knowledge and skills that will enable them to enjoy long, fulfilling, and creative lives, and contribute meaningfully to society and the economy. Alkira (2002) articulated that the term 'human development' we have used in the title of this chapter is multidimensional and suggested a set of dimensions, including *basic human functional capabilities, axiological categories, dimensions of well-being, universal human values, quality of life domains, universal psychological needs and basic human needs*. Maslow, in his well-known book Motivation and Personality (1954) suggested a hierarchy of human needs including *self-actualization, esteem, love and belonging, safety needs, and physiological needs*. Max-Neef (1991) developed the Human Scale Development, which is defined as "focused and based on the satisfaction of fundamental human needs, on the generation of growing levels of self-reliance, and on the construction of organic articulations of people with nature and technology, of global processes with local activity, of the personal with the social, of planning with autonomy, and of civil society with the state" (Max-Neef, 1991, p. 8). This author classifies fundamental human needs as *subsistence, protection, affection, understanding, participation, leisure, creation, identity and freedom*. Each of these needs is also defined according to four existential categories of *being, having, doing and interacting,* and from these dimensions, a 36-cell matrix is developed. For example, the need for *understanding* means:

- *Being* equipped with critical capacity, curiosity and intuition
- *Having* things such as literature, teachers, policies and educational
- *Doing* actions such as analyzing, studying, mediating and investigating
- *Interacting* with others, for example in the family, school, university and community

The dimensions of human development sketched above provide us with a broad perspective of the role of education in general, and ETE in particular, in developing individuals and promoting their well-being and quality of life. This view was adopted, for instance, in the Human Development Reports of the United Nation Development Program (UNDP) in the years 1990 to 1996. As our era is characterized by rapid socio-economic changes that are breaking down old social frameworks and workplace characteristics, today, more than in the past, ETE should shift its focus from teaching specific knowledge and skills to fostering students' higher intellectual competencies, such as critical thinking, creativity, problem solving, independent learning and teamwork, as shown in the next section.

A PERSPECTIVE ON ENGINEERING AND TECHNOLOGY EDUCATION

In the past, technology education was often identified with teaching crafts, skills oriented at the traditional industry's needs, or vocational education for low-achieving students. It is hoped that the term engineering and technology education would help in clarifying to learners, educators and the general public that the study of ETE is rigorous, will support the education of all learners regardless of career path, and appropriate as a new, fundamental subject for study in our schools.

The American Engineers Council for Professional Development (ECPD) defines engineering as "The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property." Technology is a broader term, and more difficult to define. Marc de Vries (2005) describes technology as "the human activity that transforms the natural environment to make it fit better with human needs, thereby using various kinds of information and knowledge, various kinds of natural (material, energy) and cultural resources (money, social relationships, etc.)." In summary, although the terms engineering and technology are not the same, the border between them is not precisely defined.

To demonstrate our view about the term 'engineering and technology,' let us consider the following example:

> Residents living in a high-rise building complain that during rush hour, around 8:00 a.m., they have to wait too long for the elevator. A technical solution to this problem could be, for instance, improving the elevator control program or mechanical system, replacing the elevator with a faster one, or adding elevators to the building. Engineering and technology, however, is not just about technical issues but also about human needs and behavior. These are the basic considerations in choosing how many elevators are needed in a building and how large to make them so people would feel they had enough space. Therefore, a more sophisticated solution to the elevator problem mentioned above would be to change not just the elevator's parameters but also the residents' elevator use habits. For example, consider the possibility that residents could call the elevator using personal electronic means such as a magnetic card or even their smartphones. Families using the elevator infrequently during rush hour (pensioners, for example) could get a significant reduction in their monthly building maintenance fee. The proposed solution could work well in one building but fail in another, depending on social and cultural factors. Moreover, using personal electronic means for calling an elevator might involve an

ethical problem because this enables the system to accumulate information on residents' movements in and out of the building.

This example shows that engineering and technology education is about fostering students' knowledge, aptitudes and skills related to addressing scientific, technical and social-cultural dimensions in the process of design, problem solving or inventing new artifacts and technological systems. In addition to the individual development and career-related imperatives, ETE experiences can be very valuable pedagogically for students in providing an effective way of reinforcing mathematics, science, social science and language skills by mobilizing 'engineering thinking' and 'technological thinking' as a way of engaging young people in addressing design challenges in social contexts that are personally meaningful to them.

ENGINEERING AND TECHNOLOGY EDUCATION AND FOSTERING LEARNING COMPETENCES

As we have seen, the most important challenge to ETE is the transition from teaching specific knowledge and skills to fostering students' higher-order capabilities such as critical thinking, creativity and problem solving. Unfortunately, we feel that this point has not been stressed enough in the past. While teachers and scholars in mathematics and science education often claim that the major objective of teaching these subjects in school is to develop students' thinking skills, beyond teaching useful knowledge, it can hardly be said that engineering and technology educators frequently underscore this objective. Do mathematics and science education have better tools to promote meaningful learning and develop students' critical and creative thinking than does ETE? We don't think so. For example, Brandt (1998), in his book *Powerful Learning* articulates that people learn well when:

- *"what they learn is personally meaningful to them;*
- *what they learn is challenging and they accept the challenge;*
- *what they learn is appropriate for their developmental level;*
- *they can learn in their own way, have choices, and feel in control;*
- *they use what they already know as they construct new knowledge;*
- *they have opportunities for social interaction; and*
- *they receive helpful feedback."*

We believe that all the seven characteristics mentioned above of a powerful learning environment are at the heart of engineering and technology education. This makes this field one of the best educational environments for fostering learning in school, as is explored throughout this book.

OBJECTIVES AND STRUCTURE OF THE BOOK

Over the past three decades, we have witnessed a significant increase in the amount of discussion and writing on issues such as the rationale, objectives, contents and methods of technology and/or engineering education. This has been expressed, for example, in the *International Technology Education Series* of books by Sense Publishers, within which this book is published, as well as in periodicals such as the *International Journal of Technology and Design Education* and *Technology and Design Education- an International Journal* . Series of conferences, such as *PATT, CRIPT, ASEE, ITEA, and TERC*, which take place globally, have also played an important role in presenting research and fostering discussion among scholars in the ETE community. Yet, we feel that a need exists to further accelerate discussion and writing about the role of ETE in developing students' cognitive, social and personal skills, and the methods or impediments in achieving this end. Towards this aim, this book was designed to comprise four main parts, each including three to five chapters, as described below.

The first part of the book, entitled 'Dimensions of Learning – A Theoretical Framework' includes chapters by Christian D. Schunn & Eli M. Silk, John R. Dakers, Moshe Barak, and Scott D. Johnson, Raymond Dixon, Jenny Daugherty & Oenardi Lawanto. In these chapters, the authors review a range of theories and conceptual issues relating to learning and cognition particularly appropriate for supporting learning in the context of ETE, for example, distributed cognition, cognitive apprenticeship, activity theory, self-regulated learning and the question of learning transfer.

The next part of the book is about the 'Dimensions of Human Development – Competences, Knowledge and Skills.' It includes chapters by Marc de Vries, John Williams, David Barlex, John M. Ritz & Johnny J. Moye, and Thomas Liao. These chapters discuss issues such as the basic concepts that constitute the discipline of engineering and technology education, fostering learners' dispositions 'to do' and thereby reducing the gap between abilities and actions, promoting creativity in the technology classroom, developing self-efficacy, goals, interests, values-motivation and skills related to technological design, and decision-making.

Part three of the book takes us to the 'Cultural Dimensions' of ETE. The authors Jacques Ginestié, Linda Rae Markert and Karl M. Kapp refer to subjects such as the teaching-training process concerned with the transmission of tools, artifacts and knowledge, an examination of the extent to which cultural orientation influences our capacity as individuals to become technologically literate, and questions dealing with how ETE is influenced by the third millennial culture and how this culture is influenced by technology.

The last part of the book contains three chapters addressing 'Pedagogical Dimensions' by David Crismond, Michael Hacker & Jim Kiggens, and Evangeline S. Pianfetti & George Reese. In these chapters, the authors bring into light some of the unique capabilities related to using design tasks in project-based learning environments, show how playing and developing educational games are instructional strategies that could add to the teaching and learning of contemporary engineering and technology education, and reveal ways in which computer technologies such as simulation, video and the Internet could be used to reshape the instruction of ETE and bring the curriculum closer to the active life of the mind.

CONCLUDING REMARKS

Since the contributors to this book are of different backgrounds and minds, they evidently do not share exactly the same meanings of the terms 'human development' and 'engineering and technology education.' In this sense, the book is an attempt to highlight and explore the contribution of engineering and technology education to human development from multiple perspectives, and in this way encourage further discussion, research and writing on the objectives, methods and outcomes of teaching engineering and technology education in P-12 schooling.

The editors of this work would like to express their profound thanks to the author team for their important and original contributions to this book. The authors represent a group of outstanding educators and researchers in Engineering and Technology Education who have provided visionary and consistent leadership to this field of endeavor that is poised for explosive growth. The willingness and seriousness of purpose with which each of the authors approached the development of their chapter is characteristic of the way they have approached their professional efforts. Our years of collaboration with these individuals have been personally and professionally rewarding for us.

We are grateful for the opportunity to work with and learn from such an able and visionary group of engineering and technology educators and researchers and hope that our combined work, as expressed in the following chapters, will prompt further exemplary reform efforts in the educational field that we hold so dear.

Sincerely,
Moshe Barak and Michael Hacker

REFERENCES

Alkire, S. (2002). Dimensions of human development. *World Development*, *30*(2), 181–205.

Brandt, R. (1998). *Powerful learning*. Alexandria, VA: Association for Supervision and Curriculum Development (ASCD).

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

Maslow, A. (1954). *Motivation and personality*. New York: Harper.

Nax-Neef, M. A. (1991). *Human scale development conception, application and further reflections*. New York: The Apex Press. Available at http://www.max-neef.cl/home.php

United Nations Development Program (UNDP). (1990–1996). *The human development report*. New York: Oxford University Press. Available at http://hdr.undp.org/en/reports/global/hdr1990/chapters/

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

Michael Hacker
Co-director, Center for Technological Literacy
Hofstra University on Long Island, New York
USA

PART I:
DIMENSIONS OF LEARNING – A THEORETICAL FRAMEWORK

CHRISTIAN D. SCHUNN AND ELI M. SILK

1. LEARNING THEORIES FOR ENGINEERING AND TECHNOLOGY EDUCATION

INTRODUCTION

Optimizing technical systems depends on scientifically grounded models of system performance. Similarly, the development of engineering and technology education systems fruitfully builds upon relevant learning theories. Engineering and technology involve complex skills and concepts embedded in rich contexts. We review learning theories particularly appropriate for supporting learning of such complex concepts in rich contexts, drawing heavily on information processing, distributed cognition and cognitive apprenticeship.

OVERVIEW

The goal of this chapter is to articulate ways in which contemporary learning theories drawn from the learning sciences can enhance Engineering and Technology Education (ETE). We believe that ETE has much to gain by grounding research, instructional innovation and evaluation in existing theoretical frameworks. Connecting to theory helps guide instructional designers in the construction of learning environments that are likely to be effective as they build on the scientific work encapsulated in well-established learning theories and they are also then able to contribute further to what is known in ETE disciplines by refining and expanding on those theories.

But connecting to learning sciences theory is difficult for many experienced engineers and engineering/technology educators who seek involvement in education research, but who were not trained in a social science such as psychology or education (Borrego, 2007). To that end, this chapter intends to explore a number of contemporary learning theories that could serve to ground ETE research, design and evaluation. Although we cannot possibly cover all such learning theories, the ones we have chosen may be particularly useful to the work of ETE in which students must learn complex skills and concepts and to use those concepts adaptively in rich contexts.

The chapter is organized around the following two questions:

– Goals: What is ETE as something to be learned?
– Theories: What are some currently influential learning theories that could be applied to ETE?

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 3–18.

ENGINEERING AND TECHNOLOGY EDUCATION GOALS

In thinking about learning theories that may be relevant for ETE, it is important to be explicit about the outcomes that educators would like to see in their students. There are two dimensions to consider with respect to ETE. The first dimension is that ETE naturally involves elements of science, technology, engineering and mathematics (STEM). While technology and engineering elements are clearly the most central, they inevitably draw upon science and mathematics at various points, and the design of effective ETE environments should take those connections into account.

Second, there is the question of what fundamental form the elements to be learned take. Since the days of behaviorist learning theories, it has been clear that competent activity in a domain consists of many individual components, each of which must be acquired and developed through experience (Thorndike, 1913) —addition and multiplication, for example, are separate math skills, each requiring their own practice. This need for decomposition of learning goals and practice on the components continues to receive theoretical and empirical support (Singley & Anderson, 1989; Anderson, Bothell, Byrne & Lebiere, 2004). However, developments in education, cognitive psychology and neuroscience after the days of behaviorism have shown that there is more to learn than just skills (or stimulus-response associations in the language of behaviorism) and further that different kinds of learning involve different methods. For example, procedures and concepts rely on different brain areas for learning (Knowlton, Mangels & Squire, 1996); procedures become less introspectable with practice whereas concepts become more introspectable; and procedures are most robust but least flexible when automatized whereas reasoning is generally more flexible but requires conscious control (Anderson, Fincham & Douglass, 1997). Both are important for developing expertise in a domain.

In engineering terms, a solving a problem in a domain involves a complex system requiring many skills, concepts and other competencies rather than just a simple list of skills. Here is a division that was first developed in mathematics education (Kilpatrick, Swafford & Findell, 2001) that could be applied productively to ETE. Success appears to require all five elements:

- *Procedural fluency*—skill in carrying out procedures flexibly, accurately, efficiently and appropriately. This would include the use of tools, models and mathematics in technology/engineering problem-solving.
- *Conceptual understanding*—explicit comprehension of relevant concepts from engineering, technology, science and mathematics, understanding what possible operations are available and why they work, and an understanding of the relationships between concepts and operations.
- *Strategic competence*—ability to formulate, represent and solve complex STEM problems.
- *Adaptive reasoning*—capacity for logical thought, reflection, explanation and justification.
- *Productive disposition*—habitual inclination to see STEM as sensible, useful and worthwhile, coupled with a belief in diligence and one's own ability to solve technology or engineering problems.

A strong ETE curriculum will help students make progress at all five levels. Thus, it is important to consider each of these elements and learning theories that describe their acquisition. In the sections that follow, we will describe more concrete actions that ETE designers can use to develop more effective learning environments for each element.

ENGINEERING AND TECHNOLOGY EDUCATION LEARNING THEORIES

There are several broad theories of learning to consider that highlight some of the major outcomes from the learning sciences. Within each broad learning theory, there are more detailed theories of particular factors that influence learning, but here we focus only on the broad theories and the key distinctions they raise for the ETE teacher and designer.

One can roughly organize the components to be learned from more micro components (a large number of small pieces to be learned that are each executed quickly in time during problem-solving) to more macro components (a smaller number of larger pieces to be learned that are applied more pervasively during problem-solving). For example, there are many simple procedures to learn, each of which might only take a second to execute, whereas there are a few productive dispositions that need to be active through a potentially multiple-week-long process of solving a complex engineering problem. Similarly, one can organize learning theories in terms of having a more micro (short time scale focus on micro features of behavior) vs. macro (longer time scale focus on macro features of behavior) perspective (see Figure 1). This difference is more heuristic/approximate than absolute in that all of the theories make some contact with all of the components. However, a clear point of emphasis exists within each theory.

Theories	**Micro**	*Components*
Information Processing	↑	Fluent procedures
	│	Conceptual understanding
Distributed Cognition	│	Strategic competence
	│	Adaptive reasoning
Cognitive Apprenticeship	↓	Productive disposition
	Macro	

Figure 1. Micro to macro organization of learning theories and components of competent behavior in ETE.

INFORMATION PROCESSING (COGNITIVE) THEORIES OF LEARNING

One of the key insights of Information Processing theory is that complex tasks must be decomposed into informational components that are *encoded*, *stored* and *processed*, and fundamental cognitive limitations exist at each step that influence performance and learning. The mind, like a computer, does not have infinite capacity. A general flow of information is shown in Figure 2.

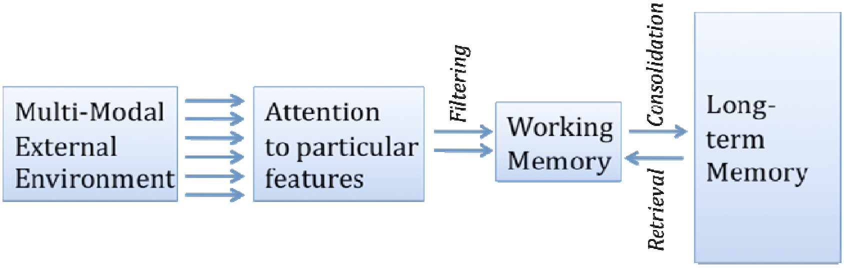


Figure 2. Flow of information from the environment into the mind.

Attention Issues

The problem-solver, especially in more complex engineering and technology settings, sits in a rich environment with all kinds of sensory signals impinging on his/her body (sights and sounds most importantly, but also smell, touch, temperature, pain and hunger). Well-practiced, automatic skills can make some use of much of this information, but more conscious, deliberate problem-solving depends on using information in working memory. The problem-solver actively selects which information to encode into working memory via an attentional filter: only information that is attended is moved initially to working memory, and only a very small bandwidth of information that is perceived can be attended. The mind appears to attend to locations and modalities one at time, but can switch rapidly between locations and modalities (Wickens & McCarley, 2008).

Novices often do not know what information to attend in a complex environment, and so the instructional designer and teacher must support the learner in attending to the right features at the right time. This might involve simplifying the environment to remove less relevant features, making critical features more salient, or bringing features closer together that must be encoded immediately to solve a problem (Wickens, 2008; van Merrienboer & Sweller, 2005). But note that learners will have trouble moving from a very simplified learning environment to the real performance environment if the information found in the simplified environment is perceptually different from the real environment and different information encoding skills are required.

Simply pointing out critical features to encode by itself can produce large speedups in learning because feature noticing can be subtle. For example, the skill of chicken sexing (determine a day-old chick's sex by visual inspection) used to take thousands of hours to perfect, but was later learned in a matter of a few hours once learners were explicitly told which features were important to encode (Biederman & Shiffrar, 1987). Closer to ETE, Kellman, Massey and Son (2010) found that training middle and high school students in mathematics classes to recognize patterns and fluently extract meaningful perceptual structures in mathematics problems greatly improved equation solving performance and solving novel problems.

Working Memory Issues

Moving information into attention is a first step, but not the last one in terms of information processing. In addition to limitations on how much can be attended at once, working memory is extremely limited in capacity—approximately four independent visual/spatial items and four independent verbal/acoustical items (Baddeley, 2003). Thus, as problem-solvers attend to new things, old things are lost from working memory; they must be mentally rehearsed (or reexamined to re-encode them) to be kept in working memory over time.

With experience, problem-solvers can 'chunk' combinations of information so that these familiar combinations only consume one item, effectively increasing working memory capacity in that familiar situation—for example, a chess expert can remember a whole board because sets of pieces can be grouped into familiar chunks, but a chess novice is stuck thinking about each piece on its own (Chase & Simon, 1973). Similarly, complex devices to a novice are overwhelming to remember because the novice cannot encode the subsystems of the device in terms of familiar groupings (Moss, Kotovsky & Cagan, 2006).

This severe capacity limitation on working memory has a number of implications for the instructional designer or teacher, especially because reflection by the learner on the task or situation, thought to be useful for learning, also relies on this same limited working memory capacity (van Merrienboer & Sweller, 2005). First, it is important to think through how many components the task being performed requires for a problem-solver to consider simultaneously in working memory (called the intrinsic cognitive load). It is important not to overwhelm the learner, taking into account the chunks that a learner is likely to already have. The peak cognitive load moment in a task is when errors are most likely to occur (Carpenter, Just and Shell, 1990). Addressing this issue might involve using familiar situations when first introducing procedures/tasks having a higher intrinsic load.

Second, it is important to find and reduce additional features of the learning situation that might be adding to working memory requirements (called the extrinsic cognitive load). For example, cluttered displays often imply that learners must keep track of where key information is being kept. Somewhat counter-intuitively, giving learners a very specific result to compute in an example produces a higher cognitive load than just asking students to compute a variety of results in the same situation because the specific goal must be stored in working memory (van Merrienboer & Sweller, 2005)—as a result, the specific goal situation produces more errors and reduces learning. Similarly, initially studying examples that show the solution process produces better learning outcomes than having students immediately solve problems on their own *because* the cognitive load of solving problems is higher than that associated with studying worked examples.

Consolidation/Fluid Fact Retrieval

As noted above, the working memory requirements of a situation are reduced when the problem-solvers can encode the situation in terms of larger familiar chunks. Where do these chunks come from? The chunks reside in long-term memory, which has essentially unlimited capacity (i.e., it never gets 'full'), but information is stored relatively slowly in working memory through a process called consolidation. In addition, problems may occur in retrieving the right chunks at the right time (i.e., stored information can get lost in the sea).

Expert performance involves having rapid access to relevant long-term memory chunks and this rapid access is built up gradually through repeated exposure. Here there is no free lunch, no cognitive shortcut (Anderson & Schunn, 2000). Rather, a relatively simple relationship exists by which each exposure slowly increases the probability of retrieving the information later and decreases the rate at which information is forgotten. There is one important caveat: studying information repeatedly spread out over time, rather than cramming, can have a large effect on how quickly information is forgotten (Pavlik & Anderson, 2005). So, for foundational information that is to be used in subsequent units or courses, it is very useful to revisit that information repeatedly at multiple points in the curriculum, spaced out over time.

Proceduralization

Chunking and storage in long-term memory is what happens to facts or memories for particular task arrangements and outcomes. A different kind of learning happens with skills. Here, information moves from being represented as facts to being represented as actions, a process called proceduralization. As a simple example, learning to drive a car begins with being told or reading about the steps involved. Students might be able to recite what the steps are, but they cannot actually consistently execute the steps until they have practiced the steps repeatedly. Over time, with enough practice, a problem-solver might actually lose the ability to recite the steps involved verbally because he or she no longer relies on that form of knowledge.

Similar to consolidation, proceduralization is a slow learning process with no magic bullets other than finding ways for students to more consistently practice only relevant steps. If a problem-solver wants to become fast and accurate at a procedure, hours of practice are required. Interestingly, there does not appear to be any point at which improvements stop with practice: even after thousands of hours of practice, people appear to keep getting faster with increasing practice, although of course the amount of improvement with each hour of practice diminishes (Anderson, Fincham & Douglass, 1997).

Proceduralization reduces working memory requirements because elements of the procedure do not need to be represented in working memory. Proceduralization does *not* by itself automatize the skill in that the skill, when first proceduralized, depends on explicit goals found in working memory and can be easily stopped or adapted through metacognitive reflection. However, with enough practice, the skills become automatic in the sense that they do not require any attentional resources to start the procedure, but they also cannot be easily stopped or adapted. For example, adults automatically read words as soon as they appear and cannot prevent themselves from reading the words. Sometimes problem-solvers need to complete multiple skills simultaneously; this dual task activity becomes more feasible when at least one of the skills has been practiced to the point of automaticity.

Prior Knowledge/Misconceptions

The previous analysis gives the sense of knowledge elements in isolation, each practiced in isolation. However, there are connections, particularly with respect to concepts. Cognitive research has found that one of the strongest predictors of how well a student is likely to learn something is how the new learning is related to what the student already knows and how their prior knowledge is organized (National Research Council, 1999, 2007). If the concepts to be learned and the way they are organized match neatly with a learner's pre-existing knowledge base, then the learning is likely to be smooth and rapid. However, in science and engineering, students often lack relevant conceptual frameworks or have frameworks that are not developed enough to support new learning adequately. If students cannot relate new information to a meaningful framework, they will probably resort to memorizing terms that will be quickly forgotten or that will remain in isolation, unable to be connected to other knowledge or applied when relevant.

ETE, including supporting science education, often extends everyday understanding to new levels that cannot be seen directly or experienced in everyday life. For example, much of biology and chemistry involves learning about entities and processes at a microscopic level. In biology, many students correctly associate properties like breathing, growth and reproduction with living organisms, but their understanding of these properties is based on their everyday experience. They understand something like breathing as taking air in and out through one's mouth or nose, and the need to do so is self-evidently obvious. This is correct as far as it goes, but a scientific understanding delves much deeper and explains these properties in terms of exchanges of gases that are required at the cellular level for cells to engage in the metabolic processes that support life. The way a person, a fish and a tree "breathe" may appear quite different on the surface, but the processes of cellular respiration unify and explain the common need to exchange gases and help us understand how different groups of organisms meet that need (see Chapter 5 for a more detailed discussion of the transfer of conceptual knowledge). To make sense of this, students must add new levels of concepts and explanatory systems to their understanding of the natural world and then work out how those levels are connected to their pre-existing views of the world (Smith, Maclin, Grosslight & Davis, 1997).

While some elements of ETE involve concepts very foreign to students, some concepts are misleadingly familiar to students. Through everyday informal interaction in the world, students sometimes develop misconceptions of how the natural and man-made world around them actually works. For example, in physics, most students have very serious misconceptions that are in direct opposition to Newton's Laws: students strongly believe that a table does *not* push up on a book sitting on it and they strongly believe that objects stay in motion only because a force continues to be applied to it (Clement, 1982). Because these informal understandings have been developed through years of experience, they are incredibly resistant to change through instruction. Instruction that ignores these misconceptions tends to fade quickly, leaving only the misconceptions in the learner's head, whereas instruction that evokes and directly attacks these misconceptions has significantly improved student learning (Hammer & Elby, 2003; Kim & Pak, 2002).

Because these connections and reparation of existing knowledge are so crucial to learning, teaching and learning strategies that involve sense-making by the students have often been found to be especially effective. For example, encouraging students to self-explain during reading (i.e., monitor whether they understand what was read, make connections between paragraphs or between text and diagrams, make predictions and provide explanations for the provided information) can lead to great improvements in understanding the text, in retaining the material and afterwards the ability to apply the information later in new contexts (Chi et al., 1989). See Chapter 5 for a broader analysis of factors that influence this kind of learning.

Cognitive Task Analysis

Practice is the key to expert performance. But it is critically important that time be devoted to practicing all critical skills in the goal task. The benefits of practice are very specific to the particular skills that were practiced. For this reason, it is important to do a cognitive task analysis of the steps involved in completing a task. Note the term 'cognitive' in cognitive task analysis. A non-cognitive task analysis involves analyzing the external steps involved in completing a task. A cognitive analysis includes the mental steps required in the task, including mental calculations and retrievals from long-term memory.

A cognitive task analysis can be difficult to complete, especially by experts who have proceduralized many elements of the task, thereby losing the ability to articulate the procedures they execute verbally. So, one cannot simply interview experts to determine required skills. Instead, one must observe experts at work, perhaps having them give a think-aloud protocol that offers some access to the contents of verbal working memory (Ericsson & Simon, 1983). From this trace of external actions and contents of verbal working memory, one must infer the steps taken by the problem-solver.

Why is it worth the effort to do a cognitive task analysis? First, it clarifies what skills and concepts must be practiced, which makes it clearer as to what kinds of practice tasks should be assigned to ensure that all components skills and concepts receive some practice. Different problems can involve different subsets of skill application. As a simple example, different subtraction problems may or may not involve particular borrowing steps.

Second, the cognitive task analysis creates some opportunities for improving the efficiency of learning with intelligent learning systems that track student performance at the cognitive components level. Solving problems can take considerable learning time. If a given student has already made considerable progress on skills A, B, C but not skills D, E, less efficient use of learning time would be made to present more problems involving A, B, C or A, B, E and more efficient use of learning time to present problems involving just D, E. Cognitive tutors that present problems in exactly this way (in addition to providing immediate feedback on which cognitive steps were incorrectly completed) can take students to the same learning outcomes in much less time (Anderson, Corbett, Koedinger and Pelletier, 1995).

Third, important transfer across tasks can happen at the level of shared cognitive components. So, learners can be given simplified learning tasks (to simplify attentional demands, to reduce working memory requirements and to focus time on unlearned elements) but still transfer to real tasks *if* the tasks share important cognitive components. For example, Klahr and Carver (1988) conducted a cognitive task analysis of program debugging skills. They then explicitly taught these skills to students, which they quickly mastered and practiced. Then, in a test of transferring these skills to a completely different task that should have shared important cognitive elements of debugging, Klahr and Carver found that students were much better at debugging errors in written instructions, such as arranging items, following map routes, or allocating resources.

Summary of Information Processing

From an information processing point of view, it is important to determine the information that students need to be processing, considering perceptual encoding, working memory, and long-term conceptual and skill components. Further, this analysis must examine both eventual fluent problem-solving *and* the learning environment. Learning takes place through accurate focus on and practice with the critical elements. Given the frequent complexity of ETE, it is easy to overlook critical skills or concepts without a careful cognitive task analysis conducted by the designer of the ETE learning environment.

DISTRIBUTED COGNITION LEARNING THEORIES

Information processing theories place a strong emphasis on the mental workings of individual minds. Distributed cognition generalizes the information processing theory framework to include the physical environment around the learner, including interactions with other problem-solvers. As noted in the previous section, cognitive load is a key bottleneck to complex problem-solving and learning. External tools and other problem-solvers in the environment can be used to share the load. For example, in a plane cockpit, the pilot uses dials to help remember the state the plane is in, uses the co-pilot to help run through check-lists before take-off, and even uses simple perceptual features of dials and indicators to compute simple computations about whether to change the plane's speed (Hutchins, 1995).

This distributed extension of information processing applies to ETE in a number of different ways. First, engineering and technological problem-solving tend to involve working with complex external environments and groups of individuals working together, rather than individuals working alone or doing purely mental calculations. Thus, it is not necessary for ETE learners to be able to do complex tasks purely in their heads because it is unlikely that they will encounter that performance standard later.

Second, problem-based learning is often implemented as group-work. By assigning different individuals different roles (including monitoring overall performance or learning of individuals), the overwhelming complexity of many ETE learning tasks becomes manageable. However, it is important that the tasks be divided such that the cognitive load is decreased rather than increased. In tightly coupled tasks distributed across individuals, each problem-solver has the additional challenge of having to keep track of their partner's task state as well as their own task state. Such distribution increases rather than decreases each learner's cognitive load. It is better to have multiple learners work on more independent tasks or have them attend to the same task state but perhaps from different perspectives (Prince, 2004).

Third, engineers and technologists use thinking tools, often called models, that distribute thinking in another way and this requires an additional strand for learning. Models are tools or formalisms that represent aspects of some external situation for a particular purpose. Common examples from ETE include graphs, equations, physical prototypes, computer-aided design models and design analysis tools. A given situation could be represented by any and all of these examples (Gainsburg, 2006). Each representational tool has strengths and weaknesses. Which model or combination of models should be used at any given time depends upon the problem-solver's purposes. Even within a given type of model (e.g., physical prototype), there are choices as to which features to include and which to exclude (e.g., color, moving parts, structural strength).

This last element is a critical component of strategic competence (one of the key components from Figure 1)—the ability to formulate, represent and solve complex STEM problems. Complex ill-defined problems (as frequently occurs in engineering and technology problem-solving) can move from being nearly unsolvable to trivial through the selection of the appropriate representational tools (Kaplan & Simon, 1990).

But modeling, as a skill, can be a challenge to learners. Students initially do not see models as representational—standing for something else—but rather just things on their own, serving no greater purpose. Further, students are usually given models rather than being allowed to modify and strategically select models, thereby undercutting the development of strategic competence.

Models & Modeling Perspective and Model-Eliciting Activities

In the mathematics education and engineering education communities, a new general approach to instruction is developing called the models & modeling perspective (M&M; Lesh & Doerr, 2003), focusing on the complexities and benefits of models as a particular kind of distributed cognition. Whereas the information processing theoretical perspective often led to careful arrangements of problem-solving activity, the M&M perspective has advocated a different sort of instructional activity exemplified by model-eliciting activities (MEAs; Hamilton et al., 2008). MEAs are a form of problem-based learning well matched to ETE in which the problem-solvers are asked to produce conceptual tools for constructing, describing, or explaining meaningful situations. This process of developing such a conceptual tool typically involves a series of express-test-and-revise cycles. The iterative model development process helps students both to develop more sophisticated ways of understanding important conceptual ideas and to acquire a productive disposition toward thinking about their own ideas or models of situations as tools—useful and adaptable for solving real problems (Lesh & Lehrer, 2003).

MEAs have been developed for K-12 and undergraduate mathematics, technology and engineering education (e.g., http://modelsandmodeling.net). A number of well-defined principles for developing MEAs exist (Lesh et al., 2000). In addition, MEAs are typically contextualized around a problem where students have to sort through a wide range of quantitative data and develop a procedure or process for a client. For example, the *Nano Roughness* MEA (Moore & Diefes-Dux, 2004) challenges students to quantify the roughness of nanoscale materials that a biomedical company is considering to use for artificial hip joints. One principle of MEAs is the *Model-Construction Principle*—that the problem requires students to create a mathematical model of the situation. In the *Nano Roughness* MEA, students examine atomic force microscope (AFM) images that provide quantitative data on the surface height of materials and use this information to generate their own procedures for quantifying roughness, of which there are many possibilities.

MEAs can result in a form of local conceptual development in which students make progress in a particular situation with the specific tools available in a way that parallels larger developmental processes of more general conceptual structures (Lesh & Harel, 2003). Thus, MEAs provide students with opportunities to develop their ways of thinking about central conceptual ideas within realistic problem-solving contexts.

We have begun to explore in our own work with robotics technology classes in middle schools how the M&M perspective and MEAs can provide a sound theoretical basis for improved learning (Silk et al., 2010). For example, we provide middle-school aged students with the case of a robotics team that programs synchronized dancing Lego robots. The fictional team receives different dance routines from fans via the Internet. The problem is to program these various dance routines in a way that different sized robots will dance in synchrony. The students' task is to develop a script that the fictional team can use to program robots for these arbitrary scripts quickly and accurately. Since the situation is open-ended, the students must develop their own physical and mathematical models to determine how different robotics moves vary across different sized robots and then use these models to develop the script. Here, students are thinking about specific proportional relationships in the problem, and through a model refinement process, they may further improve their mathematical concept of proportionality or their robotics concept of proportional control.

COGNITIVE APPRENTICESHIP LEARNING THEORIES

All areas of professional education, including engineering and technology education, have had a long history of apprenticeship approaches to learning. At school, students were meant to learn the underlying principles and most fundamental skills/knowledge (writing, mathematics, science), and then through internships, co-op experiences, or on-the-job training, learn the 'real' skills of the discipline. Even instruction that was intended for all children, rather than just the next generation of a particular profession, has been influenced somewhat by applying lessons from apprenticeship learning to instruction.

Traditional Apprenticeship Learning

Analysis of learning in traditional apprenticeship situations noticed important common instructional features. One important feature is that much early apprenticeship learning involves observation by the apprentice of more expert performance, rather than immediately having the learner engage in problem-solving, read about problem-solving, or hear lectures about problem-solving (Lave, 1988).

The second important feature is the expert provides many supports for the learner during problem-solving, called scaffolds. For example, the expert may provide hints or do parts of the task, leaving the first or last pieces for the learner. Gradually over time, these scaffolds are removed, a process called fading (Vygotsky, 1978). A number of intelligent computer tutoring systems have successfully used this scaffolding and fading approach to speed up learning (Renkl, Atkinson & Grosse, 2004), including of engineering materials (Reisslein, Sullivan & Reisslein, 2007).

From such apprenticeship experiences related to ETE, students develop a productive disposition towards STEM (the last key component listed in Figure 1). Because they see performance of STEM in action, the usefulness of STEM components is made very persuasively. Observation of a diligent expert provides a good model for work ethics in STEM. Finally, the scaffolding and fading help to ensure that students develop and maintain high self-efficacy about their own ability to solve STEM problems.

Cognitive Apprenticeship Learning

Although apprenticeship learning does produce expert performance, the path is often quite slow, and the learning that results can be somewhat fragile or specific to the particular learning environment of training (Suchman, 1987). This last element was particularly troubling for applications to school environments, which could not be made like work environments for large numbers of students. Information processing theorists examined apprenticeship learning and proposed a hybrid theory called Cognitive Apprenticeship that was meant to speed up and make the transfer from schooling to other settings more robust (Collins, Brown & Holum, 1991).

One element of cognitive apprenticeship is that the expert tries to make all aspects of the task visible to the learners, which further supports the learner's ability to engage in more adaptive reasoning across settings (the fourth key component from Figure 1). In traditional apprenticeship, it is up to the learner to figure out which features to encode and what steps are going on. For ETE, in which many steps are mental and abstract, traditional apprenticeship leaves the learner with a huge inference task. To make aspects of the task more visible to the learner, an instructor might think aloud during problem-solving. For example, in mathematics instruction, Schoenfeld (1987) found it particularly useful to show students the heuristics that mathematicians use for selecting among possible problem-solving steps rather than just the formal steps found in particular algorithms. In addition, an instructor might ask learners to alternate between being a critic or guide and a learner or doer receiving critical comments. Reciprocal teaching is an approach that has used this element of cognitive apprenticeship to great effect in reading instruction (Palinscar & Brown, 1984) and physics instruction (Reif, 1999).

A second element of cognitive apprenticeship is the importance of varying situations such that transfer to new situations will become more likely. Preferably this varying of situations is done by gradually increasing the complexity of the tasks and the diversity of the skills and concepts required to complete the task. That is, rather than simply working on complete problems as they come and providing scaffolding for the students, the order of selected problems is chosen purposefully with respect to complexity and diversity of skills and concepts (Collins, Brown & Holum, 1991).

However, the sequencing of problems does not mean instruction should begin with micro-problems that are completely divorced from real problem situations because the students will then lose the connection between what they are learning and the situations to which these skills and concepts should apply. Instead, instruction should go from global to local so problem-solvers can see the relevance. That is, a full problem can be introduced, but then instruction can transition to solving components of the larger problem. This issue of global/local is particularly applicable to problem-based learning approaches used in ETE. Rich problems can be attempted and yet students can practice critical component skills in effective order by supporting the transition from the larger problem to the component sub-problems.

For example, in our synchronized dancing robots problem described earlier, we can present the larger synchronized robots problem to students at the very beginning of a long sequence of lessons and then help the students break down the larger program into components, such as linear distance, linear speed, turn amount and turn speed. Each of these components can be divided further into measurement and programming tasks. But the students 'see' the larger problem at the very beginning, rather than beginning the unit with a discussion of measuring linear distances with robots, which the students see as an odd task out of context. There is now emerging evidence that providing a greater 'need-to-know' enhances learning in STEM (Mehalik, Doppelt & Schunn, 2008).

Overall, cognitive apprenticeship approaches support the development of adaptive reasoning in problem-solvers by encouraging students to reflect on the skills and strategies involved in solving larger, more complex problems.

CONCLUSION

Successful problem-solving in engineering and technology settings requires attending to five larger elements in the problem-solver: procedural fluency, conceptual understanding, strategic competence, adaptive reasoning and productive disposition. These five elements are not developed quickly and easily, and learning environments must be carefully organized across years of instruction to meet this challenge.

Given the complexity of what must be learned, it is not surprising that a range of learning theories must be used to explain how this learning happens and what environmental features best support it. As a rough heuristic, we have organized the learning goals from more micro elements to more macro elements, and have then shown how different learning theories connect to these elements. But the mapping is certainly complex and much research remains to be done. In the meanwhile, we strongly encourage active sense-making by the reader in terms of trying to apply the contents of this chapter to their own ETE setting.

REFERENCES

Anderson, J. R., Bothell, D., Byrne, M., & LeBiere, C. (2004). An integrated theory of the mind. *Psychological Review*, *111*(4), 1036–1060.

Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive tutors: Lessons learned. *The Journal of the Learning Sciences*, *4*(2), 167–207.

Anderson, J. R., Fincham, J. M., & Douglass, S. (1997). The role of examples and rules in the acquisition of a cognitive skill. *Journal of Experimental Psychology-Learning Memory and Cognition*, *23*(4), 932–945.

Anderson, J. R., & Schunn, C. D. (2000). Implications of the ACT-R learning theory: No magic bullets. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 5, pp. 1–33). Mahwah, NJ: Erlbaum.

Baddeley, A. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience*, *4*(10), 829–839.

Biederman, I., & Shiffrar, M. M. (1987). Sexing day-old chicks: A case study and expert systems analysis of a difficult perceptual-learning task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*(4), 640–645.

Borrego, M. (2007). Conceptual difficulties experienced by trained engineers learning educational research methods. *Journal of Engineering Education*, *96*(2), 91–102.

Carpenter, P. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures: A theoretical account of the processing in the Raven Progressive Matrices Test. *Psychological Review*, *97*, 404–431.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology*, *4*, 55–81.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science*, *15*, 145–182.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *The American Journal of Physics*, *50*(1), 66–71.

Collins, A., Brown, J. S., & Holum, A. (1991). Cognitive apprenticeship: Making thinking visible. *American Educator*, *15*(3), 6–11, 38–46.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data* (2nd ed.). Cambridge, MA: MIT Press.

Gainsburg, J. (2006). The mathematical modelling of structural engineers. *Mathematical Thinking and Learning*, *8*(1), 3–36.

Geary, D. C., Boykin, A. W., Embretson, S., Reyna, V., Siegler, R., Berch, D. B., et al. (2008). *Report of the task group on learning processes*. Washington, DC: U.S. Department of Education.

Hamilton, E., Lesh, R., Lester, F., & Brilleslyper, M. (2008). Model-eliciting activities (MEAs) as a bridge between engineering education research and mathematics education research. *Advances in Engineering Education*, *1*(2), 1–25.

Hammer, D., & Elby, A. (2003). Tapping epistemological resources for learning physics. *Journal of the Learning Sciences*, *12*(1), 53–90.

Hutchins, E. (1995). How a cockpit remembers its speeds. *Cognitive Science*, *19*(3), 265–288.

Kaplan, C. A., & Simon, H. A. (1990). In search of insight. *Cognitive Psychology*, *22*, 374–419.

Kellman, P. J., Massey, C. M., & Son, J. Y. (2010). Perceptual learning modules in mathematics: Enhancing students' pattern recognition, structure extraction, and fluency. *Topics in Cognitive Science*, *2*(2), 285–305.

Kilpatrick, J., Swafford, J., & Findell, B. (Eds.). (2001). *Adding it up: Helping children learn mathematics*. Washington, DC: National Academies Press.

Kim, E., & Pak, S. J. (2002). Students do not overcome conceptual difficulties after solving 1000 traditional problems. *American Journal of Physics*, *70*, 759–765.

Klahr, D., & Carver, S. M. (1988). Cognitive objectives in a LOGO debugging curriculum: Instruction, learning, and transfer. *Cognitive Psychology*, *20*, 362–404.

Knowlton, B. J., Mangels, J. A., & Squire, L. R. (1996). A neostriatal habit learning system in humans. *Science*, *273*, 1399–1402.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge, MA: Cambridge University Press.

Lesh, R., & Doerr, H. (2003). *Beyond constructivism: A models & modeling perspective on mathematics teaching, learning, and problems solving*. Mahwah, NJ: Lawrence Erlbaum.

Lesh, R., & Harel, G. (2003). Problem solving, modeling, and local conceptual development. *Mathematical Thinking and Learning*, *5*(2&3), 157–189.

Lesh, R., Hoover, M., Hole, B., Kelly, A., & Post, T. (2000). Principles for developing thought-revealing activities for students and teachers. In A. Kelly & R. Lesh (Eds.), *Handbook of research design in mathematics and science education* (pp. 591–646). Mahwah, NJ: Lawrence Erlbaum Associates.

Lesh, R., & Lehrer, R. (2003). Models and modeling perspectives on the development of students and teachers. *Mathematical Thinking and Learning*, *5*(2&3), 109–129.

Mehalik, M. M., Doppelt, Y., & Schunn, C. D. (2008). Middle-school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. *Journal of Engineering Education*, *97*(1), 71–85.

Moore, T. J., & Diefes-Dux, H. A. (2004). Developing Model-Eliciting Activities for undergraduate students based on advanced engineering context. *Proceedings of the Thirty-Fourth ASEE/IEEE Frontiers in Education conference*. Savannah, GA. Retrieved from http://fie-conference.org/fie2004/index.htm

Moss, J., Kotovsky, K., & Cagan, J. (2006). The role of functionality in the mental representations of engineering students: Some differences in the early stages of expertise. *Cognitive Science*, *30*(1), 65–93.

John, D., Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academies Press.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: The National Academies Press.

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction*, *1*(2), 117–175.

Pavlik, P. I., & Anderson, J. R. (2005). Practice and forgetting effects on vocabulary memory: An activation-based model of the spacing effect. *Cognitive Science*, *29*(4), 559–586.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, *93*(3), 223–231.

Reif, F., & Scott, L. A. (1999). Teaching scientific thinking skills: Students and computers coaching each other. *American Journal of Physics*, *67*(9), 819–831.

Reisslein, J., Sullivan, H., & Reisslein, M. (2007). Learning achievement and attitudes under different paces of transitioning to independent problem solving. *Journal of Engineering Education*, *96*(1), 45–55.

Renkl, A., Atkinson, R. K., & Grosse, C. S. (2004). How fading worked solution steps works - a cognitive load perspective. *Instructional Science*, *32*(1–2), 59–82.

Schoenfeld, A. H. (1987). *Cognitive science and mathematics education*. Hillsdale, NJ: Erlbaum.

Silk, E. M., Higashi, R., Shoop, R., & Schunn, C. D. (2010). Designing technology activities that teach mathematics. *The Technology Teacher*, *69*(4), 21–27.

Singley, M. K., & Anderson, J. R. (1989). *The transfer of cognitive skill*. Cambridge, MA: Harvard Press.

Smith, C., Maclin, D., Grosslight, L., & Davis, H. (1997). Teaching for understanding: A study of students' pre-instruction theories of matter and a comparison of the effectiveness of two approaches to teaching about matter and density. *Cognition and Instruction*, *15*(3), 317–393.

Suchman, L. A. (1987). *Plans and situated action: The problem of human-machine communication*. New York: Cambridge University Press.

Thorndike, E. L. (1913). *Educational psychology: The psychology of learning* (Vol. 2). New York: Teacher's College.
Van Merrienboer, J. J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: recent developments and future directions. *Educational Psychology Review*, *17*(2), 147–177.
Vygotsky, L. S. (1978). Mind in society. In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), *Interaction between learning and development* (pp. 79–91). Cambridge, MA: Harvard University Press.
Wickens, C. D. (2008). Multiple Resources and Mental Workload. Human Factors. *The Journal of the Human Factors and Ergonomics Society*, *50*(3), 449–455.
Wickens, C. D., & McCarley, J. S. (2008). *Applied attention theory*. Boca Raton, FL: Taylor & Francis.

Christian D. Schunn and Eli M. Silk
Learning Research and Development Center
University of Pittsburgh
USA

JOHN R. DAKERS

2. ACTIVITY THEORY AS A PEDAGOGICAL FRAMEWORK FOR THE DELIVERY OF TECHNOLOGY EDUCATION

INTRODUCTION

As I write this chapter I occasionally look out over a field full of sheep tending their spring lambs. It is a pleasant day and the sheep spend their time grazing or resting as the lambs explore their new environment. Yesterday it rained. There was no appreciable difference in the sheep's behaviour. They did not take shelter nor did they construct any form of shelter from the rain. They just continued to act as sheep do, come rain or shine. They exist in this particular field because the farmer decided that they should. Their ability to move beyond the boundaries of the field in question is restricted by a stone dyke that was constructed by human beings sometime in the past. The sheep have no agency, there is no considered meaning directing their actions, they do not purposefully alter their environment in order to shape it according to their needs and desires. Indeed, they have no cultural heritage that defines them, they simply form part of what might be described as the natural world. The particular sheep that I am describing are domestic sheep (*Ovis aries*). Their behaviour or observed activities are innate. This is true for most non-human animal species. Some animals such as primates are known to act, in a very limited way, with intent and, in some cases, even use technologies to assist in some of their endeavours. Domestic animals such as the sheep described above are bred specifically for their wool and for food production. They are to all intents and purposes a technology. They form part of a system known as agriculture. It is through a subset of agriculture that a community of human beings known as farmers cultivate livestock. Unlike the primitive and quasi-natural existence of the sheep described above, this process of cultivation is deeply infused with meaning and purpose and intentionality, and it is these traits that motivate human beings towards goal-orientated action that manifests itself in the form of their labour.

Traditionally, in scientific terms, the actions of the farmer in relation to the sheep can be understood by observing and interpreting their collective interactions. This is traditional anthropology. However, this affords only a very limited understanding. We may merely conclude from our observations 'what it is' the farmer is doing and 'how it is' that the farmer is acting, and whether these actions conform to acceptable levels of animal husbandry based upon socially acceptable, historically established conventions. What we miss in this analysis is the meaning and the purpose that motivate the farmer's action at that particular time. These can be many and varied, and may change depending upon a number of circumstances that are unlikely to be

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 19–34.

revealed by observation alone. The farmer will have a number of goals in cultivating sheep depending upon circumstances and cultural influences. A farmer may cultivate sheep on a small scale only and perhaps only for personal use, whereas the farmer who cultivates the sheep that I am observing appears to do so for commercial reasons and therefore does so more intensively. In this case, the most prominent goal motivating the farmer in a capitalist culture is to make a profit. Conversely, the goal of the small-scale farmer may be to lead an independent and sustainable lifestyle. However, the object of the activity with which both farmers are engaged, as distinct from their individual goals, is to produce food and wool. Whilst the goal of profit-making particularly is not directly related to the object of producing food and wool, it is nevertheless contingent.

Another significant and important factor associated with the activity of producing food and wool is the division of labour. My ability to eat my lamb cutlet tonight whilst keeping warm by wearing my wool sweater will be dependent upon a number of related activities involving a number of other human beings. The lambs have to be sheared. They have to be transported from the farm to the slaughterhouse; they have to be slaughtered, which may also involve some religious ceremony (e.g., kosher slaughter). They have to be butchered; they have to be sold; they have to be cooked. All of these processes are culturally determined, rule-driven and involve a variety of communities that require a division of labour, rendering them social in that the object of their collective activity, as distinct from their individual goals, is to produce food or woollen-based artefacts. Finally, and importantly, activities need to be mediated by technology and/or technique. In the case described above, mediation may include shearing tools, trucks, slaughterhouses, shops, stoves, etc. and the methods associated with their actions.

A SHORT DISCUSSION RELATING TO ACTIVITY THEORY

Marxist Origins

Activity theory has never, until only very recently, been considered in anything but a theoretical sense as opposed to an applied or practical format. It follows, and is predicated upon, Marxist thinking. In more recent times, theorists have begun to research and analyse activity theory within more practical contexts, and have produced some innovative and interesting perspectives in terms of education and business (see, for example, Cole et al., 1997; Engeström et al., 1999; Kaptelinin and Nardi, 2006). However, in order to better understand activity theory, it is important to have a grasp of its philosophical heritage.

Marx (1954) argues that the thing that defines human beings from all other animals is that the purpose and intention of all human activity is directed towards the transformation of the natural world in order to accommodate human needs. In virtually all other animal species, actions are considered to be undertaken in harmony with nature and are, to a large extent, innate. Animals may kill other animals or alter their environment in some way (beavers building dams or birds constructing nests, for example), but they do so in such a way that their actions have little lasting impact upon the balance of the natural world. If we were able to imagine a world in which human beings had never existed, we might well conclude that it would take a very different form in which ‘Nature’ had evolved in Her own terms. A balanced and sustainable ecological system would have been preserved (discounting catastrophic incidences such as meteor intrusions or extreme earthquakes, etc.). However, this has not been the case, and human beings, who also form part of nature (albeit in oppositional form), have, in evolutionary terms, constantly attempted to dominate and control ‘Nature,’ forming an imbalanced and less sustainable ecological system in the process. In so doing, they have changed the way that they interact with the world and with themselves: in today’s digital world, we act very differently from the way in which our ancestral forebears acted 100 years ago in their industrialised world, and they, in turn, acted very differently from those who lived in medieval times. Important to the development of these cultural and social alterations in human activity is the application of technology and technique. In order to discover and change their world and as a consequence, themselves, human beings have to be actively involved, and, for Marx, that activity is made manifest in their labour:

> “Labour is, in the first place, a process in which both man and Nature participate and in which man of his own accord starts, regulates and controls the material re-actions between himself and Nature. He opposes himself to Nature as one of her own forces, setting in motion arms and legs, head and hands, the natural forces of his body, in order to appropriate Nature’s productions in a form adapted to his own wants. By thus acting on the external world and changing it, he at the same time changes his own nature. He develops his slumbering powers and compels them to act in obedience to his sway. We are not now dealing with those primitive instinctive forms of labour that remind us of the mere animal. An immeasurable interval of time separates the state of things in which a man brings his labour-power to market for sale as a commodity, from the state in which human labour was still in its first instinctive stage. We presuppose labour in a form that stamps it as exclusively human” (Marx. 1954: 173–174).

Whilst this paragraph clearly presages Marx’s famous distinction between ‘use value’ and ‘exchange value,’ it is the concept of object-orientated activity where human actions are directed towards the external world, as alluded to by Marx above, that form the inspiration for the formation of Leont’ev’s concept of Activity Theory. Considered by most to be the founding father of Activity Theory, Leont’ev was a member of the cultural historical school led by Vygotsky. Influenced by Marx, Vygotsky and his followers studied the “object-orientated action mediated by cultural tools and signs” (Engeström and Meittinen, 1999: 4). Essentially, object-oriented action is any purposeful interaction between the subject and the object that brings about some mutual transformation. In its most basic form, this relationship can be demonstrated as seen in Figure 1.

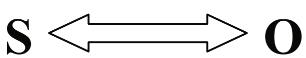


Figure 1. Subject – object relationship.

In Figure 1, S represents the individual or collective human subject and O the object of the subject's activity. In Activity Theory, the subject and object cannot be considered independently but must be considered in the form of their relationship. For this relationship to exist, it must be imbued with meaning and purpose.

> "A basic or, as is sometimes said, a constituting characteristic of activity is objectivity (or rather 'object orientedness'). Properly, the concept of its object (Gegenstand) is already implicitly contained in the very concept of activity. The expression 'objectless activity' is devoid of any meaning. Activity may seem objectless, but scientific investigation of activity necessarily requires discovering its object. Thus the object of activity is twofold: first, in its independent existence as subordinating to itself and transforming the activity of the subject; second, as an image of the object, as a product of its property of psychological reflection that is realised as an activity of the subject and cannot exist otherwise" (Leont'ev, 1978 in Kaptelinin and Nardi. 2006: 137).

Human activities are always directed towards their objects, and the objects of their activity will have some impact upon humans (hence, the two-directional arrow between the subject and object in Figure 1 above). "When people design, learn or sell, they design, learn or sell something. Their dreams, emotions and feelings are also directed toward something in the world" (Kaptelinin and Nardi, 2006: 66). It is this interaction between the subject and the object that gives rise to motivation and desire. "Human beings and objects are [ ] bound together in a collusion in which the objects take on a certain density, an emotional value – what might be called a 'presence" (Baudrillard, 2005: 14). Objects can be considered to be material like a car or a house, or they can take on an ideal form such as an aspiration or a thought. However, this distinction can tend to cause some confusion. In order to address this, I will use the term 'object' as meaning the object of activity and not a physical object. In other words, the object of human activity is motivated towards fulfilling some individual or social need and these needs are developed and changed over time. Activity cannot thus be reduced to either the subject or the object unilaterally; it is the subject-object relationship that determines how both the subject and the object develop (Kaptelinin and Nardi, 2006: 66).

Vygotsky's unit of analysis in this respect centred upon the mediating tools that intervened in object-orientated actions (Vygotsky, 1978). These tools can take material form, psychological form or any combination thereof. Moreover, these tools, in whatever form, will influence the outcome of the subject/object relationship. Vygotsky's triadic model of mediation is shown in Figure 2.

In order for the subject to interact with the object of activity to achieve some transformational goal-orientated outcome, some form(s) of mediation must be incorporated. So, if the subject, say a carpenter, wants to join two pieces of wood together (the purpose of which constitutes the object of the activity), she must use several tools, some of which may be her carpentry knowledge (psychological tools) and a hammer and nails together with selected pieces of wood (material tools) in order to realise that outcome. However, it is virtually impossible that the actual object of the activity will be simply to join two pieces of wood together, devoid of any meaning.

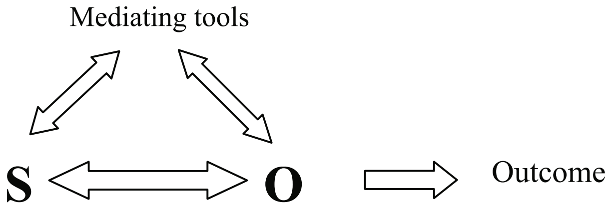


Figure 2. Vygotsky's triadic model.

There will be a reason for the carpenter's actions and they will be imbued with meaning for her. Otherwise, the activity would be random, purposeless, spontaneous and impulsive. If human beings acted in such a way, there would be no coherent structure to the world: actions would be devoid of meaning. It is much more likely that the object of the activity will have significant meaning associated with the activity such as creating an artefact, and the reason for creating the artefact will be further imbued with meaning. These multi-stable meanings will vary across space, time and participants. Like our farmers before, the carpenter may be motivated by money, or the development of higher level carpentry skills, or both. In order to better understand the object of a subject's activity, Vygotsky analysed the cultural tools that mediated the activity. Vygotsky's triadic model tended, however, to favour individual action. Leont'ev wanted to extend the analysis in order to consider collective activity as well as individual action. To this end, he made a distinction between the concept of individual *action* and collective *activity*.

Actions, for Leont'ev, are goal-orientated and individual in nature. Activity, on the other hand, is collective and social, and has, as a central feature, the division of labour. In a now famous passage (to those who read activity theory in any depth) describing a primitive hunt, Leont'ev distinguishes between activity and action:

> "A beater, for example, taking part in a primeval collective hunt was stimulated by a need for food or, perhaps, a need for clothing, which the skin of the dead animal would meet for him. At what, however, was his activity directly aimed? It may have been directed, for example, at frightening a heard of animals and sending them towards other hunters, hiding in ambush. That, properly speaking, is what should be the result of the activity of this man. And the activity of this individual member of the hunt ends with that. The rest is completed by the other members. This result, i.e., the frightening of game, etc. understandably does not in itself and may not, lead to satisfaction of the beater's need for food, or the skin of the animal. What the processes of his activity were directed to did not, consequently, coincide with what stimulated them, i.e., did not coincide with the motive of his activity; the two were divided from one another in this instance. Processes, the object and motive of which do not coincide with one another, we shall call 'actions'. We can say, for example, that the beater's activity is the hunt and the frightening of the game his action" (Leont'ev, 1981: 210).

Activity as a whole is composed of complex multi-stabilities that are set within relative or particular narratives. In other words, there are no activities that are immutable and universal in nature. Activities in this sense are collective and contextual. Activities are not typically directed towards their motives. Rather, they comprise units of activity that are purposeful and meaningful to the particular subject(s) involved at that particular time and in that particular space. They are thus formed by predetermined local and relative actions, or in other words, they are socially and culturally determined, each having its own goal (the division of labour) and it is that object that forms the motivation for the subject's particular action.

To summarise, "Activity theory begins with the idea of a purposeful subject. Only living things have needs. These needs can be met by acting in the world, by bringing together the subject's need and an object. When a need meets its object, the object becomes a motive and directs the subject's activity. For humans, needs are, in significant measure, culturally shaped. The most fundamental notion of activity theory is the motivated activity of a subject enacted in culturally meaningful ways" (Kaptelinin and Nardi, 2006: 199). Considered in a classroom context, the motivating factors that form a need to learn about design, for example, would involve a multitude of goal-orientated actions undertaken by a number of participants across time and space who all contribute in some culturally meaningful way, thus acting intentionally towards some tangible outcome that serves, in some fashion, to facilitate learning about design (or just learning). So a school designed by architects and constructed using materials fabricated by others will offer a curriculum designed by policy-makers that will be delivered by teachers to young people. All of these multifarious goal-orientated actions are intended to combine in order to form a culturally meaningful activity called learning.

The Use of Tools, Intentionality and Systems

Drawing directly from Marx and Engels, Leont'ev introduces two mutually dependent mediating aspects relating to the subject-object activity involved in the Marxian concept of labour (Engeström and Meittinen, 1999):

> "The first is the use and making of tools. 'Labour', Engels said, 'begins with the making of tools'. The second feature of the labour process is that it is performed in conditions of joint, collective activity, so that man (sic) functions in this process not only in a certain relationship with nature but also to other people, members of a given society. Only through a relation with other people does man (sic) relate to nature itself, which means that labour appears from the very beginning as a process mediated by tools (in the broad sense) and at the same time mediated socially" (Leont'ev, 1981: 208).

For Leont'ev then, human cultural and social development cannot be considered only in terms of individual actions upon the objects of Nature. A collective activity system is constituted by not only individual human actions, but by all of Natures objects acting together, material as well as organic, human as well as animal. These multi-stable activity relationships combine to form what Latour (2005) describes as 'Actor Network Theory', or to what Delueze & Guattari (1988) refers to as an 'assemblage'. Collective activity can only exist in a culture guided by purposeful intention. Or as Miettinen (1999) puts it:

> "A gradual breaking of the direct, immediate, impulse based relation to the objects of the environment. With cultural development – characterised by communication and the construction and use of tools – a specifically human type of consciousness emerged. [Such a consciousness] also implies the capability if imagining and planning what the future may hold; that is, intentionality" (Miettinen, 1999).

Miettinen also noted that only humans can "take the initiative in the construction of new assemblies of humans and materials" (in Kaptelinin and Nardi, 2006: 200). Technologies do not have needs, motives or intentions. They are, however, tied to a task that has varying degrees of meaning to a human. A technology, in this sense, is "something-in-order-to" (Heidegger, 1962). It is through the intentional use of technology as 'something-in-order-to-serve-some-human-need' that significantly assists in the formation of a given culture. It is then through the continued development of technology that the (re)-formation of any given culture continues to develop and change over time.

To recap, Activity Theory is more concerned with the analysis of a given activity system. The system under analysis may include many 'actors': human, non-human and technological. A technological system, whether a simple lever or a complex machine, has no inherent intentionality: this can only be designated or given by the designer, the fabricator and ultimately, the user of the technology. Technological systems can thus only be understood in terms of their designated purpose considered in conjunction with the interaction of human beings, and this designation is open to constant interpretation and reinterpretation. A car, for example, is simply a concatenation of inert materials that have been fabricated and subsequently assembled together in order to form what we have come to know as a car. However, without the inclusion of a human 'actor' as the user or the observer, the car is essentially meaningless. It does nothing independently, it has no independent conscious intention, it awaits its crucial vital dynamic component: it is only the human being who has any purpose and intentionality in her association with the car and the environment. These human purposes and intentions are multi-stable. Whilst many will argue that the primary function of a car is to get from A to B, Activity Theory helps bring to light the intention of the human-technology relationship. A suicide bomber has a different purpose and intention for a car than a commuter has, for example. The object of their respective activity is quite different, as will be the subsequent outcome.

Human activity can be analysed in similar terms. It is the purpose and intention motivating those involved in any activity that serves to reveal the meaning that lies behind any given activity. Activity Theory is not concerned with individual participants *per se*. Rather, it is concerned with revealing the meaning behind the actions of the participants. It does this by exploring the purpose or intent that participants or subjects in a given activity system, such as a classroom, have towards the object of their activity, in order that they might achieve some meaningful outcome by transforming the object of activity into a new outcome. Considered in reverse, Activity Theory can help reveal the underlying meaning and hence the motivation of the subjects in the classroom setting. This is a fundamentally different approach to analysing classroom practice because it does not consider the teacher separately from the pupils. Nor does it separate the subject content or the assessment procedures. It considers the activity only in terms of the participants, and it is this classroom context that I now wish to consider in greater detail. It is important to highlight that I am presenting this analysis in a philosophical context. I have not undertaken any empirical research personally but have used other data, including empirical studies, to inform my arguments.

ACTIVITY THEORY CONSIDERED IN A TECHNOLOGY EDUCATION SETTING: A PHILOSOPHICAL EXPLORATION.

There is a now a considerable corpus of research into contemporary pedagogy, curriculum development and the concept of knowledge, as well as the purpose of technology education. I do not intend to challenge or support any of this research in this chapter. Activity Theory, whilst recognising the importance of these on-going discussions, is more interested in meanings, intentions and motivations as agentive processes rather than as hierarchically imposed goals.

Goals may be the properties of the teacher by way of schools as institutions but not necessarily the properties of the pupils in the classroom. In this sense, "the institutional goals [ ] are part of a larger culture… but not the goals of individual subjects" (Kaptelinin and Nardi, 2006: 205).

Using the theoretical tools underlying the concept of Activity Theory, teachers can reform their pedagogy to create a more constructive learning environment that is less goal-driven, as suggested above. These new intellectual tools enable a more contextualised and authentic learning experience in technology education.

> "Education provides new 'tools of the intellect', to be sure. But without contexts of use, these tools appear to 'rust' and fall into disuse" (Cole, 1990: 106).

Building upon the previous discussion, I will now offer what I consider to be several flawed models for delivering technology education, culminating in one that utilises Activity Theory to enhance classroom practice. I have discussed the subject-object relationship above. I now offer this in a technology education classroom context.

Figure 3 illustrates that the subject acts upon an object in order to achieve some desired outcome. The model shown in Figure 3 forms a crude template for a teacher's goal-driven actions upon a technology education class. This model, I will argue, forms the dominant orthodoxy of teaching practice in schools today where the teacher is considered to be the expert and the student the passive learner. In this model, the technology teacher (perceived as the subject and separate from the object) will act upon the class (perceived as the object and separate from the subject) by teaching the class in order to [insert outcome]. However, this model is flawed in several respects.

First, it considers the class as being some material homogeneous entity rather than as a heterogeneous group, which suggests that the class, or year group, must move together as a single collective unit as directed by the teacher.

Figure 3. Problematic relationship between subject and object.

Second, it suggests a passive learning environment. The class (perceived as the object) is acted upon by the teacher (perceived as the subject). The way in which the class is thus modified is brought about by the actions of the teacher onto the class, in order to achieve some goal-orientated outcome designed by the teacher (or curriculum). In other words, the learners' needs are prescribed by others.

Third, it is a very restrictive model for the development of creativity through design, for example. The outcome is controlled and designed by the teacher, the class has no agency in the process; their needs are again prescribed by others.

Fourth, the process is linear and unidirectional.

Finally, the class (perceived as the object) in this model must constantly look back to the teacher (perceived as the subject and separate) in order to seek direction and thereby know how to achieve the prescribed outcome ahead of them (represented by the dashed arrow in Figure 3). Whilst the class looks back, the orientation is still unidirectional: from the subject (teacher) through the object towards some outcome.

The teacher (subject) and the class (object) are thus seen to be distinctly separate components in this activity system. The teacher (subject) unilaterally directs the class (object) towards an outcome, preconceived by the teacher (and others who set the exam criteria and design the curriculum).

The Significance of Mediation

Remember that activity theory recognizes that in all activity, the relationship between the subject and the object is always mediated by tools. It is as a result of this mediation that the outcome will be shaped, one way or the other. If the teacher (perceived as the subject) needs to get her class (perceived as the object) to pass an exam in design, for example (the outcome), she will have to make some serious decisions as to how she might purposefully undertake this task. She will have to consider what resources she might employ: books about design; design tools like pencils, paper, CAD, etc.; her own expertise and experience; some concept for the students to work around. It is these tools that mediate between the subject and the object. This is illustrated in Figure 4.

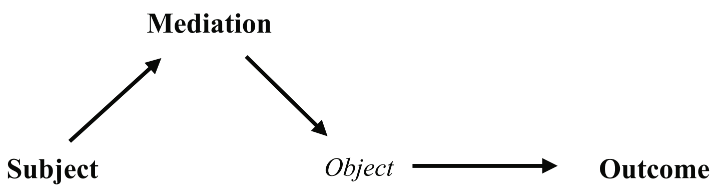


Figure 4. Mediation between the subject and object.

The subject (perceived as the teacher) and the class (perceived as the object) are thus mediated by tools, which, in this case are provided by the teacher (or the school) for the class to use in order to engage in an action. The object of this will be to achieve some desired outcome decided by the teacher, who, in turn, is guided by those who set exams as well as policy-makers, head teachers and curriculum developers, etc. So, if, for example, the teacher wants to get the whole class to pass the design exam, she must consider the meditational tools that she will use in order to achieve this. Options might include, at one end of the spectrum, the teacher making available several authentic situated design tasks that she thinks will help motivate the class to work towards developing a better understanding of the concept of design, also passing the exam. At the other end of the spectrum she might simply get the class to practice past exam scenarios until they are able to pass all the required elements. It is important at this stage to remind ourselves of the distinction between action and activity: action is goal-driven and individual in nature whereas activity is collective and social in nature (Leont'ev, 1981). This reveals two distinct classroom dynamics. One is action, the dominant orthodoxy in which the teacher (perceived as subject) attempts to transform the class (perceived as the object) into passing an exam. This is individual in relation to the teacher who is goal-driven and passive to a large extent on the part of the class. The second variation follows a very similar model but does allow some agency on the part of the pupils.

This model is essentially behaviourist in form. The teacher (perceived as the subject) is trying to shape and thus change the behaviour of the class (perceived as the object) in order to have the class achieve the desired outcome as stipulated by the system. The class has little (or no) agency in this model, even in the one in which the teacher uses situated learning concepts because it is she who selects them independently of the pupils. It is Piaget, a constructivist, who offers us an enhanced model. He argued that children develop their understanding of the world by interacting with it and constructing meaning from it as a result of this reflection. This is illustrated in Figure 5.

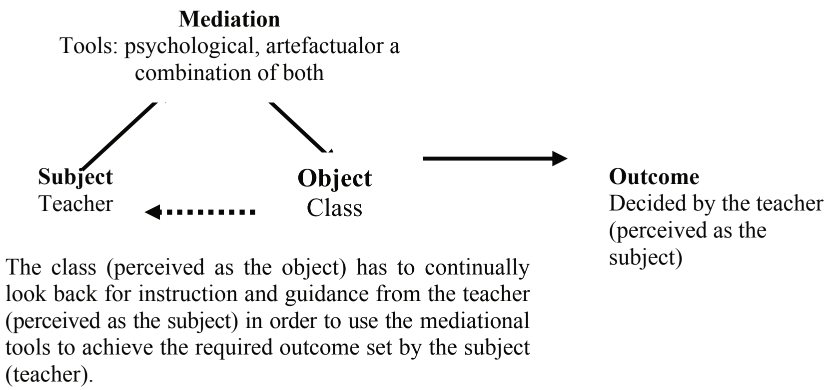


Figure 5. Teacher directed model of instruction.

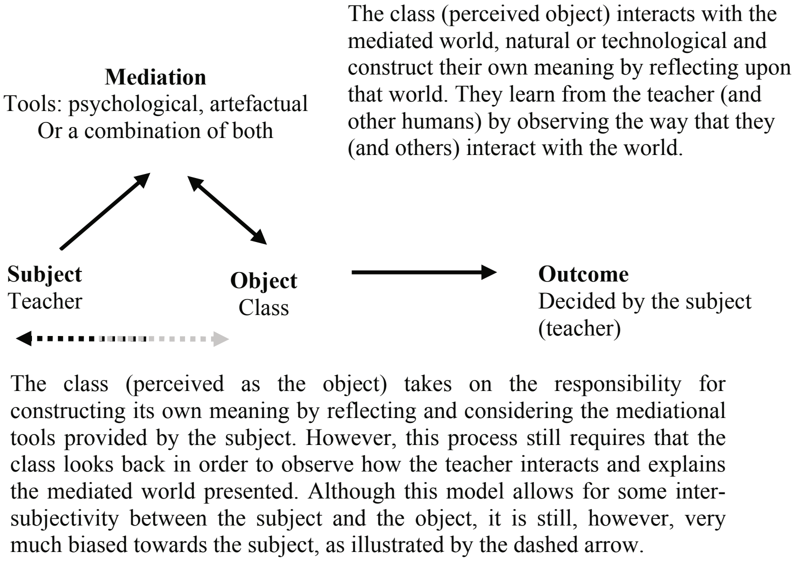
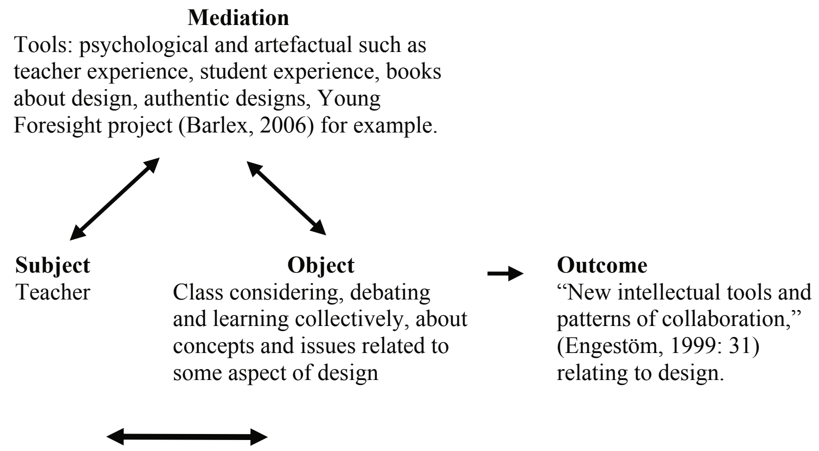


Figure 6. Constructivist pedagogy.

The model represented in Figure 6 is not meant to depict the large corpus of work and theory developed by Piaget. It does, however, represent my interpretation of a constructivist model of teaching. Furthermore, it brings to light the fact that the model cannot work if the object is the class. In this case the class would have to be a homogeneous mass, so to speak. Given, however, that any class is a heterogeneous collection of individuals with different needs and wants, different purposes and intentions, the models discussed thus far can work only if the object is taken to be an individual. In this case, the teacher can lead the class towards a common outcome only if she adjusts the mediational tools to take account of every individual in the class.

It is Vygotsky, a social constructivist, who changes the model to one in which socio-cultural and historical considerations are taken into account. This is represented in the model seen in Figure 7.

This model, based upon Vygotsky's, resolves four of the five flaws outlined earlier. The learner in this model is no longer passive but takes an active role alongside the teacher and the classmates. The arrows indicate a more dialogic model in which this active role enables a more collaborative and thus creative learning environment in which participants have the freedom to test out individual and collective ideas. These ideas consequently allow the participants to begin to look forward by enabling them to try out new and innovative design ideas that do not require (at least initially) any reference to previous ideas. This is in line with Kimbell and Perry's (2001) notion of creative environments where technology education classes are "packed with opportunities to explore and exploit designerly hunches" (p. 8). The one flaw this model does not resolve is the one related to heterogeneity. It still considers the class(object)



This model demonstrates my extended interpretation of Vygotsky's triadic model. This model anticipates Engestrom's more complex form demonstrating an activity system. This model rejects to a greater extent the notion of the class alone as the object of activity. The object of activity in this model is more open to interpretation. Moreover, the arrows indicate a more dialogic form of inter-subjectivity where all participants have agency and are working towards a collaborative set of outcomes.

Figure 7. Social constructivist model.

as homogeneous as is the case in all the previous models. In light of this, it can only consider the individual separately, albeit within the structure of the class. This, however, brings to light the clarion call that resonates with all student teachers (as well as in-service teachers): they simply cannot teach 20 or more pupils individually.

Activity theory enables us to consider a way to overcome this problem. If we consider a technology education class as an activity system rather than as a series of actions undertaken by the teacher in order to achieve prescribed goals, we become less concerned with the individuals. Rather, we are concerned with revealing the meaning(s) behind the actions of the participants. If the activity in the class is technology education, then the participants or actors in that activity are collectively the teacher, the students and the materials; together they constitute the subject of the activity. The object of the activity is no longer the class, seen as some material homogeneous mass. Instead the object becomes the design of [insert that which is to be designed] in order to transforming procedural and conceptual knowledge development into an outcome that will satisfy some human need. Some examples may help to clarify this.

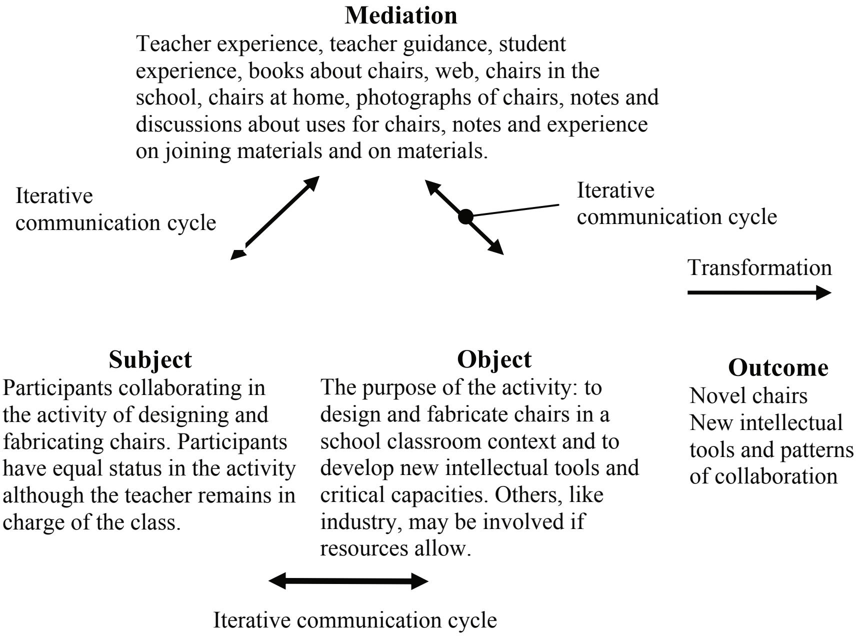
The subject (now teacher and students) may wish to transform the design of a chair (object of their activity) in order to learn more about product design (outcome).

The mediational tools required for this will be constituted by looking back to historical, pre-existing materials, data, methodologies and techniques (tools). These will inform the student and the teacher how to transform the concept of a pre-existing chair into some novel form, and in so doing, learn about product design (outcome). Moreover, as the tools used in mediation will be socio-cultural, these will serve to shape the design of the new chair. If the mediational tools comprise, for example, things like chairs, techniques, materials, tools like saws and hammers, methodologies and influences that are culturally Chinese, then the new design will reflect this, whereas if the mediational tools are culturally European medieval, that is what will be reflected. It is the mediational tools that shape the outcome. Mediation will thus be constituted by looking back to historical pre-existing, socio-cultural data, both material- and knowledge based, and this will help to inform the student and the teacher in the transformation of the object into some novel design.

Although the activity of designing a chair requires the subjects to look back, it also, however, facilitates looking forward into the unknown – a novel chair design; new methods of fabrication, new use of materials. The outcome in this scenario may include the production of an artefact in the form of a chair; the development of psychomotor skills related to the construction of the chair; the development of skills associated with designing a chair, etc. The activity allows, moreover, for the development of conceptual knowledge. It is the tools used in mediating the activity as well as the collective teacher/class subject that will enable this development to occur. Given that the activity is designing and producing a new chair, each participant in the activity has agency. It is this collective activity that changes the pedagogical dynamics of the class structure. Rather than the teacher differentiating the activity for each child based upon perceived ability (unidirectional), the child, as an active agent in the activity, determines her own involvement (bidirectional). She does this in association with the teacher and her peers. The emphasis is no longer directed towards the individual but to the activity (see Figure 8).

It is significant to note that in the example given above, there are no clear and absolute 'correct' outcomes or solutions to the problem. Moreover, there is a great potential for spontaneous learning to take place. The participants' design and construction is subject to discussion with teachers and fellow students (and others, if involved in the activity, such as experienced chair designers, for example). In this model, not all students have to design or make the same thing. Indeed, they may only design or make, or be part of a design group, construction group or both: understanding about the division of labour. This forms the basis of an interpretation of the activity that is founded upon the students' experience to date and a reinterpretation through discussion and interaction with others. This model facilitates wider group participation, which, in turn, encourages broader discussion. An activity led by the teacher alone has a limited referential field of experience, whereas, an activity that involves 20 or 30 participants widens this field considerably and consequently the potential for creative activity.

By utilizing this new form of pedagogy informed by Activity Theory, teachers are no longer considered to be experts in some specific subject domain, depositing pre-established information into the minds of the young (a form of enculturation that is



The significant difference in this model is four-fold:

- The subject of the activity comprises all participants who have equal status in the activity. The teacher is in charge of the class, not the activity. The activity is shared.
- The object becomes the object of the activity or the purpose of the activity.
- Mediation is guided by the teacher but informed by all participants in the activity
- The outcome is dependent upon the mediational tools employed and is manifested by the transformation of the object, not the participants. They will derive their own meaning by participating in the activity. The outcome is thus, fluid and dynamic and not fixed.

Figure 8. Pedagogical model influenced by activity theory.

closer to indoctrination). Rather, they become proficient in facilitating learning about culturally meaningful activities that are considered useful to the learners (a form of enculturation that is liberating). The outcomes of the participants' activity are no longer limited: a chair might become a stool or a bench or even a coat rack. The activity is constantly negotiated and renegotiated between the participants. If the collective meaning behind the activity is restricted to passing examinations only, then the participants can easily work collectively towards that goal. However, under these circumstances they may conceive their participation in education as being somewhat reductive. If, on the other hand, their collective intention is directed towards learning something that is infused with meaning for them, their intentions will be motivated towards that end. In this latter case, the process is thus no longer school-based, abstract and exam-orientated having only a momentary impact on the participants. Instead, the activity system becomes socio-culturally significant with more enduring patterns of interaction. "It is this projection from the object to the outcome that, no matter how vaguely envisioned, functions as the motive of [the] activity and gives broader meaning to [the participants] actions" (Engeström, 1999: 31).

CONCLUSIONS

Activity theory teaches us that the quality of learning is determined by the nature of students' activity. Interaction with physical and intellectual tools (mediation) is central to learning. The outcomes of learning are not just about acquiring existing knowledge and skills, important though that is, but it must also be about developing students' intellectual skills (as seen in Figure 8). Whereas the development of existing knowledge and skills (using woodworking tools or understanding the properties of timber, for example), does involve an expert-apprenticeship form of pedagogy, and the knowledge developed is essentially value-neutral (a saw is for sawing, hardwoods are classified for us) and risk aversive. The development of intellectual tools requires a more collaborative and explorative approach. No one, not even the teacher, has authority over this type of knowledge. It tends to be value-laden and risk-laden: Is that a good design? Is that the best material? Is that method of production sustainable? These types of questions can only be encouraged in a pedagogical framework such as the one represented in Figure 8. Activity theory offers us a pedagogical framework to enable the development of these intellectual skills that, I would argue, are distinctly lacking in the delivery of technology education.

REFERENCES

Baudrillard, J. (2005). *The system of objects* (J. Benedict, Trans.). London: Verso.

Cole, M. (1990). Cognitive development and schooling. In L. C. Moll (Ed.), *Vygotsky and education: Instructional implications and applications of sociohistorical psychology* (pp. 89–110). Cambridge, UK: Cambridge University Press.

Cole, M., Engeström, Y., & Vasquez, O. (1997). *Mind culture and activity: Seminal papers from the laboratories of comparative human cognition*. Cambridge, UK: Cambridge University Press.

Deleuze, G., & Guattari, F. (1988). *A thousand plateaus*. London: Continuum.

Engeström, Y., & Meittinen, R. (1999). Introduction. In Y. Engeström, R. Meittinen, & R. L. Punamäki (Eds.), *Perspectives on activity theory* (pp. 1–18). Cambridge UK: Cambridge University Press.

Engeström, Y. (1999). Activity theory and individual and social transformation. In Y. Engeström, R. Meittinen, & R. L. Punamäki (Eds.), *Perspectives on activity theory* (pp. 19–38). Cambridge, UK: Cambridge University Press.

Heidegger, M. (1962). The question concerning technology. In D. F. Krell (Ed.), *Basic writings Martin Heidegger* (pp. 311–341). London: Routledge.

Kaptelinin, V., & Nardi, B. A. (2006). *Acting with technology: Activity theory and interactional design*. Cambridge: MIT Press.

Kimbell, R., & Perry, D. (2001). *Design and technology in a knowledge economy*. London: Engineering Council.
Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*. Oxford: Oxford University Press.
Leont'ev, A. (1978). *Activity, consciousness and personality*. Englewood Cliffs, NJ: Prentice Hall. (Originally published in Russian in 1975).
Leont'ev, A. N. (1981). *Problems of the development of the mind*. Moscow: Progress. (Originally published in Russian in 1940)
Marx, K. (1954). Capital. In S. Moore, E. Aveling, F. Engels (Eds.), *Capital: A critique of political economy* (3rd German ed., Vol. 1.). Moscow: Progress Publishers. (Originally published in Russian in 1887)
Miettinen, R. (1999). The riddle of things: Activity theory and actor network theory as approaches to studying innovation. *Mind, Culture and Activity: An International Journal*, *6*(3), 170–195.
Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, Massachusetts/London: Harvard University Press.

John R. Dakers
Delft University of Technology
The Netherlands

MOSHE BARAK

3. FOSTERING LEARNING IN THE ENGINEERING AND TECHNOLOGY CLASS

From Content-Oriented Instruction Toward a Focus on Cognition, Metacognition and Motivation

INTRODUCTION

It is widely agreed that one of most important objectives of education in general, and engineering and technology education in particular, is fostering students' cognitive skills and their development as independent and confident learners. Although in recent decades, the field of engineering and technology education has been enriched by considerable writing on issues such as the nature of technology, technological literacy, and design and problem-solving, less has been written about the role of engineering and technology education in promoting students' learning skills and motivation to learn. This question is acute in engineering-oriented technology education programs, such as those in Israeli high schools, because teachers who possess a strong engineering background frequently tend to concentrate on teaching specific subject matter in areas such electronics or mechanics. These teachers often regard the development of students' learning skills as a side effect or a 'natural outcome' of learning engineering subjects.

The purpose of this chapter is to examine ways of promoting students' cognition, metacognition and motivation competences in the context of learning engineering and technology. The chapter starts with a brief review of theories dealing with the promotion of learning skills in the engineering and technology class. Then, preliminary outcomes from a program aimed at enhancing learning skills in engineering and technology in Israeli high schools are discussed. Conclusions and directions for further research are also presented.

LITERATURE REVIEW: PERSPECTIVES OF LEARNING AND COGNITION IN THE ENGNIEERING AND TECHNOLOGY CLASS

Self-Directed Learning (SDR)

According to Knowles (1975), Self-Directed Learning (SDL) is "a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources, choosing and implementing appropriate learning strategies, and evaluating learning outcomes" (p. 18). Long (1989) asserts that the major characteristic of the

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 35–53.

self-directed learner is the degree to which the learner maintains active control of the learning process. This competence is influenced by personality skills, such as self-confidence, and achievement motivation, as well as general skills, such as goal setting, decision making and self-awareness.

Self-Regulated Learning (SRL)

Self-Regulated Learning (SRL) is described by Zimmerman and Schunk (1989) as the ability to control and influence one's learning processes, for example, planning, goal-setting, strategy implementation, summarizing, and monitoring one's progress. Although this term is quite close to the notion of self-directed learning mentioned above, the two terms are not identical. While self-regulated learning refers mainly to the cognitive, metacognitive and motivational aspects that occur before, during and after accomplishing a task, self-directed learning is a broader concept that also comprises aspects such as interest in learning, formulation of long-term objectives, identifying needs and resources, or considering whether to learn independently or with others. The concept of self-directed learning has been investigated in the context of adult education (Brockett and Hiemstra, 1991; Candy, 1991; Long, 1989), for example, in nursing education (O'Shea, 2003), engineering education (Bary and Rees, 2006; Stewart, 2007), and higher education in general (Silen and Uhlin, 2008). Recently, researchers have become increasingly interested in the ways education can foster these competences among learners at all school levels because self-directed learning is strongly associated with terms such as independent learning, lifelong learning and distance learning, which are central to today's dynamic world.

Zimmerman and Campillo (2003) stated that self-regulating skills develop when problem-solvers: are engaged in open-ended assignments; need to address a number of solutions or problem-solving methods and select the optimal one depending on the specific context; are required to anticipate positive or negative likely outcomes of various courses of action; need to constantly think not only of the problem but also be aware of the thought processes involved in solving the problem. One can see that these characteristics of schooling which foster self-regulated learning are very applicable to engineering and technology education. Moreover, design and problem-solving in engineering and technology differ from learning other school subjects in that technological problems are often derived from several contexts and could involve not only mathematical, scientific or technical considerations but also cultural, social and economic aspects. In addition, engineers and technologists must often consider issues such as moral dilemmas, ethical questions, responsibility, integrity, reliability, risks, safety and environmental issues (De Vries, 2005; Harris et al., 2000). Schraw et al. (2006) and Barak (2010) presented a model of self-regulated learning in science and technology consisting of three main dimensions: cognition, metacognition and motivations, as discussed in the following sections.

Cognition

The term cognition relates to the conscious mental processes by which knowledge is accumulated and constructed, such as being aware, knowing, thinking, learning and judging. It is common to distinguish between lower-level cognitive processes, such as perceiving, recognizing, memorizing, understanding and conceiving, and higher-level mental functions, such as analyzing, conclusion-drawing, reasoning, synthesizing, problem-solving, assessing and creative thinking. Today, educators understand that learning is developmental, and people best learn and construct new knowledge by building on their current knowledge through active interaction with the physical environment, for instance, materials, tools and sophisticated artifacts such as computers; and through social interaction, for example, among learners, instructors, experts, parents and the community. These views of learning have been influenced by several learning theories, including cognitive-constructivism (Piaget, 1952), social-constructivism (Vygotsky, 1978), situated cognition (Brown et al., 1989), distributed cognition (Salomon, 1993), and activity theory (Leontiev, 1978). In this book, Christian Schunn (Chapter 1) and John Dakers (Chapter 2) highlight the role that engineering and technology education could play in learning and cognition in school classrooms in light of these learning theories.

Metacognition and Reflection in Learning

Metacognition is broadly defined as any knowledge or cognitive process that refers to monitoring or controlling any aspect of cognition, for example, memory, attention, communication, learning, problem solving and intelligence. The notion of metacognition, which is sometimes presented as 'thinking about thinking,' 'knowing about thinking' or even 'thinking about knowing,' is commonly associated with the work of Flavell (1979), who distinguished between two concepts: metacognitive knowledge and metacognitive regulation. Metacognitive knowledge includes knowledge of general strategies that might be used for different tasks, knowledge of the conditions under which these strategies might be used, and knowledge of the extent to which the strategies are effective (Pintrich, 2002). Metacognitive regulation involves the use of knowable metacognitive strategies or sequential processes to control cognitive activities aimed at meeting a specific goal. This includes, for example, the ability to select, combine and coordinate different strategies in an effective way (Boekaerts, 1999). Johnson (see Chapter 4 in this book) argues that transferability of knowledge and skills from one context to another requires the engagement of executive control processes so that students understand under what conditions a particular task is best suited, develop strategies for applying their knowledge, monitor or regulate progress, and evaluate the quality of the process outcomes. Students who possess domain knowledge but monitor and control their cognition poorly may face failure in solving problems. On the other hand, metacognition could help compensate for lack of experience in solving problems and the successful transfer of learning.

The concept of reflective practice (Dewey, 1933) relates to the continuous process of learning from experience and involves the individual considering critical incidents in his/her life experiences, asking questions about what we know and how we came to know it, and 'learning to learn.' Schön (1996) suggested that reflective practice involves thoughtfully considering one's own experiences in applying knowledge to practice while being coached by professionals in the discipline.

Although researchers strongly agree that metacognition and reflection are essential for learning, it is not an easy task to integrate these activities into routine schooling. Later in this paper, we will see an example of treating this challenge in the context of engineering and technology education.

Motivation

Motivation is often presented as comprising the internal state or condition that activates behavior and gives it direction, the desire or want that energizes and directs goal-oriented behavior, and the influence of needs and desires on the intensity and direction of behavior (Huitt, 2001). According to Boekaerts (2002), motivational beliefs, which refer to the opinions, judgments and values that students hold about objects, events or subject matter domains, act as favorable contexts for learning. Competence and control beliefs (Schunk and Zimmerman, 2009) relate to students' perceptions about their means, processes and capabilities to accomplish a certain task. These beliefs are self-evaluative because learners must weigh their knowledge, skills and strategies against the demands of the task to determine the perceptions of competence. Control beliefs are the students' perceptions about the likelihood of accomplishing desired ends or outcomes. One might feel competent in addressing a task successfully, for example, designing a given system, but less confident in achieving the desired ends if the conditions are unfavorable. Schunk and Zimmerman (2009) write that competences and control beliefs make key contributions to the predication of achievements beyond the effects of other variables, for example, when students are out of school and pursuing careers.

From a social-cognitive perspective, self-efficacy is defined as people's beliefs in their capability to produce designated levels of performance that exercise influence over events that affect their lives (Bandura, 1997). It is the belief that one has the capability of executing the courses of actions required to manage prospective situations. According to Bandura's (1997) social cognitive theory, pupils with low self-efficacy avoid difficult tasks and have low aspirations and a weak commitment to goals. They interpret poor performance as low aptitude, and they lose faith in their capabilities. In the context of engineering and technology education, Hill (2007) points to the following key factors affecting students' motivation to learn:

- contextualization learning in the students' world,
- bringing real-world subjects into the classroom,
- giving the students choice, autonomy and control over their learning, and
- providing feedback.

This brief review of theories relating to learning, cognition and motivation reveals that engineering and technology education has the potential of serving as one of the best frameworks education has for fostering these capabilities among students. But, to what extent is this potential realized in our schools?

REFLECTION ON A PROGRAM AIMED AT ENHANCING ENGINEERING AND TECHNOLOGY EDUCATION IN ISRAELI HIGH SCHOOLS

Background

To clarify the context of this study, a brief review of the current framework of teaching engineering and technology in Israeli schools is presented. In the past, the compulsory curriculum for primary school (grades 1–6; ages 6–11) and middle school (grades 7–9; ages 12–14) included separate programs for science education and technology education. In a substantive reform that took place in the late '90s, the teaching of science and technology in primary and middle schools was integrated into one program entitled 'science and technology.' The technological subjects in these programs included subjects such as "Human-made world," "Information and Communication" and "Technological Systems & Products." In practice, the number of technology teachers has decreased significantly since this change in the curriculum was administrated and currently the teaching of technological subjects is done primarily by science teachers who often have only limited backgrounds in technology or engineering.

The situation of technology and engineering education in secondary schools (grades 10–12; ages 15–17) is different. It is important to note here that about 90% of Israeli youngsters complete 12 years of study and finish school at the age 18. Although in the past, we used to have separate high schools for technology/vocational education and general education, this system has changed over the past 20 years and today technology studies take place as elective studies in comprehensive high schools. About 40% of high school students major in engineering-related studies, such as electronics, electricity, mechanics and computer sciences. The students learn these subjects for about 10 hours a week during Grades 10–12. About a quarter of the students who major in technology are high-achievers who take advanced studies concurrently in other subjects such as mathematics and physics. These students take matriculation exams in technology that are recognized for acceptance into the country's universities. Other students, with mid to low scholastic backgrounds, may pursue post-secondary studies in technical colleges or take advantage of employment opportunities. Most of the teachers have backgrounds in engineering, which is an advantage on the one hand, but a limit to a certain extent on the other, as discussed later in this chapter.

The First Reform: From Conventional Instruction to Projects

A study conducted in schools in the early 2000s (Barak, 2002) revealed that the subjects of electricity and electronics were taught mainly through 'talk-and-chalk' lessons. In the lab, the students performed a given list of pre-designed experiments that often aimed at checking a specific component, for example, a resistor, a transistor, or an operational amplifier. They rarely worked in the lab with real technological systems such as a radio transmitter or a robot. Therefore, it was no surprise that many students expressed disappointment and even frustration in technology studies, and said things like "the studies are difficult and not interesting" or "had I known what we would be studying, I would not have chosen electronics studies" (p. 26). In light of this situation, the Ministry of Education encouraged schools to incorporate the preparation of projects in areas such as electronics, control systems and robotics as a partial substitute for conventional pencil-and paper matriculation exams. Since the early 2000s, the number of schools encouraging their students to prepare projects in technology has grown constantly, from about 80 projects in 2000 to about 400 projects in 2002, 1,400 projects in 2005, and 1,800 projects in 2009. In the year 2010, students from about 50% of the schools nationwide prepared final projects in subjects such as robotics, computer-controlled greenhouses or artifacts aimed at hearing- or vision-impaired individuals. Although the educational advantages of project-based learning in engineering and technology are well known (see Chapter 13 by David Crismond in this book), the way teachers guided their students in project work did not always achieve the aim of promoting quality learning in the classroom.

The Second Reform: Fostering Higher-Order Learning Skills

In dozens of visits to schools, informal talks with teachers and students, and research conducted in four schools (Barak and Shachar, 2008), it was found that the teachers, most of them engineers, often believed that the delivery of engineering-related subject matter was the essence of schooling. Also in project work, teachers generally had their students focus on constructing specific electronics circuits or control systems and often helped them extensively in accomplishing the task, including trouble-shooting. Many teachers regard the fostering of students' broader skills such as independent learning, problem solving and creativity as a side effect of learning subject matter or completing a technical task. For example, one of the questions Barak and Shachar (2008) presented to the students (n=53) in a questionnaire was: "In working on the project, to what extent do you depend on the teacher or work independently?" Only 23% of the students marked that they work independently or very independently on their project. Among the teachers (n=9), seven (78%) marked that the students depend greatly on them, one (11%) marked that the students depend little on him/her and only one (11%) marked that the students work independently. This was the background for the program aimed at fostering higher-order thinking and learning capabilities in engineering and technology classes, addressed below.

The "Fostering Higher-Order Thinking in Learning Electricity and Electronics" Program

This program, which took place during the years 2009–2010, aimed at enhancing the learning of technology in high schools with a focus on the ways 12th graders work on their projects in subjects such as electronics, control systems and robotics. The program included:

1. Working with the Ministry of Education's Chief Inspector for electricity and electronics studies and supervisors on establishing new guidelines for project work in schools.
2. Delivering in-service training courses to 150 teachers in the country's southern, central and northern regions.

3. Preparing new guidebooks for students on the project work process and requirements.
4. Mentoring teachers in a sample of 10 schools for introducing the new approach into their classes.

Study Objectives and Data Collection Methods

The study presented here aimed at exploring the attitudes of Ministry of Education supervisors, teachers and students towards the notion of enhancing cognition, metacognition and motivation in learning engineering and technology, and the process of introducing this change into schools. Data were collected using both qualitative and quantitative methods, including: systematically documenting the work meetings and informal talks with the participants; videotaping the lectures and class discussions in the three in-service training courses delivered to teachers; administering semi-structured questionnaires to teachers; observations in schools; and interviews with students during lab work. The researchers were the author of this chapter and a PhD student from Ben-Gurion University of the Negev.

Outcomes from Working with Ministry of Education Supervisors

The Chief Inspector and the supervising team of six inspectors are in charge of teaching the subjects of electricity, electronics, computer engineering, control system and robotics in about 300 high schools and colleges countrywide. We held conversations with this team with the aim of incorporating a change into the teaching and learning of the subjects of electricity and electronics in schools, as discussed earlier in this chapter. It was suggested, for example, that more focus would be placed on self-directed and self-regulated learning, problem-solving and reflection on learning. A specific proposed change was that the students would have the choice of using e-portfolios to document their project work rather than preparing a summative printed booklet on the project.

In the beginning, the supervising team members were skeptical about the proposed reform and some even objected to it. Some participants had comments such as: "Our duty is to teach the students up-to-date knowledge;" "We have to prepare them to work in the high-tech industry;" "The students are unable to learn new subjects by themselves;" "There must be something printed (booklet)." These responses reflect that many of the supervisors, themselves teachers, regard technology education as a type of vocational education aimed at preparing high school graduates for the workplace. Fortunately, the Ministry of Education's Chief Pedagogic Secretary announced concurrently a broad program entitled 'fostering higher-order thinking' designated for all school subjects. This gave us the opportunity and resources to initiate also a change in technology education, as described below.

Teachers' In-Service Training Course

Teachers' in-service training courses were held simultaneously in three centers in the south, center and north of the country (n=130). Later, a fourth group (n=20) was taught in the center. In total, 150 teachers attended this course, which comprised seven meetings of four hours each. The main subjects learned in the course were:

1. The need to focus technology education on fostering **higher-order thinking** competences rather than on teaching specific subject knowledge. We used Resnick's (1987) viewpoint, according to which higher-order thinking is:
   - Non-algorithmic
   - Complex
   - Yields multiple solutions
   - Requires the application of multiple criteria
   - Necessitates self-regulation
   - Often involves uncertainty
2. Using a **Problem-Solving Taxonomy** (PST) for planning instruction in the class, lab and project work. This taxonomy, which was derived from the literature on engineering education (Plants et al., 1980; Wankat & Oreovicz, 1993), includes the following five levels of assignments in learning engineering and technology:
   - **Routines** – using operations or algorithms without the need to make any decisions
   - **Diagnosis** – selecting the correct method or routine
   - **Strategy** – selecting the optimal method when a variety of options exists in solving a problem
   - **Interpretation** – solving real-world, open-ended problems
   - **Generation** – developing methods that are new to the learner
3. **Types of knowledge** in engineering and technology instruction:
   - **Declarative knowledge**, for example, names and symbols of components
   - **Procedural knowledge**, for example, how to calculate current and power in an electric circuit
   - **Conceptual knowledge**, for example, broad concepts such as energy, feedback and amplification
   - **Qualitative knowledge**, for example, the use of intuition, experience or rule-of-thumb in design, problem-solving or troubleshooting
4. Promoting **metacognition and reflection** in learning and problem-solving.
5. Factors affecting students' **motivation and self-efficacy beliefs** in the technology class.
6. Using **e-portfolios**, for example in a form of a website, to document project work and encourage reflection on learning.

In the teachers' course, we showed the participants that although engineering and technology education could be an excellent platform for fostering the sort of thinking patterns mentioned above, unfortunately, technology educators rarely use psychological and educational theories design instruction. The participants were encouraged to propose how they felt this end could be achieved. Among the theories reviewed above, Resnick's perspective of higher-order thinking was best accepted by the teachers, especially in the context of project-based learning in technology.

Other aspects, for example, the need to encourage reflection in the class and using e-portfolios, were also well accepted. This was determined in informal talks with the teachers, outcomes of a feedback questionnaire (see Table 1) and the examples the teachers presented, as demonstrated in the sections that follow.

The Position of Ministry of Education Supervisors

Members from the supervision team attended most of the classes; four of them actually lectured to the teachers and discussed with them the desired changes in teaching technological subjects in general and project work in particular. Some of the points they emphasized to the teachers, which were also published formally, were the following:

– Schools can reduce the size or complexity level of the systems the students are designing in comparison to the past; project work, however, must include explicit phases of inquiry, problem-solving and troubleshooting.
– Project work must include the use of lab instrumentation and simulation analysis.
– Students should document all their work on the project, the initial design and construction stages, troubleshooting and improvements.
– Teachers will guide the students to reflect periodically on their work by writing down their thoughts before, during and after dealing with each project stage, for example, their interest, motivation and self-confidence about completing the task.
– Students can use the e-portfolio method instead of preparing a summative booklet on their projects, which often includes merely technical information such as electronic circuits or computer programs. The students can construct the e-portfolio in the form of a word processor document or electronic presentation.

However, we also demonstrated the more advanced option of building a personal website (to be used either on a local computer or to be published on the Internet), for example using Microsoft Publisher software or the platform of Google Sites. An example of the structure and content of such an e-portfolio is shown in the section ‘signs of change in schools’ below.

The above guidelines demonstrate how the cognitive, metacognitive and motive-tional dimensions derived from the self-regulated learning theory were incorporated into schooling. This approach differs significantly from project work in many engineering-oriented classes in which teachers essentially stress learning the subject matter and completing the technical work. This point was expressed in the teachers’ responses to the current program, as seen in the following section.

Teachers’ Responses to the Suggested Reform

As previously noted, the teachers in the initial three in-service classes filled in semi-structured feedback questionnaires on the specific subjects learned in the course and a summative questionnaire at the end of the course. Many informal talks with the participants in the three classes were documented. Table 1 shows the average scores the teachers marked for some items in the final questionnaire. The mean scores ranged between 3 (high) and 4 (very high), indicating that the teachers generally

Another example is data gathering from a video of projectile motion. The educational technology program Logger Pro (see reference list) does this, as seen in Figure 4. Another example would be an animated exploration of slicing a cone. The particular technologies mentioned are merely examples.

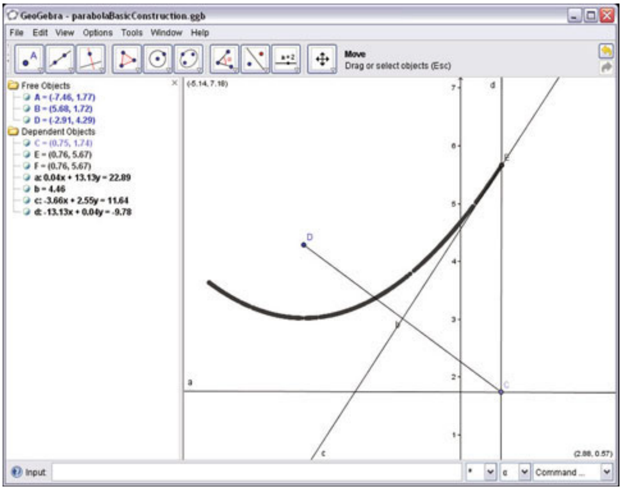


Figure 3. Dynamic analysis of quadratics equation using GeoGebra.

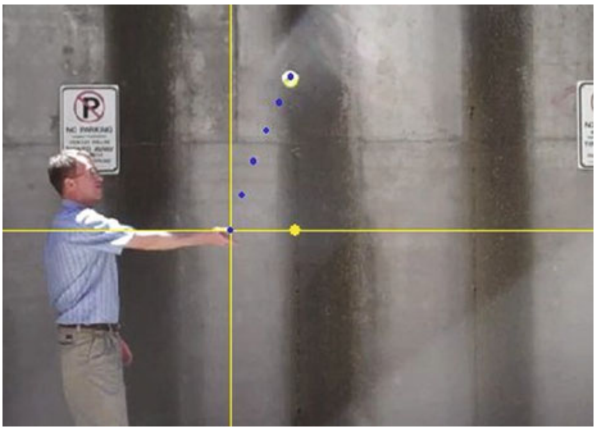


Figure 4. A physics teacher can analyze the motion of a projectile frame by frame.

Many classroom-oriented and professionally-oriented technologies exist and they are changing constantly. The tools are important, but regardless of the tools used, the goal will be to understand the properties of the satellite dish, or why a hanging cable is a catenary and not a parabola, or to get a robot to launch a projectile

> "In a short period of time, the number of students preparing projects might decrease; in the long run, this change will raise the learning level and prestige of technology education."

These comments show that the transition from merely teaching subject matter or constructing a 'practical' technological system towards promoting higher-order learning skills in the engineering and technology class was not a trivial matter for educators. Yet, some encouraging changes were observed in schools.

Signs of Change in Schools

Already during the teachers' in-service course and in the visits at schools in the subsequent academic year, we witnessed initial signs of change in the school level, as exemplified below.

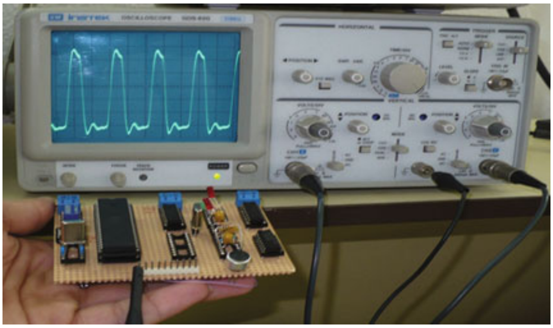


Figure 1. A teacher showing how students can demonstrate their work in the lab; the aim is not only to promote a deeper learning but also to encourage the students to reflect on their learning.

One of the program participants, an electronics teacher who also serves as a part-time supervisor, took the photo seen in Figure 1 to his school and displayed it during the teachers' course.

The picture in Figure 1 shows how students can use a digital camera (often available on their mobile phones) to keep records of their work, for example, tests and measurements they are carrying out at the different work stages. This could help them to describe in their portfolio how they analyzed their system's performance in comparison to the theoretical design or show how they dealt with the difficulties or faults they encountered in their system. The teacher explained that this method could encourage students to be aware of their learning and reflect on their experience. Moreover, the teacher showed closer pictures of the oscilloscope screen and controllers, which can provide specific data such as signal amplitude and frequency. The learners can use this information to show how they analyze or explain electronic circuit design and functioning.

The second example was the case of a teacher from a school serving mainly low-income families who started to change the project work in her class while attending the course. The class comprised 16 students (12th-graders), all of whom were mid-level achievers, who prepared final projects in electronics. The teacher documented her students' project work over about six months as a mini-research study within the framework of studies for an MSc in science and technology education at Ben-Gurion University of the Negev. Data collection methods included: keeping a diary of the students' activities in the lab and her discussions with them; keeping records of the students' work on their projects; holding semi-structured interviews with the students at the school's year-end in which the students were asked about their interest in learning, their motivation to complete the project, and their successes or difficulties in learning technology (the interviews were recorded and transcribed). Following is a brief review of the changes the teacher noted in her class:

1. In the past, the teacher used to assign a project for each group. In the new approach, she asked the students to propose their own ideas for a project or choose a subject from a suggested list, such as activating devices by mobile phone, controlling motor speed by remote control, transmitting and receiving sounds.
2. Instead of providing each group with all of the components for the project, the teacher requested that the students buy some of the components themselves at electronics shops. The intention was to help the students learn about the components' availability and prices, and increase their ownership of their projects.
3. In the new approach, the students are required to draw the electronics circuit and carry out simulation analyses using professional electronics design software.
4. During system checking and troubleshooting, the learners need to measure electronics signals such as voltage, current, frequency or waveform at different points in the system and compare these findings to the theoretical values.
5. The students are required to keep records of all their project work as mentioned above. The can choose to either use the e-portfolio method or prepare a printed booklet on their project as is common in many schools.
6. In documenting their projects, the students are asked to reflect on their work, for example, their interest in the project and their success or difficulties in carrying out the task.

Since the teacher was trying out the new project work method for the first time, she let the students decide whether they wanted to use the new method or continue with the traditional approach, which includes merely constructing the electronic circuit and troubleshooting. Out of the 16 students in the class, only four agreed to try out the new method. The rest, according to the teachers, thought that this method was too difficult for them. The teacher described that the changes she had made in the class considerably increased students' motivation to complete their projects. She wrote:

> "The students' attendance in the lab lessons was quite good in comparison to other school subjects… some of them arrived to school only to work on their projects… sometimes they refused to leave the lab on the breaks…"

One of the students, whose project was a system for activating electronic devices using a mobile phone, documented his project in the form of a personal website, as illustrated in Figure 2 (home page). The student constructed this website using

Figure 2. The homepage of the website a student prepared for his project (the English translation was especially prepared for this chapter).

Microsoft Publisher software included in the standard Microsoft Office package that learners and teachers often use in school or at home. One can see that the website comprises the following pages or sub-folders: "Home page"; "The circuit"; "Block Diagram"; "Explanations"; "Data sheets"; "Gallery"; "Operation"; "Measurements"; and "Reflection".

In the 'Block diagram' folder, the student posted the chart shown in Figure 3.

It is important to note here that drawing the sketches, charts and block diagrams, such as in the example shown in Figure 3, can be very challenging for learners. For example, the block diagram seen in Figure 3 is not very professional because the motor appears as a component with two wires connected to it rather than as a functional block. In addition, there is no such block called 'Rotation direction.' This is the output variable. However, understanding and drawing block diagrams is a vital aspect of learning engineering and technology (Barak and Williams, 2007). Johnson (Chapter 4 in this book) articulates that sketches and block diagrams are essential tools for learning the structure and function of complex technological systems and their inter-related components, building multiple mental representations, abstraction, conceptual understanding, and transfer of knowledge across various problems and technological contexts. In the case mentioned above, the Explanation link on the project website included concise explanations the student wrote about each project sub-system and component, as well as a comprehensive description of the system's structure and functioning.

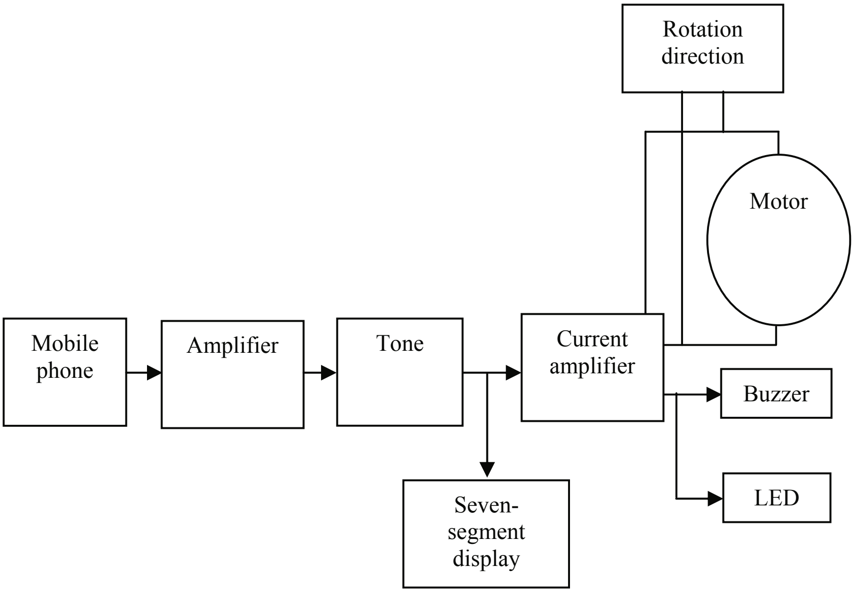


Figure 3. The system block diagram the student included on the project website (the English translation was especially prepared for this chapter).

Following are some examples from what the student wrote on the 'Reflection' page:

> "I chose this subject because it appeared to be the most interesting and challenging."
> "I felt excellent while buying the components; the salesperson was very helpful."
> "I was very excited when I first started wiring the components."
> "In summary, engaging in the project was very beneficial to me; it was much more interesting than learning in class."
> "I attended these lessons regularly even though I had some difficulties."

In the last sentence above, for example, the student hinted that although he was often absent from school, he regularly attended lessons in the electronics lab to work on his project because this was important to him. Regarding troubleshooting and problem-solving, the student wrote on the 'Reflection' page of the project:

> "When I placed the first component (in the circuit) it was faulty… the teacher gave me another one and this worked properly…"
> "After I placed and connected all of the components, all of the devices worked except for the motor… when I connected the motor directly to the power supply it worked; therefore I checked its current consumption… it was 2A during start-up but decreased afterwards to 0.5A… however the amplifier supplies only 1A… I had two options: to take two or three outputs from the amplifier in order to get a higher current or replace the motor with another one that a needs a smaller start-up current… I chose the second option."

In summary, the above examples demonstrate how the teacher adapted the notion of promoting cognition, metacognition and motivation she had learned in the course into practical schooling. This case highlights why the teacher said she is determined to apply the new approach with all students in the following year.

The third case was that of a very experienced teacher who had been supervising project work in his class for about 15 years. In recent years, students from this school had won many prizes in national and international robotics competitions. We held informal talks with the teacher during the in-service course and interviewed him twice in the lab in his school in Jerusalem. The teacher had the following comments:

> "The course strengthened inside me what I had always believed: what is important (in project work) is the process. The process exists, but we did not document it… the students just started working… now I have started to ask the students: think about the faults in the project and write them down; think about what happened and why it happened…"

> "The new point is, in my opinion, the documentation of the work… making a student understand what he or she is doing… sometimes students forget what they did a week before… the fact that they have already solved a problem…"

> "(I say to a student) picture the measurements you are making that illustrate the problem… write down what the problem was and how you solved it, this is metacognition…"

> "I am not changing the projects significantly other than the documentation, which we had not done to date… this is important for thinking about thinking."

The fourth example is the case of a regional school in an agricultural area in the southern part of the country. We invited the teacher from this school to lecture in the teachers' in-service training course and present the changes that technology studies in his school had undergone over the past decade. The teacher reported that in the past, they used to teach technology using a traditional instructional method whereby the students learned the theory and carried out standard lab experiments. During this period, only 10–15 students, often characterized by middle to low scholastic backgrounds, chose to major in technology each year, and the school principal considered closing technology studies in the school. In the 2010 academic year, 60 academically excellent students applied to major in technology and the school selected the 30 best students. The teacher reported that this far-reaching change in the status of technology education in the school was obtained primarily by engaging students in projects from the very beginning of learning technology. In the 10^{th} grade, the students work in the lab on small assignments such as an alarm system; in the 11^{th} grade, they construct more complex systems based on a programmable micro-controller. In the context of working on these projects, they learn the fundamentals of electronics and computer sciences, use simulation software for design, and gain experience in constructing electro-mechanical systems. In the 12^{th} grade, the students work in pairs or small groups on advanced projects including, for instance, communication systems, control systems and robotics. The teacher presented the example of the robot shown in Figure 4. This machine was fully designed and constructed by two students as a

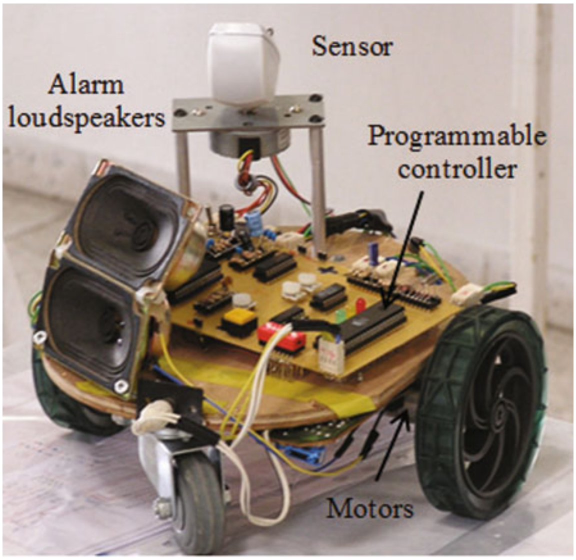


Figure 4. A final project prepared by 12th-grade students.

final project. They had to deal on their own with the mechanical system, motors, sensors, electronic circuits and programming.

In a previous study, (Barak, 2006) presented another example of students from the same school who developed a robot carrying a video camera, including the students' reflection on their work. The teacher told us that he "marketed" technology studies in his school by inviting 9th grade students (middle school) to the lab to observe the projects the older students (10th, 11th and 12th grade) were doing. This example brings into light that engaging pupils in advanced technological projects in areas such as robotics and communication systems greatly contributes to keeping engineering and technology education a dynamic and challenging field. Developing these systems often requires the integration of knowledge from several scientific and technological disciplines, and presents to the learner a higher degree of challenge, uncertainty or risk-taking compared to more traditional types of technological learning. In the current case, the teacher stated that with the new requirements for project work, he became more aware of the importance of guiding the students to document systematically all the design, problem-solving and troubleshooting stages they underwent, and of reflecting on their experience.

The fifth case is a school in the southern city of Beer-Sheva. Two teachers from this school attended the teachers' in-service course in the area, and one of them strongly supported the proposed reform during the course discussion. In the matriculation exams for the projects that took place at the end of the 2010 academic year, the teachers said that they had introduced considerable changes in students' work on their projects "exactly like what was proposed in the course." The class comprised 16 students (12th-graders) who prepared projects such as a computerized guitar tuner and a computerized temperature measuring device. In this class, the students were required to:

– Learn independently at least one subject in electronics relating to his/her project in an in-depth fashion;
– Perform systematic measurements of electronic signals in the systems they were developing and analyze the findings according to the theory;
– Photograph their work in the lab, for example, the system's construction, testing and troubleshooting;
– Prepare a detailed report (printed and electronic) of their project work, including not only technical information but also self-summaries and conclusions about their work.

DISCUSSION AND CONCLUSIONS

This chapter aimed at exploring the role that engineering and technology education could play in fostering students' learning skills and motivation to learn from the perspectives of general theories of learning, cognition and motivation. We have seen that the self-directed learning (SDL) and self-regulated (SRL) theories together suggest a comprehensive umbrella for understanding the process in which individuals become autonomous and motivated learners.

Engineering and technology education provides an outstanding environment for activating these learning processes in the classroom, for several reasons:

– First, learning engineering and technology takes place in a *rich and sophisticated learning environment*, consisting of materials, tools, machines and computers.
– Second, engaging students in design and problem-solving has to do with the notion of *contextual learning*, namely, linking what is learned in school to the students' daily lives.
– Third, engineering and technology education is about *learning by doing*, a notion that has been stressed by prominent authors such as Dewey (1933); and finally,
– Engineering and technology education deals with people's *volitions, imagination and creativity*, as David Barlex discusses in Chapter 7 in this book.

The examples we have seen in this study of engaging students in projects dealing with controlling technological systems or developing sophisticated robots very clearly demonstrates the four aspects mentioned above. Yet, the history of engineering and technology education in Israel, as described earlier in this chapter, shows that the potential advantages of teaching engineering and technology in school are not necessarily or automatically implemented. One problem is that the high school curriculum is often derived from engineering studies at the university level, and teachers normally teach this subject matter the same way they learned it, namely, using conventional instruction methods. A second problem is that learning in the lab frequently involves performing standardized experiments aimed at "checking" specific laws such as Ohm's law, or certain components such as a transistor. This type of formal learning contributes only little to developing students' competences related to self-regulated learning. A third problem is that teachers having a strong engineering background tend to see the delivery of the subject matter or accomplishing the technical task as the essence of teaching engineering and technology. Although technology educators intuitively grasp the educational advantages of project-based learning over traditional schooling, the development of students' broader learning skills does not take place spontaneously in project work.

This study revealed that in order to realize the potential of fostering students' higher-order skills in the technology class, namely, independent learning, problem-solving, metacognitive abilities and self-efficacy beliefs about mastering engineering and technology, it is essential to impart to the teachers content-pedagogical knowledge that relates particularly to achieving this end. The case explored in the current study also demonstrates that the aim of developing these skills can be expressed explicitly in the formal engineering and technology curriculum in such a way that teachers would acknowledge and be willingly to implement them in their classes.

CLOSING REMARKS

It is proposed that the community of scholars in engineering and technology education address the notion of promoting cognition, metacognition and reflection in the engineering and technology class as one of the major issues for discussion, research, curriculum development and teachers' pre-service and in-service training. An interesting direction for research is the use of advanced technological means, such as digital stills and video cameras, computer simulation and Internet tools for promoting the teaching and learning of engineering and technology.

The author would like to express gratitude to Aharon Shachar, Rachel Levi, Avi Lupo and Yoel Cohen for their important contribution to this study.

REFERENCES

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: WH Freeman and Company.

Barak, M., & Shachar, A. (2008). Project in technology and fostering learning skills: The potential and its realization. *Journal of Science Education and Technology*, *17*, 285–296.

Barak, M., & Williams, P. (2007). Learning elemental structures and dynamic processes in technological systems. *International Journal of Technology and Design Education*, *17*, 323–340.

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. (2006, March 23–25). *Introducing advanced technological subjects into the technology education curriculum: Teaching and learning issues*. Paper presented at the CCTE session, ITEA conference, Baltimore.

Barak, M. (2010). Motivating self-regulated learning in technology education. *International Journal of Technology and Design Education*, *20*(4), 381–401.

Bary, R., & Rees, M. (2006). Is (self-directed) learning the key skill for tomorrow's engineer? *European Journal of Engineering Education*, *31*, 73–81.

Brockett, R., & Hiemstra, R. (1991). *Self-direction in adult learning: Perspectives on theory, research, and practice*. London: Routledge.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Boekaerts, M. (2002). Motivation to learn. In H. Walberg (Ed.), *Educational practices series* (pp. 1–27). International Academy of Education-International Bureau of Education (UNESCO).

Boekaerts, M. (1999). Self-regulated learning: Where we are today. *International Journal of Educational Research*, *31*, 445–457.

Candy, P. C. (1991). *Self-direction for lifelong learning*. San Francisco: Jossey-Bass.

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

De Vries, M., Custer, R., Dakers, J., & Gene, M. (Eds.). (2007). *Analyzing best practice in technology education*. Rotterdam: Sense Publications.

Dewey, J. (1933). *How we think* (2nd ed.). New York: DC Heath.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, *34*, 906–911.

Harris, C. E., Pritchard, M. S., & Rabins, M. J. (2000). *Engineering ethics, concepts and cases*. Belmont, CA: Wadsworth.

Hill, A. M. (2007). Motivational aspects. In M. J. De Vries, R. Custer, J. Dakers, & M. Gene (Eds.), *Analyzing best practice in technology education* (pp. 203–211). Rotterdam: Sense Publications.

Huitt, W. (2001). *Motivation to learn: An overview. Educational Psychology Interactive*. Valdosta, GA: Valdosta State University. Retrieved from http://www.edpsycinteractive.org/col/motivation/motivate.html

Knowles, M. S. (1975). *Self-Directed learning: A guide for learners and teachers*. New York: Association Press.

Leontiev, A. N. (1978). *Activity, consciousness, and personality*. Hillsdale, NJ: Prentice-Hall.

Long, H. (1989). *Self-directed Learning: Emerging theory and practice*. Norman, OK: University of Oklahoma Press.

O'Shea, E. (2003) Self-directed learning in nurse education: A review of the literature. *Journal of Advanced Nursing*, *43*, 62–70.

Piaget, J. (1952). *The origins of intelligence in children*. New York: International Universities Press.

Pintrich, P. R. (2002). The role of metacognitive knowledge in learning, teaching, and assessing. *Theory into Practice*, *41*, 219–225.

Plants, H. L., Dean, R. K., Sears, J. T., & Venable, W. S. (1980). A taxonomy of problem-solving activities and its implications for teaching. In J. L. Lubkin (Ed.), *The teaching of elementary problem-solving in engineering and related fields* (pp. 21–34). Washington, DC: American Society for Engineering Education.

Resnick, L. B. (1987). *Education and learning to think*. Washington, DC: National Academy Press.

Salomon, G. (Ed.). (1993). *Distributed cognition*. Cambridge: Cambridge University Press.

Schön, D. A. (1996). *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions*. San Francisco: Jossey-Bass.

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education*, *36*, 111–139.

Scunk, D. H., & Zimmerman, B. J. (2009). Competence and control beliefs: Distinguishing the means and ends. In P. A. Alexander & P. H. Winne (Eds.), *Handbook of educational psychology* (pp. 349–367). Mahwah, NJ: Lawrence Erlbaum.

Silen, C., & Uhlin, L. (2008). Self-directed learning - a learning issue for students and faculty. *Teaching in Higher Education*, *13*, 451–475.

Stewart, R. A. (2007). Investigating the link between self-directed learning readiness and project-based learning outcomes: the case of international Masters students in an engineering management course. *European Journal of Engineering Education*, *32*, 453–465.

Vygotsky, L. S. (1978). *Mind and society: The development of higher mental processes*. Cambridge, MA: Harvard University Press.

Wankat, P., & Oreovicz, F. S. (1993). *Teaching engineering*. New York: McGraw-Hill.

Zimmerman, B. J., & Campillo, M. (2003). Motivating self-regulated problem solvers. In J. E. Davidson & R. Sternberg (Eds.), *The nature of problem solving* (pp. 233–262). New York: Cambridge University Press.

Zimmerman, B. J., & Schunk, D. H. (1989). *Self-regulated learning and academic achievement: Theory, research, and practice*. New York: Springer.

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

SCOTT D. JOHNSON, RAYMOND DIXON, JENNY DAUGHERTY AND OENARDI LAWANTO

4. GENERAL VERSUS SPECIFIC INTELLECTUAL COMPETENCIES

The Question of Learning Transfer

INTRODUCTION

One major goal of education is to provide students with the knowledge and skills that will prepare them to be productive citizens and enable them to make informed decisions about work, family and societal issues. It is commonly believed that what we learn in school will be applied at appropriate times later in life. Unfortunately, research on transfer of learning raises doubts about the effectiveness of education to create transferable knowledge and skills.

The concept of transfer of learning has been a topic of study for many researchers. Bransford, Brown and Cocking (1999) argued that the ultimate goal of schooling is to help "students transfer what they have learned in school to everyday settings of home, community and workplace" (p. 73). Current views of transfer (Beach, 1999; Bransford & Schwartz, 1999; Greeno, Smith, & Moore, 1993) indicate that transfer occurs when students activate and apply prior learning. This activation and application of prior knowledge can foster productive as well as unproductive transfer (Royer, Mestre & Dufresne, 2005). It is during these transfer events that the state of awareness of one's thoughts plays an essential role.

Concerns about transfer of learning were virtually nonexistent prior to the early 1900s because the commonly accepted "theory of faculties" implied that if learning had occurred, then the application of that learning in new situations (i.e., transfer) would be automatic. Unfortunately, both "experience and experiment combine to prove that such an outcome is never achieved" (Bayles, 1936, p. 211).

A new perspective on transfer resulted from numerous psychological studies conducted by Thorndike and his colleagues in an attempt to understand how certain mental functions contribute to improvements in the performance of other cognitive processes (Thorndike, 1924; Thorndike & Woodworth, 1901). These studies revealed that successful transfer of learning depended on the degree of correspondence between the stimuli, responses and conditions of the learning setting and those same factors in the transfer setting. This finding led to the creation of Thorndike's "theory of identical elements." According to this theory, as long as a similarity exists between the context in which learning occurred and the new situation in which the learning should be applied, then the transfer will be automatic. When differences exist between

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 55–71.

the learning and application settings, then transfer is less likely to occur. While this basic concept holds true today, it fails to consider the role of learner characteristics and individual cognition in supporting transfer (Bransford, Brown, & Cocking, 1999).

In contrast to the theory of identical elements, Judd (1936) argued that similarity between the learning and application settings is not enough. Instead, he promoted the idea that learning generalized principles was the answer to the problem of transfer. Building on this perspective, if one can learn generalized rules and how to apply them in different situations, the chances of appropriately applying those rules in new situations will be greatly enhanced.

While both of these theories offer contrasting insights into the drivers that promote successful transfer of learning (e.g., identical elements vs. rule generalization), what is clear is that that the context of the learning environment is a critical factor and transfer does not generally occur automatically.

One area of schooling that is particularly relevant to the enhancement of learning transfer is engineering and technology education. This emerging field of study is historically based on vocational and technology fields, which by nature are hands-on and require high levels of creative and critical thought in order to design and problem-solve. While general schooling has tried to enhance creative and critical thought processes over the years, little progress has been made.

It is claimed here that engineering and technology education can be an effective vehicle for developing students' general competences, such as problem-solving, decision-making and creativity. It is through technical design and problem-solving experiences that students will create a deeper understanding of general concepts such as systems, control, feedback, design and optimization. As an added benefit, experiences through engineering and technology education will enhance learning in other closely related fields such as mathematics, science and technology. This form of learning benefits all students because practical hands-on experiences and principle-based understanding support the transfer of knowledge and skills from school to daily life and to the workplace as technologies advance and as careers change.

TYPES OF TRANSFER

The Role of Context in Supporting Transfer (Near vs. Far Transfer)

Over the years, scholars have attempted to categorize transfer from different perspectives and for different purposes. Probably the most common categorization is the dichotomy of near and far transfer (Clark & Voogel, 1985; Perkins & Salomon, 1996, 1988; Royer, 1986). The concept of near transfer is consistent with Thorndike's theory that emphasizes the contextual similarity between the learning situation and the situation in which the learning is later applied. In other words, the transfer situation is very near to (or similar to) the situation in which the knowledge and skills were originally learned. Near transfer occurs rather easily because of the similarity between the learning and application contexts and the learner's familiarity with the new situation as a result of prior experience. In this sense, learning has been contextualized for application in real-world settings (Resnick, 1987).

In contrast, far transfer relates to the application of knowledge and skills in situations that are significantly different from the context in which the original learning occurred. In other words, there is a far distance between the original learning context and the context where that learning is likely to be applied later. Because of this contextual difference, far transfer is more difficult than near transfer because the learner has not previously experienced applying the learning in the new context. Although it is more difficult to achieve, far transfer is becoming more critical because of the rapid growth and change in knowledge, technology and the workplace (Leberman, McDonald, & Doyle, 2006).

As an example, imagine a new technician on her first day at work being asked to repair a machine that is identical to the machines she practiced on at her technical institute. The technician's familiarity with the machine will allow her to be confident and proficient because the experience she gained at the technical institute can be applied immediately to her new work assignment. In contrast, imagine a second technician who is faced with a new computer-controlled machine that is drastically more modern than what he used in his technical training program. While the basic principles underlying the two technical systems remain the same, the details of the system layout and the component function are radically different from what was experienced at the technical institute. In this case, the technician is less likely to directly apply prior knowledge and skills because of the great difference (i.e., far transfer) between the learning situation and the context of application. This difficulty occurs because the technician has developed, through experience and deliberate practice, particular ways of working with familiar systems that easily map onto similar machines and systems. Unfortunately, the relevance of prior knowledge and skills is not readily apparent when dealing with machines and systems that differ in shape, form, or function. Clearly, more principle-based understanding is needed to support transfer of learning to new and different contexts and situations.

The Cognitive Effort Required for Transfer (Low Road vs. High Road)

A second common dichotomy of transfer types involves how transfer actually occurs, that is, either automatically or with considerable cognitive effort (Perkins & Salomon, 1996). Automatic transfer, often called low-road transfer, occurs when skills are developed to a high level of automaticity and are then applied in similar or familiar situations. The cognitive effort required for low-road transfer is minimal because it occurs subconsciously as a result of the extensive practice that led to conditioned and reflexive behavior. This form of transfer often involves procedural skills such as driving. Driving skills can be developed to a level of near automatic performance, and transfer occurs easily because there is little variation in one automobile to the next.

In contrast, high-road transfer involves purposeful and conscious analysis of a situation to determine what prior learning can be applied in novel situations. In contrast to the automatic performance that occurs for low-road transfer, high-road transfer requires the mindful search for knowledge and strategies that can be applied in an unfamiliar situation. For example, the Pythagorean Theorem is typically taught as an abstract equation with little consideration for its practical application. In this sense, learning is decontextualized and has little meaning beyond the specific application in which it is taught. The opportunity for far transfer might occur later when the student is working on a summer construction job and discovers that Euclidean geometry can be used to determine if a wall is square. This form of transfer requires a conscious search of past experience because the problem is novel and has little direct similarity to the abstract equation that was learned previously.

COGNITIVE CONCEPTS THAT CONTRIBUTE TO SUCCESSFUL TRANSFER

At the core of every engineering and technology educator's teaching strategy is the presentation of content and practice in a systematic manner that is conducive to effective near and far transfer. In fact, according to Sutton (2003) and the International Technology Education and Engineering Association (ITEEA), technologically literate people must be able to transfer their knowledge and skills from one situation to another. Employers, however, often complain about students' inability to transfer concepts and procedures learned in the classroom to situations that are very different from the context in which it was learned. Failure by students in this critical area has caused many to question the effectiveness of the teaching strategies used. It is argued here and elsewhere that instructional strategies and concepts in technology education need to focus on broader, more abstract levels of learning and metacognitive understanding (Johnson, 1995). By placing greater importance on teaching cognitive strategies and skills, technology education students will be better prepared to transfer successfully their learning to new situations. The following section highlights several important cognitive concepts that contribute to successful transfer. These include metacognition, mental representations and analogical reasoning.

Metacognitive Skills and Transfer of Learning

Transferability of knowledge is not limited simply to acquisition of knowledge or possessing a cognitive ability to invoke the memory of a task done in the past. It also requires the engagement of executive control processes (i.e., metacognition) so that students understand under what conditions a particular task is best suited, develop strategies for applying their knowledge, monitor or regulate progress and evaluate the quality of the process and/or product.

The study of metacognition has become one of the hallmarks of psychological and educational theory and research. Students with good metacognitive skills are more knowledgeable of and responsible for their own cognition and thinking (Pintrich, 2002), and as a result, tend to learn better (Bransford, Brown, & Cocking, 1999; Chambres, Bonin, Izaute, & Marescaux, 2002; Case, Gunstone, & Lewis, 2001; Mokhtari & Reichard, 2002; Phelps, Ellis, & Hase, 2002). The results from these studies also suggest that metacognition improves learning and helps one improve transfer of what was learned to new situations.

It is clear that successful learning and transfer depends not only on having adequate knowledge but also sufficient metacognitive ability that involves awareness and control of that knowledge. Despite numerous research findings suggesting that the use of metacognition is essential in learning (Bransford, Brown, & Cocking, 1999; Clark & Mayer, 2003), it is a challenge to adopt metacognitive activities as an integral part of students' routine academic activities in school. This section will briefly discuss metacognition, how it differs from cognition, and its role in improving learning transfer.

In simple terms, metacognition is one's awareness of his/her own thinking or thinking about one's own thinking. Metacognition is an active monitoring process of one's cognitive activity (Brown, 1978; Kluwe, 1982; Schoenfeld, 1987). It also involves a process by which the brain organizes cognitive resources (Cuasay, 1992) and involves overseeing whether a cognitive goal has been met. As specific tasks are performed, individuals use this awareness to control their actions.

Flavell (1976), an early researcher in metacognition, divided it into two aspects: (a) *metacognitive knowledge* and (b) *metacognitive experiences or strategies*. He described metacognitive knowledge as "knowledge concerning one's own cognitive processes and products or anything related to them" (p. 232). It can lead someone to engage in or abandon a particular cognitive enterprise based on its relationship to his/her interests, abilities and goals. Metacognitive experiences or strategies, on the other hand, help one to plan, evaluate and regulate cognitive activities. Flavell also identified three different types of metacognitive knowledge: *person* (the knowledge a person has about him or herself and others as cognitive processors); *task* (the knowledge a person has about the information and resources necessary to undertake a task); and *strategy* (the knowledge regarding the strategies that are likely to be effective in achieving goals and undertaking tasks). These three components of metacognitive knowledge interact with each other and shape one's engagement in tasks.

From a different point of view, Pintrich (2002) divided metacognition into metacognitive knowledge and metacognitive control. Metacognitive knowledge refers to strategies that might be used for a particular task and knowledge of the conditions under which these strategies might be used. Metacognitive control is a cognitive process that learners use to monitor, control and regulate their cognition and learning. Despite differences in defining and categorizing metacognition, common elements are present in those definitions.

The difference between cognition and metacognition is based on functionality. While cognition concerns one's ability to build knowledge, information processing, knowledge acquisition and problem-solving, metacognition concerns one's ability to control the working of cognition to ensure that cognitive goals have been achieved (Flavell, 1979; Gourgey, 1998). It is also a process by which one becomes aware of any knowledge deficiency and takes necessary steps to overcome it (Chi, 2000). Metacognitive activity usually precedes and follows cognitive activity.

Mental Representation and Transfer of Learning

The extent and quality of learning transfer to solve a problem is also dependent upon the quality of the mental representations that students have of the problem. Mental representation is germane to the issue of learning transfer, especially when transferability is required within a context that is quite different from the context under which technological concepts and procedures were learned. It is therefore important that technology educators understand the underlying cognitive processes that support mental representation, (i.e., schema, naïve theories and mental models) and the role they play in the transfer of learning.

Schemata. Paivio (1990) describes schemata as mental structures that represent our general knowledge of objects, situations and events. According to Brewer (2001), as the mind is exposed to many different forms of content, the mind creates abstract cognitive representations that contain generic knowledge organized to form unconscious qualitative mental structures and processes. Hamilton and Ghatala (1994) indicated that schemata not only represent knowledge that can be verbalized about things and situations (declarative knowledge), but also general knowledge that guides our behavior (procedural knowledge).

Naïve theories. Like schemata, naïve theories are knowledge structures that are developed as people gain new knowledge. This coherent system of knowledge allows one to conceptualize causal explanations of phenomena, form questions about the unknown and make sensible predictions (Brewer, 2001). These cognitive structures are often referred to as intuitive, folk, naïve or common sense theories (Gelman, 1996). Naïve theories differ from scientific theories in that they are not as detailed, explicit, coherent or tested as scientific theories. Studies show that children use naïve theories to organize their experiences with the world into sensible and clearly delimited ontological groupings. Through naïve theories, students can make inferences about internal or invisible entities such as electron flow (Brewer, 2001). As schemata are modified with new episodic information, naïve theories are modified and improved as children gain knowledge that disconfirms their previously held theories.

Mental models. Mental models are subtypes of naïve theories. Brewer (2003) described mental models as cognitive representations of mechanical causal domains that allow students to explain and make predictions about these domains. They are unstable, subject to change and are often used to make decisions in novel situations. Various types of causal mental models can be used by the teacher to help students understand and predict the behavior of technical systems. These include general domain models, specific device models (Kieras & Boviar, 1984) and system models (Collins, 1985; Kempton, 1986).

General domain models are generic models that apply to a wide class of devices and systems within a domain. According to White and Frederiksen (1989), the electrical circuit depicted in Figure 1, which represents a general domain model, can accurately simulate the behavior of a large class of circuits, thus helping students solve a wide range of circuit problems. For example, the student can be asked to predict the state of a single device after a switch is closed, or to describe the behavior of the entire circuit as various switches are opened and closed, or to determine what faults are possible given the behavior of the circuit.

Specific device models have specific information about the physical characteristics of devices and their individual function. A drawing illustrating the location of buttons, levers, switches and indicators of a computer-controlled device, along with information that explains their functions, is a typical example of a device model. Figure 2 depicts the device model used by Kieras and Boviar (1984) in a study that examined how using a device model from the outset of instruction can facilitate better retention and reduce the time needed to execute a procedure.

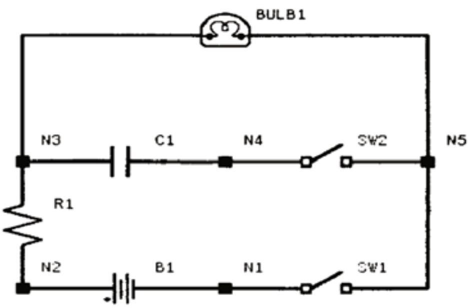


Figure 1. General domain model (White & Frederiksen, 1989).

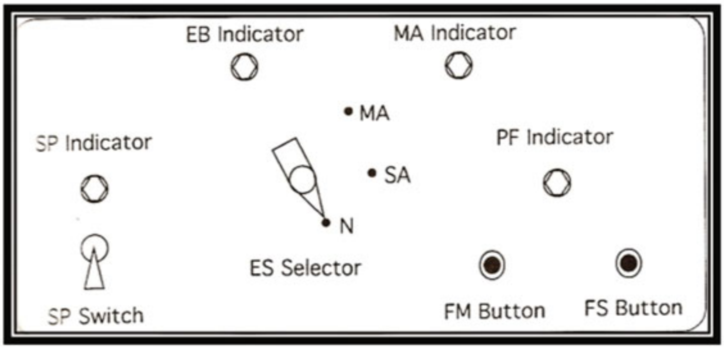


Figure 2. Device model used by Kieras and Bovair (1984).

Analogical Reasoning and Transfer of Learning

Analogical reasoning is regarded as a fundamental cognitive tool that supports transfer of learning (Ball, Ormerod, & Morely, 2004). Reasoning through the use of analogy occurs when similarities between two situations, concept, or phenomena are identified and the relevant information is mapped from the familiar to the less familiar (Mason, 2004). Analogies enable individuals to not only make connections to new phenomena but to also further elaborate their understanding of the known phenomena through a process called abstraction. This process is not only relevant to learning transfer in general, but is also particularly relevant during design problem-solving. The retrieval of prior knowledge to solve engineering design problems through the use of analogies is an important part of the design process. An example of the use of analogies during design problem-solving is George de Mestral's creation of Velcro® (Velcro Industries N.V., 2010). Noticing the cocklebur's ability to "stick" to clothing, de Mestral studied its features and was able to design a fabric fastener that contained similarities between cocklebur and the new design. This connection between known and new phenomena (in this context within design) is an important aspect of analogical reasoning.

Gentner's (1983, 1989) structure-mapping theory explains analogical reasoning through two primary processes: (a) structural alignment and (b) inference projection. Structural alignment enables learners to identify similarities between the familiar (base) and new (target) domains. Inferences about the target domain are based on what is already known about the base domain. Analogical reasoning is supported by the degree to which the base and target domains correspond (Markman & Gentner, 2001). Gentner's (1989) systematicity principle indicates that higher-order relationships, such as causal connections between the base and target domains, are preferable to isolated relations.

Transfer of learning through analogical reasoning "occurs when information and experiences from one known situation are retrieved and utilized in the search for the solution to an entirely different situation" (Magee, 2005, p. 33). Based on the structure mapping theory, Holyoak and Thagard (1997) developed a series of steps to explain how transfer of learning is accomplished through analogical reasoning. These steps include: (a) retrieval, (b) mapping, (c) inference and (d) learning. Previously learned analogies are accessed in the retrieval step and are mapped onto the target domain through the cognitive process of inference, which leads to understanding the new domain (i.e., learning). These general steps are applicable across most domains and can particularly inform the development of design abilities. For example, Dym and Little (2004) promoted the use of analogies to encourage creative, divergent thinking during engineering design. These basic analogical reasoning steps can be applied to the engineering design process. As Ball, Ormerod and Morely (2004) found in their study, engineering designers use analogical reasoning during the design process. Expert designers tend to use a specific type of analogical reasoning process called schema-driven analogizing, where they apply abstract knowledge to familiar problem types, developing a design solution.

Analogical transfer in problem-solving. Researchers have examined the role of analogical reasoning to support learning transfer in problem-solving contexts more generally. Magee (2005) argued, for example, that analogical transfer is "particularly well suited for problems whose solution requires creative thought" (p. 34). Studies examining analogical transfer in problem-solving have largely focused on spontaneous transfer (e.g., no hints are given to the subjects) or by using a base exemplar as a hint (Reeves & Weisberg, 1993). Subjects are typically presented with a novel problem and an analogous story that shares a solution principle (Clement, 1994).

Gentner and Markman (1997) summarized three generalizations that have emerged across these types of studies. The first is that transparency between the target and base domains appear to make analogical mapping easier for individuals. Second, subjects that possessed greater understanding of the base domain (i.e., experts) were better able to transfer their understanding under adverse conditions. Third, different types of similarities require individuals to rely on different sub- processes of transfer. According to Anolli et al. (2001), the evidence indicates that "people fail to transfer spontaneously the solution procedure described in the source to the target if they are not instructed about the source-target relationship" (p. 238). In addition to being aware of the analogous relationship, content and context appear to play a crucial role in the process (Markman & Gentner, 2001). Subjects are more likely to use analogies that share similar or overlapping content and contexts, resulting in a tendency toward near, rather than far, transfer (Reeves & Weisberg, 1993).

EDUCATIONAL IMPLICATIONS FOR USING COGNITIVE STRATEGIES TO SUPPORT TRANSFER

Whether students' prior knowledge is coherent or fragmented, the high level of awareness that students have of their own understanding helps them recognize when their knowledge can or cannot be reconciled with new data, ideas, concepts, conditions or contexts. In many instances, students try to understand new phenomena by creating a mental model that helps them predict how things will behave. Students often use analogical reasoning to bridge the known to the unknown. It is in this context that cognitive and metacognitive skills play an important role in the transfer of learning. Students who possess domain knowledge but monitor and control their cognition poorly may fail when solving problems; however, in contrast, metacognition can help compensate for lack of experience in solving problems (Schoenfeld, 1999). Thus, helping students gain cognitive skills and the ability to monitor their thinking and understanding of new concepts is essential for achieving successful transfer of learning.

Enhancing Transfer through Improved Metacognition

As with other knowledge, metacognitive understanding develops with age and experience (Garner & Alexander, 1989). It is an ongoing process that leads to an understanding of self as agent (McCombs & Marzano, 1990). Metacognition plays an important role in human learning at any level (e.g., K-12, post-secondary, organizations) and for any knowledge domain (e.g., language, science, technology, engineering and mathematics) to do all kinds of cognitive enterprises (e.g., reading, troubleshooting, case-study, design). Research shows that metacognition is teachable (Chan & Moore, 2006; Paris, 1986), and with proper instruction and practice, students are able to improve their degree of control over learning and master complex transfer problems (Takahashi & Murata, 2001). In this study, students in the metacognition instruction group were asked to evaluate the problem-solving process, the goal and the strategy to solve the problem. The findings suggested that by activating student metacognition, students in the metacognition group are better able to understand their degree of progress and require less time to solve transfer problems compared with those in the control group. In another study, Steif, Lobue, Kara and Fay (2010) found that having students taught through discussion about salient problem features in statics improves students' problem-solving skills. The use of metacognitive prompts that initiate systematic discussion helps students develop a better mental representation and monitor their problem-solving process. This finding is consistent with research on self-explanation, where students who generate more explicit and deeper explanations of the process outperform students who generate fewer or shallower explanations (Chi, de Leeuw, Chiu, & LaVancher, 1994). These abilities are essential for engineering and technology education, particularly for solving design problems.

Design problems are ubiquitous, complex and ill-structured, and they offer substantial challenges to students and professional engineering designers. Solving an engineering design problem is a structured and staged process. The ways in which students use strategies, observe what transpires and search for alternative solutions illustrate how metacognition is applied in design activities. Furthermore, metacognitive skills “help students become active participants” (Paris & Winograd, 1990, p. 18) to solve problems that involve ambiguous specification of goals with no predetermined solution path and often require the integration of multiple knowledge domains (Reitman, 1965; Simon, 1973). Instructional strategies that provide scaffolding (e.g., cooperative learning, peer-tutoring, reciprocal teaching, self-explanation) encourage students to experience and practice using both cognitive and metacognitive strategies and evaluate the outcomes of their efforts, which may improve their degree of control over learning and performance.

Teaching for transfer involves linking new knowledge to existing schemata, naïve theories and mental models of students, and reorganizing these cognitive structures where necessary. This adds relevance to the new information that is being learned and also enables students to begin the process of modifying their inaccurate models and theories. An effective way to link new knowledge with existing knowledge and procedures is through concept maps. Concept maps are used to improve problem-solving in many knowledge domains (Lee & Nelson, 2005). They have been used successfully to enable learners to interpret problems (Zhang, 1997), remember important information while solving problems and become aware of new relations among the concepts that are embedded in a problem (Hayes, 1989). For example, if the instructor is teaching about the concept of energy and its use in technology, she could brainstorm with the class while generating a concept map of the different ideas on a flip chart or on the whiteboard. An alternative approach would be to place the students in groups and allow them to generate their own concept maps of energy and its use in technology (see Figure 3).

Teaching students about complex systems and their inter-related components can also be challenging. Barak and Williams (2007) found that by exposing students to block diagrams, they can learn to identify basic variables within a system, such as input, output, feedback and distortion; explore dynamic phenomena in a system; distinguish between dynamic analysis and steady-state analysis; and recognize the difference between the real system and the model. However, as these authors stated, describing a system through a model is not an easy task. Using schematic diagrams is also challenging, because their level of detail can detract the students from understanding the general concept of the system’s operation. A variation of concept maps, called functional flow diagrams, can remove or reduce the complexity of schematics and improve students’ overall mental representation and conceptual understanding of the causal behavior of systems (Johnson & Satchwell, 1993; Satchwell, 1996). An example is illustrated in Figure 4.

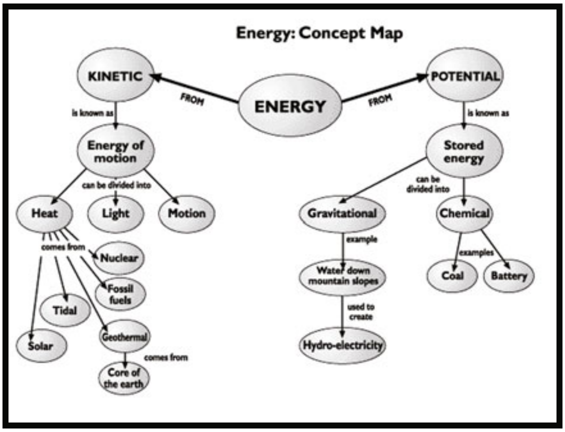
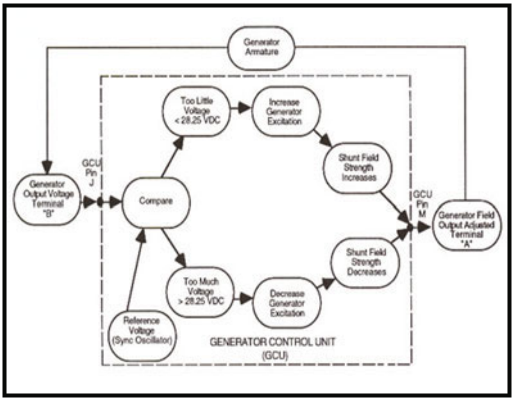


Figure 3. Concept map of energy (retrieved from www.hydro.com.au/education/discovery/concept1.html)

a



b

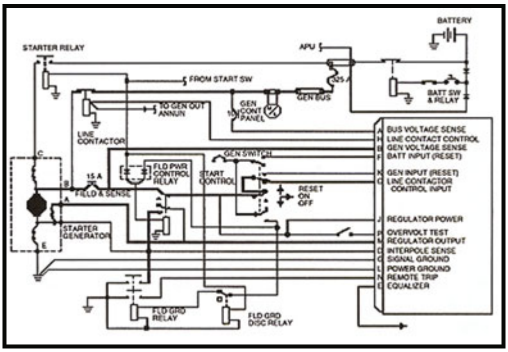


Figure 4. A functional flow diagram (a) and schematic diagram (b) of a system (Johnson & Satchwell, 1993; Satchwell, 1996).

Hands-on experience with troubleshooting and problem-solving is important in order for students to develop mental representations of similar systems they will encounter later in the real world and at their workplaces. For example, the understanding of system concepts such as feedback and control can be deepened by inviting students to design and assemble a real pneumatic or hydraulic system in similar or related contexts. In addition, the expertise and creativity of students will improve with increased hands-on, deliberate practice at designing, problem-solving and troubleshooting. Using simulation to supplement hands-on activities can also enhance students' mental representation of complex systems. According to Spector (2000), simulation provides an opportunity for students to analyze systems of different levels of complexity, explore dynamic phenomena that are difficult to follow in real conditions, and examine models and conditions that cannot be physically created.

Research shows that experts represent problems by their conceptual features while novices represent problems primarily by their surface features. In fact, in designing, Ball, Ormerod and Morely (2004) found that experts use more schema-driven analogies (i.e., analogies that have similar conceptual structures) while novices primarily use case-driven analogies (i.e., analogies that have similar surface features). These findings underscore the importance of exposing students to a variety of problems that have different surface features, but bear the same underlying conceptual structure, in order to develop proper mental representations of concepts that govern the operation of systems. For example, a technology teacher could teach the concepts of mechanical advantage and velocity ratio by allowing students to experiment with gears, pulleys, clutches, hydraulic and pneumatic systems. A similar pedagogical strategy can be used when teaching ill-structured problems such as engineering design. Solving ill-structured problems help students learn to think systematically and qualitatively. Transfer of general principles can be enhanced by teaching multiple cases that have different surface features, but require similar underlying concepts for solution. By explicitly comparing various cases, students can abstract the underlying concepts that make them similar and develop the ability to transfer general principles to real-world problems (Gentner, Leowenstein, & Thompson (2005).

Enhancing Transfer through Improved Analogical Reasoning

Many scholars have pointed out the benefits of analogical reasoning as a cognitive tool across many different educational contexts, including science (Gibson, 2008), technology (Daugherty & Mentzer, 2008), computer programming (Lai & Repman, 1996), grammar (Vokey & Higham, 2005) and auditing (Marchant, 1989). Teaching via analogical reasoning "facilitates the coding and organization of knowledge, improved access and retrieval of knowledge from memory and reduction of misconceptions" (Mason, 2004, p. 295). Numerous instructional strategies have been developed to support analogical reasoning, including teaching-with-analogy (Glynn, 1989), bridging analogies (Brown & Clement, 1989), multiple analogies (Spiro, Feltovich, Coulson, & Anderson, 1989) and student-generated analogies (Wong, 1993).

These instructional strategies all recognize that learners should first have a clear understanding of their existing base domain knowledge so they can access the relevant information that is structurally similar to the new target domain. Mason (2004) cautioned that if learners do not have a sufficient understanding of the base domain, misconceptions can result by mapping non-relevant or surface features to target domains that are either incorrect or lead to inappropriate comparisons. Also, many studies have shown that individuals have trouble transferring knowledge between vastly different analogous situations. This is largely due to the challenge that individuals face in accessing the relevant knowledge from memory (Clement, 1994).

Mandrin and Preckel (2009) argued that learning through analogical reasoning "requires a high level of guidance and learning hints" (p. 135). Instructional approaches should thus stimulate comparisons and develop learners' awareness of similarities in their pursuit of learning. For example, Reeves and Weisburg (1993) advocated for the use of concrete examples and scaffolded analogical transfer problems that become increasingly more abstract and different in terms of content. Instructors can help students map newly learned principles to surface feature similarities. Subsequent problems should be increasingly different in content to lead toward more abstract understanding of the principles. Similarly, case-based reasoning is a pedagogical technique for developing cognitive understanding to assist students in making useful analogical inferences (Kolodner, 1997). Case-based reasoning uses computational modeling to understand the roles of encoding, retrieval and adaptation in analogical reasoning processes. This line of research has educational implications including the need for students to be motivated to learn by applying their learning to real-world problems. Cases can provide this motivation by suggesting "issues to focus on and solutions to problems, warn of potential pitfalls, support projection of the effects of a chosen solution and so on, facilitating solution of more complex problems" (Kolodner, 1997, p. 62).

Daugherty and Mentzer (2008) explored the viability of instructional strategies that utilize analogical reasoning within a technology education context. They argued that instructors could model analogical reasoning for their technology education students. For example, a schema for systems theory (input → process → output with feedback loops) can be used to transfer understanding through analogical reasoning. By understanding how system components are interconnected, students can transfer that understanding to how the components of other technological devices interact. Daugherty and Mentzer offered inter-modal transportation as an example, wherein students can be encouraged to map the inputs (cargo), the processes (containerization) and the outputs (shipping, globalization, economic growth, etc.). Such explicit modeling of cognitive processes and analogical reasoning could significantly improve thinking and understanding in a technology education context.

CONCLUSIONS

This chapter highlighted the importance of fostering transfer of learning by focusing on cognitive and metacognitive principles. Building a deep understanding of knowledge and skills, with a base in underlying principles, is critical for learning that transfers to new and unfamiliar situations. By providing students with carefully selected learning experiences accompanied by scaffolded and problem-based instruction, engineering and technology education can serve as a vehicle for addressing the many challenges of learning transfer.

As highlighted by Perkins and Saloman (1992), the research on transfer is discouraging because most studies suggest that transfer is difficult to achieve for many reasons. However, upon closer examination of the conditions under which transfer occurs and the cognitive mechanisms that support learning transfer, we are left with a much more positive perspective. Education through engineering and technology education can achieve significant success in promoting transfer if it is properly designed in ways that support learning beyond superficial understanding.

REFERENCES

Anolli, L., Antonietti, A., Crisafulli, L., & Cantoia, M. (2001). Accessing source information in analogical problem-solving. *Quarterly Journal of Experimental Psychology*, *54A*(1), 237–261.

Ball, L. J., Ormerod, T. C., & Morely, N. J. (2004). Spontaneous analogising in engineering design: A comparative analysis of experts and novices. *Design Studies*, *25*, 495–508.

Bayles, E. E. (1936). A factor unemphasized in current theories regarding the transfer of training. *Journal of Educational Psychology*, *27*(6), 425–430.

Beach, K. D. (1999). Consequential transitions: A sociocultural expedition beyond transfer in education. In A. Iran-Nejad & P. D. Pearson (Eds.), *Review of research in education* (Vol. 24, pp. 101–140). Washington, DC: American Educational Research Association.

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. In A. Iran-Nejad & P. D. Pearson (Eds.), *Review of research in education* (Vol. 24, pp. 61–101). Washington, DC: American Educational Research Association.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience and school*. Washington, DC: National Academy Press.

Brewer, W. (2001). Models in science and mental models in scientists and nonscientist. *Mind and Society*, *2*, 33–48.

Brewer, W. (2003). Mental models. In L. Nadle (Ed.), *Encyclopedia of cognitive science* (Vol. 3, pp. 1–5). London: Nature Publishing Group.

Brown, A. L. (1978). Knowing when, where and how to remember: A problem of metacognition. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 1, pp. 225–253). Hillsdale, NJ: Erlbaum.

Brown, D. E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science*, *18*, 237–261.

Case, J., Gunstone, R., & Lewis, A. (2001). Students' metacognitive development in an innovative second year chemical engineering course. *Research in Science Education*, *31*(3), 313–335.

Chambres, P., Bonin, D., Izaute, M., & Marescaux, P. J. (2002). Metacognition triggered by social aspect of expertise. In P. Chambres, M. Izaute, & P. J. Marescaux (Eds.), *Metacognition process, function and use* (pp. 153–168). Norwell, MA: Kluwer.

Chan, L. K. S., & Moore, P. J. (2006). Development of attributional beliefs and strategic knowledge in Years 5 to 9: A longitudinal analysis. *Educational Psychology*, *26*(2), 161–185.

Chi, M. T. H., de Leeuw, N., Chiu, M. H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science*, *18*, 439–477.

Chi, M. T. H. (2000). Self-explaining expository texts: The dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.), *Advances in instructional psychology* (pp. 161–238), Hillsdale, NJ: Erlbaum.

Clark, R. E., & Voogel, A. (1985). Transfer of training principles for instructional design. *Educational Communication and Technology Journal*, *33*(2), 113–123.

Clark, R. V., & Mayer, R. E. (2003). *E-learning and the science of instruction*. San Francisco: Pfeiffer.

Clement, C. A. (1994). Effect of structural embedding on analogical transfer: Manifest versus latent analogs. *American Journal of Psychology*, *107*(1), 1–38.

Collins, A. (1985). Component models of physical systems. In *Proceedings of the seventh annual conference of Cognitive Science Society* (pp. 80–89). Irvine, CA: Cognitive Science.

Cuasay, P. (1992). Cognitive factors in academic achievement. *Higher Education Extension Service*, *3*(3), 1–8.

Daugherty, J., & Mentzer, N. (2008). Analogical reasoning in the engineering design process and technology education applications. *Journal of Technology Education*, *19*(2), 7–21.

Dym, C. L., & Little, P. (2004). *Engineering design: A project based approach* (2nd ed.). Hoboken: Wiley.

Flavell, J. H. (1976). Metacognitive aspects of problem solving. In L. B. Resnick (Ed.), *The nature of intelligence* (pp. 231–236). Hillsdale, NJ: Erlbaum.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive developmental inquiry. *American Psychologist*, *34*, 906–911.

Garner, R., & Alexander, P. A. (1989). Metacognition: Answered and unanswered questions. *Educational Psychologist*, *24*, 143–158.

Gelman, S. A. (1996). Concept and theories. In R. Gelman & T. Kit-Fong Au (Eds.), *Perceptual and cognitive development: Handbook of perception and cognition* (2nd ed., pp. 117–150). San Diego, CA: Academic Press.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*, *7*, 155–170.

Gentner, D. (1989). The mechanisms of analogical learning. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 199–241). Cambridge, MA: Cambridge University Press.

Gentner, D., Loewenstein, J., & Thompson, L. (2003). Learning and transfer: A general role for analogical encoding. *Journal of Educational Psychology*, *95*(3), 393–408.

Gentner, D., & Markman, A. B. (1997). Structure mapping in analogy and similarity. *American Psychologist*, *52*(1), 45–56.

Gibson, K. (2008). Analogy in scientific argumentation. *Technical Communication Quarterly*, *17*(2), 202–219.

Glynn, S. M. (1989). The teaching with analogies model. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 199–241). Cambridge, MA: University Press.

Gourgey, A. (1998). Metacognition in basic skills instruction. *Instructional Science*, *26*(1–2), 81–96.

Greeno, J., Smith, D. R., & Moore, J. L. (1993). Transfer of situated learning. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition and instruction* (pp. 99–167). Norwood, NJ: Ablex.

Hamilton, R., & Ghatala, E. (1994). *Learning and instruction*. New York: McGraw-Hill.

Hayes, J. R. (1989). *The complete problem solver* (2nd ed.). Hillsdale, NJ: Erlbaum.

Holyoak, K. J., & Thagard, P. (1997). The analogical mind. *American Psychologist*, *52*(1), 35–44.

Johnson, S. D. (1995). Transfer of learning. *The Technology Teacher*, *54*(7), 33–35.

Johnson, S. D., & Satchwell, R. E. (1993). The effect of functional flow diagram on apprentice aircraft mechanics' technical system understanding. *Performance Improvement Quarterly*, *6*(4), 73–91.

Judd, C. H. (1936). *Education as cultivation of higher mental processes*. New York: Macmillan.

Kempton, W. (1986). Two theories of home heat control. *Cognitive Science*, *10*, 75–90.

Kieras, D. E., & Bovair, S. (1984). The role of a mental model in learning to operate a device. *Cognitive Science*, *8*, 363–385.

Kluwe, R. H. (1982). Cognitive knowledge and executive control: Metacognition. In D. R. Griffin (Ed.), *Animal mind-human mind* (pp. 201–224). New York: Springer-Verlag.

Kolodner, J. L. (1997). Educational implications of analogy: A view from case-based reasoning. *American Psychologist*, *52*(1), 57–66.

Lai, S. L., & Repman, J. L. (1996). The effects of analogies and mathematics ability on students' programming learning using computer-based learning. *International Journal of Instructional Media*, *23*(4), 355–364.

Leberman, S., McDonald, L., & Doyle, S. (2006). *The transfer of learning*. Burlington, VT: Gower.

Lee, Y., & Nelson D. W. (2005). Viewing or visualizing-which concept map strategy works best on problem-solving performance? *British Journal of Educational Technology*, *36*(2), 193–203.

Magee, G. B. (2005). Fostering understanding by structural alignment as a route to analogical learning. *Journal of Economic Behavior & Organization*, *57*, 29–48.

Mandrin, P., & Preckel, D. (2009). Effect of similarity-based guided discovery learning on conceptual performance. *School Science and Mathematics*, *109*(3), 133–145.

Marchant, G. (1989). Analogical reasoning and hypothesis generation in auditing. *The Accounting Review*, *64*(3), 500–513.

Markman, A. B., & Gentner, D. (2001). Thinking. *Annual Review of Psychology*, *52*, 223–247.

Mason, L. (2004). Fostering understanding by structural alignment as a route to analogical learning. *Instructional Science*, *32*, 293–318.

McCombs, B. L., & Marzano, R. J. (1990). Putting the self-regulated learning: The self as agent in integrating will and skill. *Educational Psychologist*, *25*(1), 51–69.

Mokhtari, K., & Reichard, C. A. (2002). Assessing students' metacognitive awareness of reading skills. *Journal of Educational Psychology*, *94*(2), 249–259.

Paivio, A. (1990). *Mental representations*. New York: Oxford University Press.

Paris, S. G. (1986). Teaching children to guide reading and learning. In T. Raphael (Ed.), *Contexts of school-based literacy* (pp. 115–130). NY: Random House.

Paris, S. G., & Winograd, P. (1990). Metacognition in academic learning and instruction. In B. F. Jones (Ed.), *Dimension of thinking and cognitive instruction* (pp. 15–44). Hillsdale, NJ: Erlbaum.

Perkins, D. N., & Salomon, G. (1988). Teaching for transfer. *Educational Leadership*, *46*(1), 22–32.

Perkins, D. N., & Salomon, G. (1992). Transfer of learning. In *International encyclopedia of education*. Oxford: Pergamon Press.

Perkins, D. N., & Salomon, G. (1996). Learning transfer. In A. C. Tuijnman (Ed.), *International encyclopedia of adult education and training* (2nd ed., pp. 422–427). Tarrytown, NY: Pergamon.

Phelps, R., Ellis, A., & Hase, S. (2002). *The role of metacognitive and reflective learning processes in developing capable computer users*. Paper presented at the 18th annual conference of the Australasian Society for Computers in Learning in Tertiary Education (ASCILITE) (pp. 481–490), Melbourne.

Pintrich, P. R. (2002). The role of metacognitive knowledge in learning, teaching and assessing. *Theory into Practice*, *41*(4), 219–225.

Reeves, L. M., & Weisberg, R. W. (1993). On the concrete nature of human thinking: Content and context in analogical transfer. *Educational Psychology*, *13*(3/4), 245–258.

Reitman, W. R. (1965). *Cognition and thought*. New York: Wiley.

Resnick, L. B. (1987, December). Learning in school and out. *Educational Researcher*, *16*, 13–20.

Royer, J. M. (1986). Designing instruction to produce understanding: An approach based on cognitive theory. In G. D. Phye & T. Andre (Eds.), *Cognitive classroom learning: Understanding, thinking and problem solving* (pp. 83–117). New York: Academic Press.

Royer, J. M., Mestre, J. P., & Dufresne, R. J. (2005). Introduction: Framing the transfer problem. In J. P. Mestre (Ed.), *Transfer of learning: From a modern multidisciplinary perspective*. Greenwich, CT: Information Age Publishing.

Satchwell, R. E. (1997). Functional flow diagrams to enhance technical system understanding. *Journal of Industrial Teacher Education*, *34*(2), 50–81.

Schoenfeld, A. H. (1987). What's all the fuss about metacognition? In A. H. Schoenfeld (Ed.), *Cognitive science and mathematics education* (pp. 189–215). Hillsdale, NJ: Erlbaum.

Schoenfeld, A. H. (1999). Looking toward the 21st century: Challenges of educational theory and practice. *Educational Researcher*, *28*(7), 4–14.

Simon, H. A. (1973). The structure of ill-structured problems. *Artificial Intelligence*, *4*, 145–180.

Spector, J. M. (2000). System dynamics and interactive learning environments: Lessons learned and implications for the future. *Simulation & Gaming*, *31*(4), 509–512.

Spiro, R. J., Feltovich, P. J., Coulson, R. L., & Anderson, D. K. (1989). Multiple analogies for complex concepts: Antidotes for analogy-induced misconception in advanced knowledge acquisition. In S. Vosniadou & A. Ortony (Eds.). *Similarity and analogical reasoning* (pp. 498–531). Cambridge, MA: Cambridge University Press.

Steif, P. S., Lobue, J. M., Kara, L. B., & Fay, A. L. (2010). Improving problem solving performance by inducing talk about salient problem features. *Journal of Engineering Education*, *99*(2), 135–142.
Sutton, M. J. (2003). Problem representation, understanding and learning transfer: Implications for technology education research. *Journal of Industrial Teacher Education*, *40*(4), 47–61.
Takahashi, Y., & Murata, A. (2001). Role of metacognition to promote strategy transfer in problem solving. *Proceedings of IEEE International Conference on Systems, Man and Cybernetics*, *5*, 2787–2792. doi:10.1109/ICSMC.2001.971931
Thorndike, E. L. (1924). Mental discipline in high school studies. *Journal of Educational Psychology*, *15*, 1–22.
Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review*, *8*, 247–261.
Velcro Industries N. V. (2010). *Who is Velco USA Inc.*? Retrieved May 17, 2010, from www.velcro.com/index.php?page=company
Vokey, J. R., & Higham, P. A. (2005). Abstract analogies and positive transfer in artificial grammar learning. *Canadian Journal of Experimental Psychology*, *59*(4), 54–61.
White, B. Y., & Frederiksen, J. R. (1986). *Intelligent tutoring systems based upon qualitative model evaluations*. Available at http://www.aaai.org/Papers/AAAI/1986/AAAI86-052.pdf
Wong, E. D. (1993). Self-generated analogies as a tool for construction and evaluating explanations of scientific phenomena. *Journal of Research in Science Teaching*, *30*, 367–380.
Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science*, *21*, 179–217.

Scott D. Johnson
Raymond Dixon
University of Illinois

Jenny Daugherty
Purdue University

Oenardi Lawanto
Utah State University

PART II:
DIMENSIONS OF HUMAN DEVELOPMENT: COMPETENCES, KNOWLEDGE AND SKILLS

MARC J. DE VRIES

5. A CONCEPT-CONTEXT FRAMEWORK FOR ENGINEERING AND TECHNOLOGY EDUCATION

Reflections on a Delphi Study

INTRODUCTION

In Part A of this book, some important learning theories have been discussed. They are concerned with the 'how' of teaching and learning. In this chapter, we move to the 'what' of teaching and learning. I will describe a framework for developing the content of Engineering and Technology Education (ETE). Thereby I will focus on basic concepts that constitute the discipline of Engineering and Technology Education. But content cannot be separated entirely from the teaching and learning strategies that are needed to turn these concepts into teachable and learnable content. In particular I will build upon the theories of constructivism and situated cognition (see Chapter 1). I will also show how this disciplinary framework is not only useful for developing education that prepares for further study (in engineering), but – even more importantly – for the technological literacy that each and every citizen needs in order to live in a technological world and have control over technology in her or his life.

CONCEPTS FOR ENGINEERING AND TECHNOLOGY EDUCATION

The Need for a Conceptual Framework for ETE

Technology Education has always struggled with its identity as a body of knowledge distinct from other school subjects. One could, of course, claim that this problem is not important for Technology Education, as this element in the school curriculum is not so much concerned with theory, but rather with skills. When Technology Education emerged out of various types of craft education, the scope of these skills broadened from merely making skills (handicraft) into a combination of designing and making skills. Later, when social issues also became a more prominent part of Technology Education, the range of skills was further extended with technology assessment skills. But knowledge seemed not to be a major concern. In light of what was considered to be the nature of technology, this was no surprise. For a long time, technology was thought to be equal to "applied science." As a consequence, the knowledge in technology was considered to be not really new knowledge, different from scientific knowledge, but just the application of that knowledge. It was only later that in the philosophy of technology it was acknowledged that technology

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 75–87.

does have its own knowledge, different from science. It was in particular the work of historian Walther Vincenti that brought about this awareness. In his now classic book What Engineers Know and How They Know It (1990), he presented a taxonomy of technological knowledge types and also showed that science only contributes to a minority of the types in his taxonomy. Knowledge in the other types must be derived from other sources, such as design experience, empirical engineering experiments and direct trial. Since then, philosophers of technology have been active in identifying characteristics of technological knowledge (for instance, the normativity that features in various types of technological knowledge; see Meijers and De Vries, 2009).

The term "Engineering and Technology Education" suggests a broadening of Technology Education by adding the "Engineering" component. This enhances the need to identify the knowledge base for this domain, as knowledge and theories play a vital part in engineering. For such a domain, it is absolutely necessary to have clear ideas of what constitutes its knowledge base. But how can one formulate this without ending up with an endless list of detailed knowledge elements that become easily outdated because of the dynamics of engineering and technology, or that one needs a core of basic concepts that are time-independent and will remain relevant over time. There are several ways that could lead to the identification of such a core. The first is a theoretical one. In the philosophy of technology, studies have been done in technological knowledge, as was mentioned earlier. One could try to derive a core of concepts from those philosophical reflections that could serve as a conceptual framework for Engineering and Technology Education. In doing this, one could also include the work of some technology education specialists who have written about concepts in engineering. In this respect, the work of colleagues from former Eastern European countries are an interesting source (Blandow 1992; Wolfgramm 1994)[1]. In the "polytechnic" education, as it used to be called, a strong focus had been placed on general technological concepts and theories. It was the political changes more than progression in insights that made the work of these colleagues obsolete (at least, in the eyes of the educational policy-makers in those countries). Their work remains valuable for today when we search for concepts and theories that could constitute a basis for Engineering and Technology Education. But there is also a more empirical route towards a conceptual framework for Engineering and Technology Education. One could consult colleagues who have systematically reflected on the theoretical basis of Engineering and/or Technology Education. The insights that these colleagues have gained over the years can become even more useful when confronted with each other and with the insights from the philosophy of technology. One way of accomplishing such a confrontation is by conducting a Delphi study. This is what was done in the summer of 2009 by a small international group of researchers[2].

A DELPHI STUDY INTO THE CONCEPTS AND CONTEXTS OF ENGINEERING AND TECHNOLOGY EDUCATION

About 30 international colleagues in Technology Education, Engineering Education and the Philosophy of Technology were asked to generate concepts of engineering and technology that they considered to be core concepts in these domains. After a first round of responding to concepts that were suggested by the researchers and adding their own concepts, two rounds followed in which the experts were confronted with each others' concepts and given the opportunity to rethink and re-rank the entire set of concepts. Following the (fairly loose) criteria, the researchers were able to establish a consensus after these three rounds. The fact that these criteria are rather loose gives the Delphi method a certain vulnerability, about which it is often criticised. But it is still used in spite of its weaknesses also by researchers of high reputation (for instance, Osborne, Collins, Radcliffe, Millar and Duschl (2003). The outcomes of the Delphi study were discussed by a small panel of experts, some of whom had been part of the Delphi group, and others examined the results with an entirely fresh view. The main aim of this exercise was to structure the list of concepts and contexts that had been generated by the Delphi study. The total list of concepts was divided into the most basic concepts and other concepts that were regarded to be subsumable under those basic concepts. For instance, the concepts 'materials,' 'energy' and 'information' were subsumed under the core concept of 'resources.' The outcome was a concise list of concepts that will now be presented and discussed.

CONCEPTS FOR ENGINEERING AND TECHNOLOGY EDUCATION

The outcome of the Delphi study was a list of concepts presented in Table 1[3].

Without giving meaning to the terms in this table, they remain empty words. Therefore, I will now discuss this meaning, thereby drawing on both the remarks made by experts during the Delphi study and the insights from the philosophy of technology.

Table 1. Concepts list

Main concept	*Sub-concepts*
Designing ('design as a verb')	Optimising Trade-offs Specifications Technology Assessment Inventing
Modelling	(no sub-concepts mentioned in the Delphi study; one can think of abstraction and idealization)
Systems	Artefacts ('design as a noun') Structure Function
Resources	Materials Energy Information
Values	Sustainability Innovation Risk/failure Social interaction

The term ‘design’ (as a verb, or ‘designing’) has been the object of considerable reflection and research[4]. Designing is the type of problem-solving in which a design problem is solved. This differentiates it from other types of problem-solving, such as fixing a malfunctioning device or solving a cryptogram puzzle. Designing is a human activity that leads from a practical problem to a solution that usually takes the shape of an artefact. In designing, people seek a material realisation for a practical function that is to be fulfilled. Apart from the requirement of fulfilling the function, there are usually a variety of other requirements related to other aspects of the problem (price, legislation, aesthetic considerations, the psychology of the user, etc.). A design problem would not be a problem if there no conflicts would exist between requirements. Designers somehow have to solve these conflicts, either by trade-offs or by creatively redefining the requirements. Creativity is what sparks the moment of invention, the moment of finding a possible solution for a problem ‘out of the blue.’ By assessing a possible solution against the requirements, redesigning it, and repeating this in a number of cycles, an optimised solution that fits best with all requirements is gradually reached. The problem is seldom approached immediately in its full complexity. Rather, designers make a simplified version of the problem. That is what modelling, the second basic concept, is about: reducing complexity by first leaving out the less essential aspects (abstraction) and replacing irregular features of the problem with more regular ones (idealisation). An example of abstraction is: leaving out the aspect of colour when designing a new chair and focusing only on shape; an example of idealisation is to replace the complex form of the chair by a simpler one when calculating forces on the chair.

In this short description, I have shown the role of the various sub-concepts of designing and of the concept of modelling. In this description, I have also used terms that have not made their way into the table, but still can be seen as useful sub-concepts for designing (for instance, problem-solving and creativity). These did get mentioned in the Delphi study but were considered to be of less importance than the concepts appearing in the table. Some concepts did not make it in spite of the fact that they do get attention in the philosophy of technology. An example of this is the concept of heuristics, which is sometimes even considered to be the very basis of engineering methods (Koen, 2006). Heuristics differ from algorithms in that they are rather loose search rules that do not necessarily lead to success. An example of a heuristic is: trying the inversion of certain parts of the design (e.g., changing up into down or left into right). Clearly, the Delphi study need not be seen to be conclusive or exclusive here. But the Delphi study did identify a number of important concepts related to designing.

The third basic concept in the table is ‘systems.’ Already in early efforts to identify the core concepts of technology, such as the book The Man-Made World, the concept of ‘systems’ was in this core (Truxall and Piel, 1971). It also features prominently in the Standards for Technological Literacy document developed in the USA[5]. The content of this concept varies in different literature references and could take two directions: (1) the input-process-output approach; and (2) the approach of systems as a combination of parts (‘sub-systems’) that work together. Both are useful approaches and are in fact complementary. The fourth concept is that of resources.

and technology that they considered to be core concepts in these domains. After a first round of responding to concepts that were suggested by the researchers and adding their own concepts, two rounds followed in which the experts were confronted with each others' concepts and given the opportunity to rethink and re-rank the entire set of concepts. Following the (fairly loose) criteria, the researchers were able to establish a consensus after these three rounds. The fact that these criteria are rather loose gives the Delphi method a certain vulnerability, about which it is often criticised. But it is still used in spite of its weaknesses also by researchers of high reputation (for instance, Osborne, Collins, Radcliffe, Millar and Duschl (2003). The outcomes of the Delphi study were discussed by a small panel of experts, some of whom had been part of the Delphi group, and others examined the results with an entirely fresh view. The main aim of this exercise was to structure the list of concepts and contexts that had been generated by the Delphi study. The total list of concepts was divided into the most basic concepts and other concepts that were regarded to be subsumable under those basic concepts. For instance, the concepts 'materials,' 'energy' and 'information' were subsumed under the core concept of 'resources.' The outcome was a concise list of concepts that will now be presented and discussed.

CONCEPTS FOR ENGINEERING AND TECHNOLOGY EDUCATION

The outcome of the Delphi study was a list of concepts presented in Table 1[3].

Without giving meaning to the terms in this table, they remain empty words. Therefore, I will now discuss this meaning, thereby drawing on both the remarks made by experts during the Delphi study and the insights from the philosophy of technology.

Table 1. Concepts list

Main concept	*Sub-concepts*
Designing ('design as a verb')	Optimising Trade-offs Specifications Technology Assessment Inventing
Modelling	(no sub-concepts mentioned in the Delphi study; one can think of abstraction and idealization)
Systems	Artefacts ('design as a noun') Structure Function
Resources	Materials Energy Information
Values	Sustainability Innovation Risk/failure Social interaction

means. In a similar way, one can break down the concept of 'risk' by noting that this concept deals with the consequences of an action and the chance of some of these forming a threat to safety, health, privacy or other goods. Thus, at least four notions can be related to the concept of 'risk.' One more example is 'functions.' This concept is often described as a transition from a given state of affairs to a different state of affairs that has certain desired characteristics. This transition is not an accidental one but an intended one. Again, we have analysed the sub-concept in terms of certain underlying notions.

CONTEXTS FOR ENGINEERING AND TECHNOLOGY EDUCATION

The Need for Contexts in Engineering and Technology Education

We have now seen which concepts can be used for teaching about engineering and technology. But what is the nature of these concepts? Can they be observed directly in the practice of engineering and technology? This is not the case. What one sees in reality is, for instance, not systems, but cars, houses, mobile phones, fast-food stores, bridges, etc. The concept of 'systems' has a model character. It captures some aspects that these cars, houses, etc. have in common and leaves out all sorts of peculiarities. It is an abstraction. As soon as we turn from the abstract concept of 'systems' to a concrete object, like a car or a house, we will notice that this concept of 'systems' takes a different shape in each concrete manifestation[7]. This is why nowadays we use the term 'situated cognition': knowledge of these concepts cannot exist without the 'texture' that is created by the concrete situation in which the learner finds the concept (Hennessey, 1993). A car is a system, but not in the same way that a house is. Both are parts that work together, but in the case of the car, this results in motion and in the case of the house, not. That is why designers need knowledge not only of systems in general, but also more specific knowledge that applies to cars (for a car designer) or houses (for an architect). This poses a challenge to education. How do we deal with abstractions knowing that they take different shapes in different manifestations and that learners may have problems with recognition of the general features that define the concept? There was a time in which we believed that it was possible to teach the concept at an abstract level right away, and that the learners were able to 'apply' the general notions to specific situations. But that appeared to be too optimistic. Later, we believed that it would suffice to teach the general concept in a concrete situation, help the learner to make the step of generalisation to the understanding of the general concept, and then leave it to the learner to 'transfer' that knowledge to other situations. That, too, appeared to be problematic for many learners. More recently, education specialists proposed a more complicated approach. In the concept-context approach, the learner is taken through a variety of situations, or contexts, in which different manifestations of the same general concepts are present. Gradually the learner begins to understand the communalities between the manifestations and acquires the general concept. By then the understanding has become so versatile that it is no longer a problem to apply the concept to a new situation in which process the concept again takes a different concrete shape, but is still identified as a manifestation of the same abstract concept.

Here is still a debate as to what proper contexts are. Some experts believe that it suffices if the contexts are concrete situations that can be recognized or imagined by the learner. Other people put more demands on contexts and want them to be practices in which the learner herself or himself is involved (Pilot and Bulte, 2006; Bulte, Westbroek, De Jong and Pilot, 2006). Practices are coherent sets of activities aimed at a certain goal. Such practices can be travelling from home to school, living in a house, communicating with peers through the Internet, playing amateur football, etc. In the different practices, the concepts take different shapes. The systems in the context of 'home to school' travelling are mostly related to creating or enabling motion, whereas the system in the 'living in a house' can be directed towards entirely other goals. This means that a car is not easily recognised as having certain features that make it fall under the same concept ('systems') as the house in which one lives. This barrier must be overcome by having the learner grasp the concept in a variety of practices. As we will see, the experts in the Delphi study took the notion of contexts in a wider sense. In my discussion of the outcomes of the Delphi study in terms of the contexts for Engineering and Technology Education, I will elaborate a bit in the direction of the practices approach.

Outcomes of the Delphi Study: Contexts

In Table 2, the outcomes of the context part of the Delphi study are presented.

This table has a certain history. Originally, the terminology in the Delphi study suggested a dichotomy in contexts. The list of contexts as generated by the experts contained all of the domains that have become 'classic' in the USA curricula: production/manufacturing, construction, transportation, communication, and more recently, also biomedical technologies. In addition to these, the experts identified other contexts that all seemed to be related to basic human and social concerns: assuring basic needs like water, food, energy and safety for ourselves and future generations, locally and globally. In the panel discussion following the Delphi study, these additional contexts caused us to take a fresh look at the 'classic' domains and made us realise that these, too, in fact refer to basic human and social concerns. But in order to recognise this, it was seen as useful to rephrase them: 'shelter' instead

Table 2. Context

Context
Shelter ('construction')
Artefacts for practical purposes ('production'/'manufacturing')
Mobility ('transportation')
Communication
Health ('biomedical technologies')
Food
Water
Energy
Safety

of ‘construction,’ ‘artefacts for practical use’ rather than ‘production,’ ‘mobility’ rather than ‘transportation’ and ‘health’ rather than biomedical technologies. This change, in fact, replaces ends for means, and thus reveals better the basic needs underlying these domains.

The table now contains contexts at a rather abstract level. In order to make them useful for education, they must be ‘translated’ into more concrete situations. To this end, the approach in terms of practices can be valuable. As stated before, practices are coherent sets of activities in which the learners themselves usually participate. Let us now re-examine the contexts in Table 2 and see how these can be transposed to a more practical level. The context of ‘shelter’ contains practices like ‘living in a house’ or ‘participating in a church project aimed at going to a village in Africa and building a school for the community.’ The context of ‘artefacts for practical use’ can be made more concrete in a practice like ‘do-it-yourself’ or ‘making toys for deprived children in developing countries.’ ‘Mobility’ becomes recognisable for learners when it is made concrete in such practices as ‘travelling from home to school and vice versa,’ or ‘going on vacation.’ The context of ‘communication’ can be transposed into practices such as ‘using your mobile phone to stay in touch with friends,’ or ‘communicating with a friend in South America.’ For ‘food’ one can think of practices like ‘helping to cook a meal at home,’ or ‘eating in the school cafeteria.’ ‘Water’ can mean such practices as ‘using water in the household,’ or ‘purifying water when camping.’ The context of ‘energy’ can be turned into a practical context like ‘saving energy at home.’ ‘Health’ can become ‘going to the hospital for a test,’ or ‘doing voluntary work in a house for elderly people.’ ‘Safety’, finally, can be operationalised in practices like ‘making the school a safe place,’ or ‘taking measures to protect your privacy when using the Internet.’ Note that I have chosen the examples in such a way that they are all activities that pupils and students can be involved in already and thus are easily recognisable for them. This sets certain limits to possible contexts. We will not find activities like those developed by NASA to make children aware of space technologies (see http://www.nasa.gov/offices/education/about/index.html). It is possible, however, to relate those to practices in which children do participate already. For instance, one could make them design food for use in situations where there is no gravity. This will not be part of their own normal life, but by referring to eating, which is an activity they do know, they can be challenged to extending these experiences by using their imagination. These ‘exotic’ contexts are particularly suitable to enhance creativity and innovation as they challenge the learner to reflect on unfamiliar situations with often very complex problems. In a similar way, one can deal with global concerns. In the Delphi study, the non-traditional contexts were brought forward by the experts based on the consideration that learners need to develop an awareness and understanding of the broader, global issues that we should be concerned with even though they may not be a direct threat to us, here and now. Using the contexts only in the sense of practices that learners themselves are involved in would exclude almost all possibilities of including these global concerns in the curriculum, which would be undesirable. But here, too, we can stimulate references to situations that learners are familiar with. Reflecting on the issue of global energy consumption (a macro-level problem) can begin with reflection on energy consumption in the micro-situation of the learner herself or himself.

DEVELOPING A CURRICULAR STRUCTURE FOR ETE

Two Approaches for Using the Concept-Context Combination

We have now seen the concepts and contexts that can form the conceptual framework for Engineering and Technology Education. We now turn to the question of how to develop this into a curriculum structure. I will discuss two alternative approaches for this: a concept-based one and a context- based one.

In a concept-based approach, the concepts are taken as the structuring element for a curriculum framework. This means that the curriculum will have the concepts as main headings for the various parts of the curriculum. Or, in the case one elaborates this further into a textbook for Engineering and Technology Education, the concepts will be the basis for the chapter titles. This is the approach that was taken in the Man-Made World book. The concept-based approach then leads to teaching each of the concepts individually in a variety of contexts. For instance, the textbook would have a chapter on Systems, and introduce this concept by having the students go first meet this concept in the context of 'shelter.' In this part of the chapter, the student will be faced with this concept in a particular form that is determined by the specific context ('shelter'). Then the learner moves on to the next section in the book in which the same concept of systems is presented in a different context, e.g., health,' thereby again taking a particular form. By moving through the different contexts one by one, the student will gradually get an understanding of the more abstract concept of 'systems.' Then he/she moves on to the next chapter where another concept is dealt with in a similar variety of contexts. Of course, it is not necessary to have each possible context from Table 2 represented in each chapter. One can look for 'natural' connections between concepts and contexts to seek out what works out best for the learning of the concepts. Of course the learner also gradually develops an understanding of the complexity of the contexts by going through the whole sequence of chapters.

In the second context-based approach, the contexts are used as the structuring principle. In a textbook based on this approach, one will find chapter titles like 'Water,' 'Health,' 'Shelter,' etc. Each of the chapters contains activities in which the learner is confronted with a variety of concepts. In each chapter, the learner acquires an understanding of the context that is central in that chapter, and by moving through the whole set of chapters will gradually develop an understanding of the various concepts.

Both approaches have pros and cons. The evident example of the context-based approach is that it gives rise to recognition with the learners immediately. It is also a commonly practiced approach. The main reason for this is the opportunity to stay close to the pupils' and students' daily life experiences[8]. It is, however, by no means evident if indeed the concepts are recognised by going through the various contexts because learners have to develop an understanding of many concepts simultaneously. Towards the end of the curriculum or book, there will be a stronger need to make explicit what each of the individual concepts means once learners have come across them in a variety of contexts throughout the whole curriculum or book. For the concept-based approach, these pros and cons are inverted. It will be easier to develop an understanding of each of the individual concepts, but getting an understanding of the individual contexts is divided over a lengthy time period. Besides this, the chapters in the book or the parts of the curriculum will make a more coherent impression in the context-based approach because the contexts have a coherence that the learners are already acquainted with, whereas the concepts to them have no coherent meaning yet. Another advantage of the context-based approach is that it is easier to conceive broad and rich activities for each of the chapters in the book or parts of the curriculum (based on the richness of the contexts), whereas in the concept-based approach, one will probably end up with a set of smaller activities that relate to different contexts. This, however, does not mean that a narrower set of skills is developed.

It is difficult to 'prove' that either one or the other option is the best. In fact, one would want to have the best of both somehow combined. One could, for instance, start with a series of broad contexts in which a preliminary understanding of a number of concepts is developed and afterwards shift to a series of concepts that are then dealt with in a variety of narrower contexts (more like the practices as coherent sets of activities in which learners are involved themselves). The reverse order is also imaginable: starting with a series of concepts and then moving to a series of contexts[9].

ENGINEERING AND TECHNOLOGY EDUCATION FOR TECHNOLOGICAL LITERACY

Technological Literacy and the Concept-Context Approach

To develop technological literacy, one needs an understanding of both concepts and contexts, as I will argue now. It is the combination of both that enables someone to live in a world in which technology is everywhere and also to have control over that technology rather than being controlled by it. The relevance of understanding contexts is probably the most obvious one. In particular when contexts are seen as practices in which learners participate themselves, it is clear that an understanding of the nature of those practices and the role in technology in those practices contributes to technological literacy. But how can an understanding of the basic concepts we have seen contribute to technological literacy? That is because this understanding enables us to act in a more sophisticated way. Once we realise that many technological objects around us have a systems character, we understand that manipulating them means that we have to bring in the appropriate input, if necessary monitor a series of actions (the process) that the object executes, watch for certain desired outcomes, and reckon with the possibility of unexpected and perhaps even undesired outcomes. The notion of a system hierarchy helps us understand why all lamps in a chain of lamps for a Christmas tree may fail when only one of the lamps malfunctions (depending, of course, on how the lamps are connected, in parallel or in series). We then understand that this is caused by the interaction of the various subsystem lamps in the total system (the chain). This understanding helps to act in an appropriate way when being confronted with the malfunction. The notion of a socio-technical system helps us understand why certain technologies are not successful in society, and this insight can help us respond to new, emerging technologies in a more sophisticated way. What these concepts do is provide thinking tools that exceed individual situations and serve us in a broad range of decisions we have to make, in different times and different practices.

Limitations of the Concept-Context Approach; the Need for Future Research

It should be added here that the understanding of concepts is only one contribution to technological literacy, not the whole of this literacy. Apart from understanding concepts, we need skills that enable us to use this understanding in decision-making and other actions. Such skills can be practical, such as operating all sorts of devices and machines, but also cognitive skills such as cause-effect and means-ends reasoning (Garmire and Pearson, 2006)[10]. Besides that, technological literacy also comprises opinions about and attitudes towards technology. Here, too, one can ask the question if it is possible to identify a core of skills and attitudes that could be used as the basis for curriculum development. Another Delphi study might be helpful to answer this question. The reason the concept-context Delphi study was conducted was the fact that not much effort had yet been made to identify the core of concepts and contexts for Engineering and Technology Education. More had been written about skills because they have been traditionally an important part of technology education. But perhaps the dramatic changes that technology education has gone through and the engineering element as a new component in technology education may well justify new efforts to determine the core of skills in Engineering and Technology Education. Clearly, there is a challenge ahead of us here, for which again a combination of the insights of the philosophy of technology and the opinions of an international group of experts could well be a good route towards finding an answer to this question.

In this chapter, I discussed the concept-context approach as one of the strategies that could be used to turn concepts into teachable and learnable content. In the concept-context approach, theoretical notions are confronted with practical situations, and thus the dichotomy between what one can call ‘school image’ (the often rather abstract way reality is presented in school) and ‘street image’ (pupils’ and students’ intuitive ideas about reality), often found in constructivist educational research, can be broken. Cognition is always situated, and the concept-context approach does justice to this. The outcomes of the Delphi study regarding concepts and contexts for Engineering and Technology Education have given us important clues as to what constitutes a curriculum that represents the true nature of technology and engineering. The challenge now is to elaborate this into a curricular structure.

NOTES

1 In this approach, often very elaborate and complex schemes features that often did not appeal to Western European educators who were more in favour of simplicity. Nevertheless, these schemes contained a lot of sound conceptualisation.

2 The research was done by Ammeret Rossouw, B.Sc. (Delft University of Technology, the Netherlands), Dr. Michael Hacker (Hofstra University, USA) and Dr. Marc J. de Vries (Delft University of

Technology, the Netherlands). The full text of their report can be found at: https://www.hofstra.edu/pdf/Academics/Colleges/SOEAHS/ctl/ctl_Finalreport_%20CCETE.pdf.

[3] Both Table 1 and Table 2 contain the results in a slightly reformulated manner (my terms now, based on later considerations).

[4] The amount of literature about this is vast and it makes no sense listing just a few references. The journal *Design Studies* is a useful resource for recent research in this domain.

[5] ITEA 2000. It is useful to note that a difference exists in the way the term 'systems' is used in technology education in the USA. Traditional textbooks have chapters titled 'Transportation systems' or 'Communication systems,' but reading these chapters quickly shows that the term 'system' is then used to indicate a domain of applications of technology rather than an engineering concept. This use of the term matches better with what I will call 'contexts' in this chapter. In the ITEA Standards, we can see a shift in terminology compared to the traditional USA textbooks: the term 'systems' is not used in the same way as I use it here, and not in the sense of contexts.

[6] Risk is the focus of the research efforts made by a group of philosophers of technology at the Royal Institute of Technology in Stockholm, Sweden, led by Dr. Sven Ove Hansson.

[7] It is good to make explicit here that this is not obvious. Other people deny that abstract concepts have any existence at all, but are merely names for things borne in our minds. In my opinion, the abstract concepts are real and more than names. So take a realistic rather than a nominalistic stance in this chapter.

[8] It is, however, not necessarily the case that this option is more attractive from this perspective. It is well imaginable that the other option (the concept-based approach) can be elaborated on in such a way that it is full of situations that pupils and students can refer to, and that it allows for the development of a broad range of skills.

[9] This was done in *Technologisch*, a Dutch series of textbooks, for which I served as one of the authors. The same approach was used by John Williams in the textbooks *Introducing Design and Technology* and *Design and Technology in Context* (both MacMillan Education, Australia, 1994). The *Kids & Technology Mission 21* series, produced by NASA and published by Delmar in 1992, was an American example of the combination of a concept-based and a context-based approach. There were modules with titles like Design, Energy & Matter, Connections, Machines, which had a concept-based character, but also modules based on contexts, such as Community, Space, Transportation and Communication.

[10] This is one of the few references where this type of skills is discussed explicitly as part of technological literacy.

REFERENCES

Blandow, D. (1995). *Elements of technology education (inaugural lecturer)*. Eindhoven: Eindhoven University of Technology.

Bulte, A. M. W., Westbroek, H. B., De Jong, O., & Pilot, A. (2006). A research approach to designing chemistry education using authentic practices as contexts. *International Journal of Science Education*, *28*(9), 1063–1086.

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

Hennessy, S. (1993). Situated cognition and cognitive apprenticeship: implications for classroom learning. *Studies in Science Education*, *22*, 1–41.

International Technology Education Association (ITEA). (2000). *Standards for technological literacy. Content for the study of technology*. Reston, VA: Author.

Koen, B. V. (2003). *Discussion of the method. Conducting the engineer's approach to problem solving*. Oxford: Oxford University Press.

Kroes, P. A., & Meijers, A. W. M. (2006). Introduction. The dual nature of technical artifacts. *Studies in the History and Philosophy of Science*, *37*, 1–4.

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

Pilot, A., & Bulte, A. M. W. (2006). The use of “contexts” as a challenge for the chemistry curriculum: Its successes and the need for further development and understanding. *International Journal of Science Education*, *28*(9), 1087–1112.

Truxall, D., & Piel, E. J. (1971). *The man-made world*. New York: McGraw-Hill Book Company.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). Community service in higher education: A look at the nation’s faculty. *Journal of Research in Science Teaching*, *40*(7), 692–720.

Vincenti, W. G. (1990). *What engineers know and how they know it*. Baltimore: Johns Hopkins Press.

Vries, M. J. de. (2005). *Teaching about technology*. Dordrecht, Netherlands: Springer.

Wolffgramm, H. (1994). *Allgemeine Techniklehre: Elemente, Strukturen und Gesetzmäßigkeiten; Einführung in die Denk- und Arbeitweisen einer allgemeinen Techniklehre, Band 1. Allgemeine Technologie*. Hildesheim: Verlag Franzbecker.

Marc J. de Vries
Delft University of Technology
The Netherlands

P JOHN WILLIAMS

6. DISPOSITIONS AS EXPLICIT LEARNING GOALS FOR ENGINEERING AND TECHNOLOGY EDUCATION

INTRODUCTION

Researchers and practitioners in engineering and technology education have called for a range of capabilities to be developed through education as a means of preparing students for life after school in the third millennium. There is nothing new about this; technology education has always addressed personal and professional goals, although at times in quite an instrumental kind of way. Both career awareness and skill development have been justified as providing the basis for a productive and satisfying role in society. More recently, the recognition that the practical environment of engineering, design and technology education is conducive to the development of a range of cognitive skills (as well as manipulative skills) has broadened its goals. The prevailing paradigm within which these skills are encompassed is technological literacy, but given the radical recent developments in society, it may be time for a new framework to be developed that is less encumbered with the instrumentalism of capability as a component of technological literacy.

This chapter proposes that engineering and technology education should focus on the development of dispositions. The literature on dispositions is grounded in the fields of philosophy and psychology. Dispositions have been defined as patterns of behavior that are exhibited intentionally and frequently, representing habits of mind. Therefore, dispositions are concerned with not only what a student can do, but what a student is disposed to do, thereby addressing the often prevalent gap between abilities and actions. The essentiality of action aligns with the manifold notions of activity within engineering and technology education, and so progresses beyond the possibly conceptual, although activity-based, notions of technological literacy.

A RATIONALE FOR EMPHASIZING DISPOSITIONS

There is no consensus about the definition of dispositions. Some of the terms associated with discussions of dispositions include tendencies, values, habits of mind, attitudes and behaviors. The consistent conceptual overlay of these terms is action – that a disposition is not something static, or merely an attitude, but has an essentially behavioral outcome. In addition, it refers to not just what a person can do but what they are disposed to do. Katz (1993) provides a definition of dispositions as patterns of behavior that are exhibited frequently and intentionally in the absence of coercion, thus representing a habit of mind.

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 89–102.

Aspects of dispositions are verbs, that is, not something to be acquired, but an automatic response to a circumstance. A student becomes disposed to act in a certain way, and in an insecure or uncertain situation, feels secure in providing a response because the disposition provides the security.

Dispositions seem to have three characteristics:

- First, a disposition is a proclivity to act. For example, being careful, rather "be" careful.
- Second, a disposition to act implies awareness of what one is doing. For example, knowing that in the questions that are being asked, a form of critique is evident.
- Third, acting with awareness implies that a person acts with intention. That is, this specific act is intended as a careful act. To intend to do something is to be aware that this (and not something else) is what one is doing (Sockett, 2009, p. 294).

Disposition has two components – inclination and ability, which are the components for behavior. An inclination is the person's tendency toward a certain behavior. For example, a person with an inclination toward critique will tend to be critical when confronted with a situation in which he or she can respond in that way. Ability refers to the capability to engage with the disposition. For example, a person with the ability to critique will know how to question with purpose, isolate elements, and perceive patterns and consequences.

Projects that engage students and sequences of carefully structured experiences are important to ensure academic progress throughout schooling. Attention to personal development is at least equally important, and arguably more important. This is essentially related to character and values, and whether teachers agree that they are engaged in values education or not, the fact is that technology is imbued with values. Consequently, it is necessary to be explicit about this and open it up for discussion; it could then be critiqued and raised to the conscious level. This does not imply the dominance of any one set of values over any other. Technological determinists will have a different set of values than humanists, as will futurists and behavioral scientists. Huitt (1997) suggested a set of values that underpin the SCANS Report that most educators would accept as important: autonomy, benevolence, compassion, courage, courtesy, honesty, integrity, responsibility, trustworthiness and truthfulness. But the point of emphasis here is that relevant values must first be recognized as being embedded within engineering and technology education before they can be examined as to their appropriateness.

DISPOSITIONS AND MORALITY

In his paper, *Dispositions as Virtues*, Sockett (2009) argues that it is incomplete to consider educational dispositions in the absence of moral character dispositions. He holds that education is essentially a moral activity, and, particularly in the empirical tendencies of assessment and notions of skilled teaching emerging from clinical practice, unless the moral is considered, the outcome will be unacceptable. This warning would seem to apply particularly to Technology Education, where its practical focus and instrumental tendencies are not conducive to the consideration of moral dispositions.

Sockett's 2009 literature review suggested a range of perspectives on dispositions - pedagogical, institutional, philosophical and psychological. For instance:

- From a pedagogical perspective, dispositions can be viewed within reflective practice as part of intellectual character and within moral communities of practice.
- From the institutional perspective, web site announcements of different institutions' work demonstrate the variety of approaches and the complex task of working for professional consensus.
- From a philosophical perspective, attempts are made to examine meaning and use, as well as the different perspectives offered through moral philosophy.
- Finally, though some psychological perspectives refer to cognitive content, the volume of work on personality, with its strong and authoritative place in psychology, is an additional perspective.

Therefore dispositions are actions resulting from awareness and intent, and are always the result of judgment. "Our actions thus stem from our cognitive appraisals of situations where we act intentionally within which acts our dispositions are manifest" (Sockett, 2009, p. 295).

The relatively recent spate of research about dispositions, emanating mainly from the USA, is at least partly the result of the inclusion of this notion in professional teaching standards. The National Board for Professional Teaching Standards, the National Council for the Accreditation of Teacher Education (NCATE, 2008) and the Interstate New Teacher Assessment and Support Consortium all mention dispositions as being essential elements of teacher preparation and teacher quality. NCATE explicitly includes 'professional dispositions' as one of its standards, with the expectation that teacher trainees are assessed in their achievement of this standard. The Accreditation Board for Engineering and Technology (ABET) also alludes to dispositions in its reference to professional and ethical responsibility.

Thornton (2006) reviewed a number of models that have been developed to assess dispositions in the context of teacher accreditation. These included:

- Dispositions related directly to behaviors in the school setting, which tend to be comprised of checklists, rating scales and rubrics, and look more like pedagogical practices or teaching behaviors than dispositions.
- Dispositions developed around professional characteristics such as attendance, work ethic, preparation, punctuality and appropriate dress, which are really minimal dispositions and fall short of capturing the nature of true dispositions.
- Dispositions determined by reflective self-assessment, an attempt to address the complexities and psychological nature of dispositions by requiring a written response to a human relations incident. This is dependent on an individual's ability to self-report and express his metacognitive understanding in writing.
- Dispositions that focus on moral and ethical dimensions, often directed toward diversity and inclusivity.

The assessment of dispositions is fraught with pitfalls, particularly those with moral and ethical dimensions, however their inclusion in professional teacher development standards highlights their significance.

TECHNOLOGICAL LITERACY

Technology education has a history of addressing personal and professional goals, albeit often in a narrow vocational and instrumental manner. The notion that a fulfilling life in a technological society requires a certain skill set that students gain through practical activities in a school technology workshop environment has been the foundation of many technology programs. Likewise, the role of technology education as a career awareness experience leading to later prevocational and vocational mastery of competencies has been an oft argued rationale.

The traditional competency based approach to technology education was too narrow to be classified as literacy. The more recent recognition, through the application of design, that a broad range of cognitive skills exists that could be developed and nurtured through application to a practical context, provided the basis for promoting the notion that this constitutes a unique type of literacy – technological.

Arguably the most significant curriculum goal of technology education programs is technological literacy, generally constituted of an ability/use dimension, a knowledge and understanding dimension, and an awareness or appreciation of the relationships between technology, society and the environment (International Technology Education Association, 2000; Ministry of Education, New Zealand, 2006; Ministry of Education, South Africa, 2002; Department of Education Training and Employment, South Australia, 2001; Pearson and Garmine, 2006). Curricula then go on to elaborate on the specific abilities or outcomes related to these dimensions that are to be achieved in order to reach a school-based level of technologically literacy.

Literacy is an essentially dynamic construct that one is always developing towards and never achieving. This dynamism is elaborated by Leonard Waks (2006) in tracing the developments of technological literacy from its genesis in the 1970s to a contemporary context. He maintains that initial conceptions of technological literacy are no longer valid because of (a) increased localized ethnic and linguistic diversity, (b) economic and technical convergence into internationally networked systems, and (c) the need to move beyond the limitations of schooling into less structured ‘post-curricular’ designs.

Kahn and Kellner (2006) argue for a link between proliferating high technologies and the need for a reconstruction of technoliteracy. Contemporary technoliteracies can “…further radical democratic understandings and transformations of our lives, as well as [provide] a democratic reconstruction of education. …Technoliteracies must be deployed and promoted that allow for popular interventions into the ongoing and often undemocratic economic and technological revolutions taking place…” (p. 258).

Kim and Roth (2008) perceive current discourses on technology education as “taking a positive and value-neutral approach with utilitarian and vocational overtones. The discourses generally lack discussions of human agency and human responsibility for techno-scientific activities and technological literacy” (p. 185). From a position that the functions and interactions of technology are inseparable from and indispensible to daily routines, they argue that technology then becomes a process and system of relationships of being and living in the world. The type of technology often taught, unsullied as it is by common sense, aesthetics, politics and economics, inadequately creates opportunities to experience technology while contributing to everyday life in a community.

Williams (2009) also calls for a revision of technological literacy, and proposes technological multiliteracy as an alternative construct. The proposition being offered is that technological literacy is multiliterate, and the parallel drawn is with developments in the general literacy movement. Historically, general literacy was based on a mono-dimensional construct, but given social and technological developments, a broadening of the construct to multiliteracy provided the platform for a more relevant, useful and ultimately democratic approach. Similarly with technological literacy; reframing the traditional approach to technological literacy as a multiliteracies construct highlights its breadth, incorporates contemporary developments such as multiple modes of communication, and empowers students to play a more democratic role in their own development through the potential of, for example, Web 2.0.

The popularization of a multiliteracy approach within education developed as a response to the multiple modes of communication and increasing cultural and linguistic diversity faced by students (Cazden et al., 1996). Many synergies exist between technological literacy and the notion of multiliteracies within literacy education in developing relevant and engaging pedagogies that promote the critical engagement necessary for students to contribute to and achieve their full potential.

However, the problem remains that technological literacy (or multiliteracy) as a goal deals with student potential and provides no guarantee that the potential will be realized in a context that demands involvement or a response. A student may perform well in class, develop insightful portfolios, or achieve a high score on a test of technology and engineering literacy, but not possess the disposition to apply this knowledge and capability consistently and with discrimination to new and real situations.

Technological literacy as competency attainment (Dakers, 2006, p. 257) fails to provide an impelling rationale for action and is therefore inadequate to that extent. Dispositional behavior explains and provides a framework for the desired action, and goes beyond simply framing the capabilities or competencies required for this action.

DISPOSITIONS IN ENGINEERING AND TECHNOLOGY EDUCATION

A range of dispositions are discussed in the literature that could conceivably be appropriate goals for education generally. There seem to be two main categories of such dispositions: character dispositions, which relate to self-knowledge, the virtues of the will (persistence, perseverance and heed) – the kind of person that an individual is. Secondly, are dispositions of intellect that may include accuracy, fairness and impartiality in making judgments, and open-mindedness. A thinking disposition is a tendency toward intellectual activity that guides cognitive behavior. Sockett (2009) refers to integrity, trustworthiness, persistence, fairness, tolerance and civility as relevant to the profession of teaching. Misco (2007) in *Preparing Graduates for Moral Life* refers to dispositions of respect for the dignity of others, sensitivity to cultural norms, and advocacy of equity and access as central to the goal of a democratic education for secondary school students.

No educator would deny that these are worthy dispositions to develop in students, and the list could be quite extensive. However, for this chapter, I would like to focus on those thinking dispositions that would seem to have an affinity with the nature of technology education, and thus provide an alternative goal for teaching in this area. This is not to deny that moral and ethical dispositions are important, and when related to the socio-cultural milieu of technology, are essential; but that the development of sound thinking dispositions is less controversial and is historically a neglected area of technology education, but represents a potential outcome of technology education that could be its most significant contribution to the development of a child.

Thinking dispositions are referred to by Costa & Kallick (2008) as habits of mind: the characteristics of what intelligent people do when they are confronted with problems, the resolutions to which are not immediately apparent. He proposes 16 habits of mind, not because this is all there is, but because these are the ones he has developed so far. They are: persisting; managing impulsivity; listening with understanding and empathy; thinking flexibly; thinking about thinking; striving for accuracy; questioning and posing problems; applying past knowledge to new situations; thinking and communicating with clarity and precision; gathering data through all senses; creating, imagining and innovating; responding with wonderment and awe; taking responsible risks; finding humor; thinking independently; and remaining open to continuous learning.

Perkins (1993) posits that good thinking can be characterized as reflecting seven broad thinking dispositions. These are: broad and adventurous, sustained intellectual curiosity, clarify and seek understanding, planful and strategic, intellectually careful, seek and evaluate reasons, and be metacognitive.

The following discussion is an adaptation of those thinking dispositions that are most conducive to development within an engineering, design and technology education context. The tentative rationale for these dispositions (adapted from Perkins, 1993) is threefold. First, they are individually necessary; each disposition is individually necessary in order to foment an appropriate relationship with technology. The inactivity of any one disposition would represent an unbalanced approach to technology. Secondly, they are comprehensive. It is a debatable point that the dispositions are comprehensive, but based on recent literature in technology education, they are proposed here as being so. Finally they are balanced; they complement each other. Alone, none of them constitute a sound approach to technology. For example, the inclination to be adventurous, unless it is moderated by a strategic approach, would be unsatisfactory and may be counterproductive to a positive relationship with technology. Each individual disposition may work in counterproductive ways unless balanced by others.

Seek Understanding

A desire to understand is a fundamental disposition of good thinking because it seeks new knowledge and makes connections to prior knowledge. This desire to understand things clearly serves to anchor ideas in experience, and so is sympathetic to learning in engineering, design and technology, which involves this interaction between thinking and doing.

Abilities upon which a disposition to seek understanding is based include skepticism, building complex conceptualizations and identifying logical structures. A tendency to question and challenge assumptions, and persist with an enquiry is essential. These abilities, combined with a demand for justifications will fill in the gaps between what they know and don't know, and thus dispose an individual to understand what he still needs to understand.

Metacognitive

The disposition to metacognition relates to elements of both the self and society. Obviously, the ability to reflect objectively on one's own thinking is fundamental, but an awareness of the consequences of one's actions on others and the environment is also a consideration. Therefore, the reflection does not exist in isolation from the context, but it is a consideration.

The process elicits a high level of self-awareness – not only about fundamental mental processes, but an understanding of what is known and what is not known, the development and editing of mental pictures, and the desire for a productive outcome. The significance of metacognition as a disposition is that an individual is inclined to this way of thinking all the time, not just, for example, at a certain stage of a design process.

Apparently, not all use this capacity equally (Csikszentmihalyi, 1993) probably because not all take the time to reflect on personal experiences, that is, students taking time to think about why they are doing what they are doing.

Lateral Thinking

The disposition to think laterally is a common goal of design and technology education. It is characterized by flexible thinking and the accompanying ability to change ideas in response to the reception of new data, and as such to develop multiple perceptual positions (de Bono, 1967). From these positions, they can envision a range of consequences and then evaluate these in terms of the goals they are working towards, and so present a range of alternative strategies or solutions.

While lateral thinkers have the ability to be macrocentric (opposite to egocentric) and to holistically discern themes and patterns, they also have an understanding of when detailed precision is required.

Carefulness

Carefulness may seem to contradict some of the other dispositions such as risk-taking, but in technology it seems a particularly appropriate disposition. Carefulness relates to a sense of mental orderliness, evidenced in outcomes of precision and accuracy. People working toward this disposition take time to think ahead, to be careful in both the planning and execution of ideas. Taking care results from an awareness of the criteria by which excellence is judged, and the preference of excellence over expedience.

Intellectual standards and recognized and applied information are processed carefully and precisely, resulting in the construction of order out of disorder. Being careful in this sense is time-consuming and reflects a self-confidence in taking the time to think well and act accordingly. This type of carefulness is strategic; goal-setting, evaluation and plan execution are undertaken in a calculated manner.

Constructive

The obvious design and technology metaphor for this disposition is the emphasis in the subject on designing and constructing three-dimensional solutions to problems. But being constructive in a ‘good thinking’ sense involves abstracting meaning from an experience, isolating it and applying it to a new situation. While the intent here is not to subscribe completely to a constructivist epistemology, the disposition to see beyond discrete episodic experiences and transfer past knowledge to new contexts is an attribute that will foster new learning.

Imaginative

Imagining is a fundamental of innovation and entails the examination of alternative possibilities from many different perspectives. It is sympathetic to a number of the other dispositions such as risk-taking, because being imaginative is taking the risk of developing solutions to problems that are different and unexpected.

Imagining does not take place in a vacuum; it is open to and seeks feedback and criticism, and consequently refines the imaginative ideas that result. From an educating perspective, the difficulty is that it is intrinsically rather than extrinsically motivated, so a thinking context must be engineered to encourage the predominance of intrinsic rationales in order to be imaginative.

Take Risks

Risk-taking is recognized as fundamental for the development of creativity, but it is careful risk-taking, recognizing that not all risks are worth taking. This disposition is characterized by an enthusiasm to go beyond the generally accepted limits, often a difficult proposition in a classroom, and one that is easily misinterpreted by teachers as insolence or disobedience.

Risk-takers are inclined to be open-minded and do not feel uncomfortable in situations where the outcome is not clear; in fact, they may seek such situations. They are able to recognize alternative perspectives and speculate about the consequences of accepting certain assumptions. If their pursuit of a particular outcome is not successful, they can explore other pathways and view the setback as a part of the learning (design) journey.

Make Connections

The diversity of technology encourages the need to make connections, both with other people and between technologies. Group work is an often maligned aspect of design and technology (at least by students), but groups are more powerful than individuals, and many real problems are too complex to be solved by an individual. Many student inclinations to work alone need moderating by a disposition to link with other people in order to achieve satisfactory resolutions. Implied in this disposition are characteristics of openness to accept critical feedback, and consensus building through careful consideration of others' ideas.

As individuals engage in experiences encompassing the breadth of technology, they develop knowledge that enables connections to be made, connections that, by the way, enable transferability. So once the connection is made, the applicability of transfer is recognized and progress is consequently facilitated.

Critical

Being critical is a natural component of design and technology education (Keirl, 2007). It is truly a disposition in that it is not applied selectively in certain contexts, but is a frame of mind that imbues all aspects of designing in technology. It is applied to tangible products and less tangible processes; it is applied to others and to the self. It is never without purpose, not being critical for the sake of just being critical, but it evolves from a rationale, often related to making progress in working toward design solutions to problems by determining the next stage of the creative journey.

The disposition of being critical may be in opposition or may be supportive, it may be objectionable or it may be confirmatory. But either way, it is purposeful and ultimately constructive. These are not discrete dispositions and are therefore not invoked in isolation. For example, being imaginative involves taking risks, and as Keirl (2007, p. 311) points out, critiquing is a form of metacognition. Further indicating their interdependency, Rutland and Spendlove (2007) suggest that components of creativity include flexible thinking, risk-taking and being imaginative.

TEACHING DISPOSITIONS

The assumption of this discussion is that dispositions can be taught. Dewey (1922) differentiated teachable dispositions from innate characteristics or temperament in emphasizing the importance of acquiring and developing dispositions. However, they cannot be taught directly. Early research has clearly demonstrated the failure of didactic methods (Hartshorne & May, 1928) and other direct strategies (Narvaez, Bentley, Gleason, & Samuels, 1998) to achieve such ends. Rather than attempt to develop dispositions through transmission or instruction, learning experiences must be carefully crafted to foster the development of desirable dispositions. When students have consistent exposure to these learning experiences, dispositions develop as autonomic habits.

Harpaz (2007) terms this indirect teaching of thinking dispositions as a "pattern of cultivation" (p. 1849). He differentiates it from the "pattern of impartation," which involves the direct teaching of knowledge. In the pattern of cultivation, knowledge plays a marginal role. “Dispositions are cultivated indirectly, not by the transmission of knowledge but by a comprehensive culture of thinking that fosters in various ways thinking dispositions” (p. 1850). The fact that a pattern of cultivation is indifferent to knowledge suits design and technology education, in which the knowledge of the discipline is ill-defined and only contextualized by the nature of the design problem being dealt with. This frees the ‘cultivation of dispositions’ from any set knowledge, and reinforces what Fenstermacher and Soltis (1986) refer to as a liberationist approach to teaching. Cultivating dispositions is liberating in that it frees individuals from unwanted thinking traits and reinstates the individual into a controlling position through the application of good thinking.

Dispositions are a composite of many skills, attitudes, past experiences and influences. Melding all this into a pattern of behavior and then making judgments about the application to a situation is the workings of a disposition that teachers must consider. All teachers know that each student in their class responds according to the baggage they bring with them: the skills and attitudes derived from home, peer and media influences. With a focus on dispositions, the teacher’s role is to encourage the application of all this baggage to new situations in a consistently intelligent and constructive manner.

The multifaceted nature of design and technology lends itself to the nurture of integrated dispositions. By structuring opportunities for reflection and deliberation, students are able to develop defensible arguments based on evidence, develop listening skills that are open-minded, and predict consequences of decisions based on sound epistemologies.

TEACHING FOR DISPOSITIONS IN ENGINEERING AND TECHNOLOGY EDUCATION

In considering dispositions as classroom goals, the question is: How can teachers take a dynamic approach to dispositions? They are not competencies that a student masters or does not, but are comprised of attributes that are often present to some extent in all students, and the teacher’s goal is to develop them and increase the likelihood that the student will respond to any situation in a predictably consistent way.

Traditional education outcomes focus on what students know and what they can recall. Dispositions deal with how students behave when they don’t know the answer to a problem. What do they do when they are confronted with a problem for which there is no immediate and apparent answer? Teaching for dispositions has the same goal as requiring students to produce, for example, a process portfolio; in fact, one may provide evidence of the other. A process portfolio indicates how students react to an open-ended problem by providing a record of their thinking in working towards a solution; similarly, with dispositions, the focus lies in enhancing students’ creation of knowledge, not simply their recall of knowledge.

One goal of good thinking is to have students develop a critical approach to their work: their research, their enquiry, their critique and their collaborative work with others. For example, researching to acquire information is basic and is a skill that must be taught, but it is certainly more important to train students to evaluate and then apply this information in an intelligent way to the problem at hand than to simply acquire the information.

The understanding of dispositions as essentially behavioral is significant to engineering, design and technology education. In this learning area in which practice is central, a student cannot be passively creative or passively critical; it is the action that expresses these characteristics that enables teacher judgments about progress to be made, and consistent thoughtfully applied actions indicate the development of a disposition. In addition, and sympathetically with engineering, design, and technology education, judgments must be made about the appropriateness of certain dispositions in the given context. A student may be disposed to be critical, but may encounter a situation where it is not clear if this criticism is appropriate.

If the desirable dispositions of engineering, design and technology education are to be taught, and are something different from personality traits, then they have a cognitive core. The student who has a disposition to be critical makes the judgment to be so after analyzing the context and making a deduction of possible responses. It is not a feeling the student has to be critical, but a cognitive and analytical process resulting in the demonstration of the disposition. Therefore, fostering dispositions is about developing student understanding and insight.

Given the foregoing discourse on the nature of dispositions, those that may relate to engineering, design and technology education and thus become the focus of student development for engineering and technology teachers, are limited. While manipulative skills remain an important component of engineering and technology education, they are not an end in themselves but rather a means to an end. Skills are used as one of the mechanisms through which cognitive development takes place and consequent dispositions are developed. Students are taught to manipulate materials or design circuits or integrate CAD-CAM so that teachers can help them develop appropriate ways of thinking and acting, and so that students can provide evidence that they are progressing to these ends.

If the aim is to develop students' ability to deal with technological issues at a personal and social level intelligently and confidently, then a school classroom culture can foster certain dispositions. According to this conception, action to encourage the desired dispositions must address both components: inclination and ability, which requires teachers to provide students with opportunities to set goals and make plans for themselves in meaningful contexts.

Good thinking as a dispositional outcome of technology education is acquired through institutional and interpersonal social contact. At an institutional level, school culture can support certain dispositions by encouraging democratic involvement by students in school governance. At a more personal level, dispositions in engineering, design, and technology can be encouraged through guided learning, including cognitive apprenticeships, reciprocal teaching and expert scaffolding. The teacher can also utilize peer groups to develop good thinking dispositions by establishing an environment for rigorous thinking and thus create social demands for the sought after dispositions.

What can a teacher do establish an environment that fosters the progressive development of desirable dispositions? Claxton and Carr (2004) discuss four aspects of the classroom environment that are relevant to the fostering of dispositions. The first is a **prohibiting** environment in which the pedagogy employed by the teacher makes it difficult for an individual to be uniquely responsive. For example, in the not uncommon situation in design and technology where all students are practicing skills after a teacher has demonstrated them, and they are all working on the same project, there is little opportunity for students to respond in unique ways.

Conversely, an **inviting** environment is one in which student responses are encouraged and in which it is clear that individual responses are valued and not denigrated. Further, a **potentiating** environment not only invites the expression of dispositions, but encourages students and 'stretches' them to test their responses. Learning is a shared activity between teachers and students, which may exist in the context of students identifying their own design problems and managing their own processes in solving these problems.

If a teacher uses a limited range of pedagogies, the **affordance** thereby provided for students to react in ways that enable them to advance their own learning is also limited, and will only appeal to those students who have a complimentary learning style. In order to enable in all students the development of desirable dispositions, a broad range of pedagogies must be employed by teachers.

It is relevant to consider what might be the nature of progress in working toward dispositions in engineering and technology. It may be that robustness, that is, the strength of disposition, is one indicator of progress. In this case, the disposition is robust enough to be evident, even in the face of an unsupportive context or forceful pressure to respond in a certain way. For example, a technological issue for which the prevailing social attitude is obvious and demeans any alternative response, and so most people conform; but a certain disposition evokes an alternative response.

Breadth may also be a measure of progress whereby a student develops enough confidence in a disposition to apply it to a broad range of technological contexts. As a disposition is applied to a broadening range of contexts, and this application is rewarded and is complementary to the students' world view, they will be emboldened to cement the disposition as an appropriate response to an increasingly broad range of contexts. Transferability is the mechanism for achieving breadth by providing the opportunity for students to apply their dispositions in a range of contexts, to test them, to refine them and to strengthen them.

GENERALIZABILITY OF THE DISPOSITIONS

The extent to which the aspects of thinking dispositions are generalizable is an issue. It is clear that transferability of knowledge and skills between contexts, even within the domain of technology, is not straightforward and cannot be assumed to take place without support. Glaser (1984) was one of the first to recognize the discipline-bound nature of knowledge and skills. This has developed into a range of more recent research on the situated nature of cognition (Hennessy, 1993) and the consequent problematic notion of transferability (Georghiades, 2000).

It seems a middle ground approach between the essentially localized nature of some knowledge and the broader more generalizable knowledge dispositions might be closer to reality. For example, Perkins and Salomon (1989) acknowledged that links exist between general and specific types of learning through the application of the general into specific learning contexts. Either way, a dispositional analysis of thinking as a cognitive framework in engineering, design and technology could help explain how attributes could be both specific and general.

Those proposing that knowledge and skills are discipline-bound (Glaser, 1984), and more recent situated cognition literature, indicate the importance of the context in grounding learning and the difficulties individuals have in generalizing their learning (or in this case, applying their disposition) to other different contexts. It may be the case that the generality of the disposition will, in application, build upon quite specific contextualized abilities.

CONCLUSION

A focus on thinking dispositions could provide educators with the opportunity to extend the goals of education beyond the pragmatics of engineering, the instrumentalism of technology education or the superficiality of design, which is evident in some education. With essentially behavioral outcomes, thinking dispositions build on skills, competencies and the potential of technological literacy to ensure that good thinking is applied in an appropriate and considered manner to opportunistic contexts. The careful structuring of classroom activities in sequences that are designed to elicit desirable dispositions is a fundamental teaching activity.

REFERENCES

Accreditation Board for Engineering and Technology (ABET). (2001). *Criteria for accrediting engineering programs: Effective for evaluations during the 2001-2002 accreditation cycle*. Baltimore: Author.

Claxton, G., & Carr, M. (2004). A framework for teaching learning: The dynamics of disposition. *Early Years*, *24*(1), 87–97.

Cazden, C., Cope, B., Fairclough, N., Gee, J., et al. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review*, *66*(1), 60–92.

Costa, A. L., & Kallick, B. (2000). Assessing the habits of mind. In A. L. Costa & B. Kallick (Eds.), *Assessing and reporting on habits of mind* (pp. 29–53). Alexandria, VA: Association for Supervision and Curriculum Development (ASCD).

Csikszentmihalyi, M. (1993). *The evolving self: A psychology for the third millennium*. New York: Harper Collins.

Dakers, J. (2006). *Defining technological literacy*. New York: Palgrave Macmillan.

de Bono, E. (1967). *New think: The use of lateral thinking*. London: Jonathan Cape.

Department of Education Training and Employment, South Australia. (2001). *South Australian curriculum standards and accountability framework*. Retrieved September 17, 2007 from http://www.sacsa.sa.edu.au/index_fsrc.asp?t=LA

Dewey, J. (1922). *Human nature and conduct*. New York: Henry Holt and Company.

Fenstermacher, G., & Soltis, J. (1986). *Approaches to teaching*. New York: Teachers College Press.

Georghiades, P. (2000). Beyond conceptual change learning in science education: Focusing on transfer, durability and metacognition. *Educational Research*, *42*(2), 119–139.

Glaser, R. (1984). Education and thinking: the role of knowledge. *American Psychologist*, *39*, 93–104.

Harpaz, Y. (2007). Approaches to teaching thinking: toward a conceptual mapping of the field. *Teachers College Record*, *109*(8), 1845–1874.

Hartshorne, H., & May, M. (1928). *Studies in the nature of character: Vol. 1. Studies in deceit*. New York: Macmillan.
Hennessy, S. (1993). Situated cognition and cognitive apprenticeship: Implications for classroom learning. *Studies in Science Education*, *22*(1), 1–41.
Huitt, W. (1997, April 18). *The SCANS report revisited*. Paper presented at the Fifth Annual Gulf South Business and Vocational Education conference, Valdosta State University, Valdosta, GA. Retrieved December 1997, from http://chiron.valdosta.edu/whuitt/student/scanspap.html
International Technology Education Association (ITEA). (2000). *Standards for Technological Literacy*. Virginia: Author.
Kahn, R., & Kellner, D. (2006). Reconstructing technoliteracy: A multiple literacy approach. In J. Dakers (Ed.), *Defining technological literacy* (pp. 253–274). New York: Palgrave Macmillan.
Katz, L. (1993). *Dispositions: Definitions and implications for early childhood practice*. ERIC #211. Retrieved from http://ceep.crc.uiuc.edu/eecearchive/books/disposit.html
Keirl, S. (2007). Critiquing in a democratic of design and technology Education. In J. Dakers, W. Dow, & M. J. de Vries (Eds.), *Proceedings the Pupils Attitude Towards Technology (PATT-18) conference* (pp. 306–312). Glasgow: Faculty of Education, University of Glasgow. Retrieved from http://www.iteea.org/Conference/PATT/PATT18/fullprog-21a[1].pdf
Kim, M., & Roth, M. (2008). Envisioning technological literacy in science education: Building sustainable human-technology-lifeworld relationships. *The Journal of Educational Thought*, *42*(2), 185–206.
Ministry of Education, New Zealand. (2006). *Technology in the New Zealand Curriculum*. Retrieved September 17, 2007 from http://www.tki.org.nz/r/nzcurriculum/draft-curriculum/technology_e.php
Ministry of Education, South Africa. (2002). *Curriculum 2005*. Pretoria: Ministry of Education.
Misco, T. (2007). Did I forget about the dispositions? Preparing high school graduates for moral life. *The Clearing House*, *80*(6), 267–270.
Narvaez, D., Bentley, J., Gleason, T., & Samuels, S. (1998). Moral theme comprehension in third grade, fifth grade and college students. *Reading Psychology*, *19*(2), 217–241.
National Council for Accreditation of Teacher Education (NCATE). (2008). *Professional standards accreditation of teacher preparation institutions*. Washington, DC: NCATE. Retrieved from http://www.ncate.org/documents/standards/NCATE%20Standards%202008.pdf
Pearson, G., & Garmine, E. (2006). *Tech tally*. Washington, DC: The National Academies Press.
Perkins, D. (1993). Beyond abilities: A dispositional theory of thinking. *Merrill-Palmer Quarterly*, *39*(1), 1–21.
Perkins, D., & Salomon, G. (1989). Are cognitive skills context bound? *Educational Researcher*, *18*(1), 16–25.
Rutland, M., & Spendlove, D. (2007). Creativity in design and technology. In D. Barlex (Ed.), *Design and technology – for the next generation* (pp. 140–153). Shropshire: Cliffeco Publishing.
Sockett, H. (2009). Dispositions as virtues: The complexity of the construct. *Journal of Teacher Education*, *60*, 291–303.
Thornton, H. (2006). Dispositions in action: do dispositions make a difference in practice? *Teacher Education Quarterly*, *33*(2), 53–68.
Waks, L. (2006). Rethinking technological literacy. In J. Dakers (Ed.), *Defining technological literacy* (pp. 275–296). New York: Palgrave Macmillan.
Williams, P. J. (2009). Technological literacy: A multliteracies approach for democracy. *International Journal of Technology and Design Education*, *19*(3), 237–254.

P John Williams
Centre for Science and Technology Education Research
University of Waikato, New Zealand
and Edith Cowan University, Australia

DAVID BARLEX

7. ACHIEVING CREATIVITY IN THE TECHNOLOGY CLASSROOM

The English Experience in Secondary Schools

INTRODUCTION

Creativity in education is elusive. Creative teaching is not necessarily the norm in a system immersed in a performance culture. In such a system, teaching that enables pupils to be creative may also be marginalised in efforts focusing on achieving ever-improving public examination results. Design and technology, the subject in the National Curriculum in England that is responsible for technology education, is not exempt from these pressures yet creativity lies at its core.

This chapter will start by setting the scene with a brief summary of recent government interest in creativity in England and current research findings concerning the conditions for creativity in the classroom. It will then discuss the implications for creativity in the technology classroom through the following eight considerations:

- Relating creativity to designing
- Achieving creativity through designing and making
- Achieving creativity through designing without making
- Developing a curriculum framework that supports creativity
- Using the Digital Design and Technology programme to support creativity
- Creativity through design and technology in the STEM context
- The relationship between assessment and creativity
- The role of collaboration in achieving creativity through design and technology

A discussion section will consider future challenges with particular reference to the strong STEM agenda. A final section of concluding remarks will suggest ways in which different members of the community of practice can work together to maintain and extend pupil creativity in design and technology in England.

SETTING THE SCENE

In 1999, the government in England invited Professor Kenneth Robinson of Warwick University to chair a working party concerned with creativity in education. Two government departments were involved in commissioning this work – the Department for Education and Employment, and the Department for Culture Media and Sport.

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 103–129.

David Blunkett, the Secretary of State for Education and Employment endorsed the report as follows:

> "The Government wants to give young people every chance to develop their full potential, to build on their strengths and to believe in themselves. Our cultural heritage, together with creativity through self expression, offers a way of developing the talent of the individual and their understanding of a diverse and complex world around them" (Foreword, Robinson, 1999).

Similarly, Chris Smith, the Secretary of State for Culture, Media and Sport was supportive of creativity in education

> "The opportunities to explore the best of contemporary culture and to express individual creativity are two vital components of any education system committed to developing the full potential of all its pupils. They also play an essential role in nurturing a lively society and dynamic economy" (Foreword, Robinson, 1999).

Members of the working party comprised musicians, artists, scientists, entertainers, entrepreneurs and writers, but curiously no designers or technologists. The report *All Our Futures: Creativity, Culture and Education* (Robinson, 1999) argues that a national strategy for creative and cultural education is essential to unlock the potential of every young person. It saw creativity in terms of the task at hand as having four features:

- using imagination
- pursuing purposes
- being original
- being of value

The Nuffield Design and Technology Project and a government agency QCA (Qualifications and Curriculum Authority) responded to the Robinson Report by inviting 20 teachers to attend a full-day meeting at which they presented pupil's work in art & design and design & technology that they considered creative. This was followed by visits to a selection of schools to watch lessons in progress and a further full-day meeting in which teachers presented and discussed pupils' work.

From this overview, it was possible to identify four features that had to be in place for pupils to act creatively in either subject:

- The activity had to be presented in a context to which the pupils could relate.
- The activity had to be supported by a significant stimulus that was often, but not exclusively, intensely visual.
- Focused teaching was necessary to provide knowledge, understanding and skills.
- An attitude of continuous reflection had be encouraged.

But the observations of lessons and the resulting work revealed that these four features alone do not ensure creative activity. The deciding factor is the way they are managed. This must be done so that pupils can handle uncertainty in exploring and developing outcomes. There must be some risk associated with the endeavour in terms of the "originality" of the activity as far as the individual pupil is concerned. This can be shown visually in Figure 1 using AND gate notation to indicate the range of requirements.

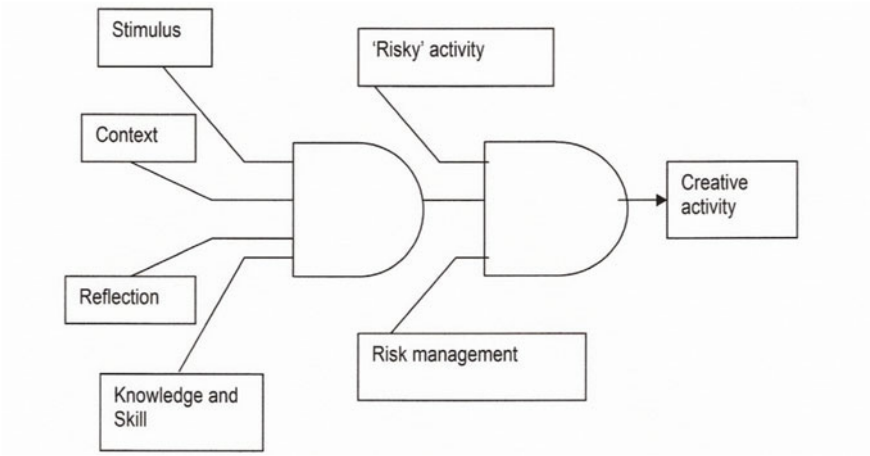


Figure 1. The double and gate model for teaching for creativity.

As a means of disseminating the findings of the Nuffield Curriculum Centre and QCA research, the Nuffield Design and Technology Project held a joint invitation seminar with DATA (Design and Technology Association) with the provocative title *Creativity in Crisis? Design and Technology at KS3 and KS4*. Presentations were made by researchers, education authority advisers and teachers followed by a series of working groups. The resulting paper (Barlex, 2003) became Research Paper 18 from the Design and Technology Association. It provides a snapshot of concerns about creativity in design and technology at the beginning of the 21st century. Two concerns of particular relevance to this chapter are: a) Jon Parker's concern about the examination system; and b) Patricia Murphy's concern about teacher practice.

Parker captures his concern nicely as follows:

> "...to a large extent, the tail wags the dog. Teachers are reluctant to change their practices when they have established strategies to ensure their A* to C grades each year. GCSE[1] coursework assessment procedures discourage teachers from breaking the mould. They seem more typically to reward those students who can jump through assessment hoops rather than encouraging those who are able to show real flair and imagination" (Parker, 2003, p. 7).

Murphy (2003) identified two broad categories of teacher 'voice.' First, there is the voice that aligned itself with a hegemonic pedagogy:

- Learners are passive receivers of information
- They are not motivated to learn
- They can only learn if knowledge was presented 'pre-digested' by the teacher
- The teacher has the sole authority for the curriculum and learning outcomes
- The teacher must provide tasks that are based on instruction and school-focused
- Any problems with learning rest with the learner, not the teacher, i.e., a deficit view of pupils limited by their innate abilities

Second, there is the voice that was strongly aligned to the situated view of learning:

– Intellectual abilities are socially and culturally developed
– Tasks must be culturally authentic
– Prior knowledge and cultural perspectives shape new learning
– Learners construct rather than receive meaning
– Pupils share responsibility for learning with teachers
– Pupils are motivated by dilemmas to which they are emotionally committed

Those teachers with the first voice hold a pedagogy that is inimical to supporting pupil creativity whereas those with the second voice can be highly effective in supporting pupil creativity. Murphy's main concern was "one of providing appropriate initial teacher education and continuing professional development to support teachers in questioning their practice by providing tools for both reflection and taking action in response" (Murphy, 2003, p. 17). Murphy is not alone in this concern. Hildebrand (1999), calling on the work of Ann Sfard (1998), argues that the prevailing transmission model of teaching has at its roots an acquisition metaphor. This must be supplanted by a participation metaphor through which the teacher and her students have a different relationship to learning, one in which the pedagogy can "remain fluid and flexible, slippery and situated, capable of being reconstructed within each context and each relationship that develops between and among the teacher and her students" (p. 12). Dow (2007) reminds us that the pedagogy that teachers adopt depends to a large extent on deeply held implicit beliefs that are usually not open to scrutiny but, when revealed, are highly resistant to change. This reinforces Murphy's call for appropriate initial teacher education and professional development.

Two pieces of recent research in the field have identified ways of describing practice that is conducive to pupil creativity and may be used to begin to address the concerns of Parker and Murphy. Marion Rutland (2005), while carrying out research for her PhD in creativity in design and technology, made an extensive literature review through which she generated a three-feature model for creativity:

– Domain relevant features – a set of practices associated with an area of knowledge, for example, design and technology or other subjects such as science and mathematics
– Process relevant features – influencing, controlling the direction and progress of the creative process
– Social, environmental factors – macro/micro environmental, social and cultural issues

This can be represented visually in Figure 2. All these features must be present in a classroom if pupils are to be creative. Investigation of classroom practice through the lens of this model indicated that in typical practice, teachers did not take sufficient account of the prevailing classroom ambience – the environment created by social and cultural factors. An appropriate ambience did not occur by chance, and teachers had to establish an environment where risk-taking was supported and rewarded (Rutland and Barlex, 2008). Such an environment would, of course, require the teacher to adopt a situated view of learning.

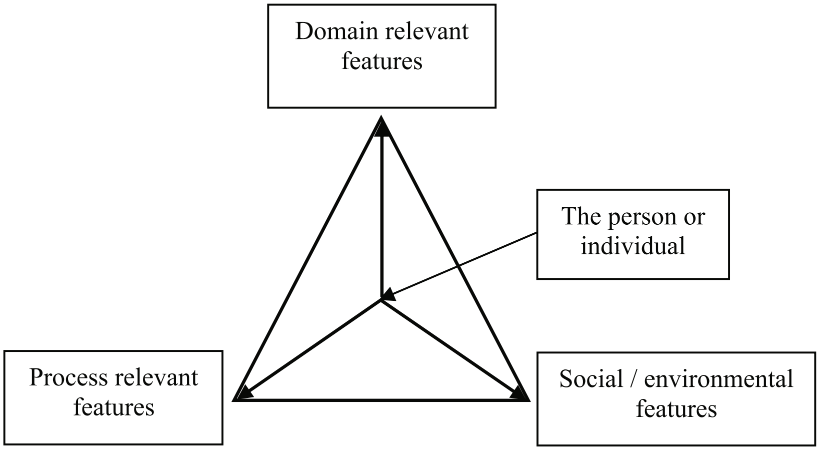


Figure 2. Three-feature model for creativity (after Rutland, 2005).

Bill Nicholl (Nicholl, McLellan, & Kotob, 2008) led an extensive two-year research project in creativity in design and technology. The research aims of the investigation were to support the leadership of excellence in teaching and learning design and technology by:

– Developing explicit models of learning and teaching in design and technology that explicitly develops creativity
– Supporting heads of design and technology departments to become more effective in their role as leaders of a learning environment in the subject, creating and managing a learning environment.
– (Nicholl, McLellan, & Kotob, 2008, p. 10).

The investigation identified two main features concerning the classroom situation that echo the findings of Marion Rutland (Rutland and Barlex, 2008) and the Nuffield Curriculum Centre QCA research (Barlex, 2003). Creativity will flourish if...

– The classroom climate is conducive to creativity
– The key elements of creative tasks are in place, e.g., ambiguous and risky, but include task-directed scaffolding.
– (Nicholl, McLellan, & Kotob, 2008, p. 44).

In addition, the research indicated it was important that teachers believed "that creativity and performativity can co-exist" (p. 44). This is an interesting finding in relation to Parker's concern that teachers fearful of underperforming in public examinations reject opportunities to enable their pupils to be creative.

Interestingly the investigation developed the use of three strategies to enhance pupil creativity derived from designer professional practice: conceptual combination (the merging of two or more concepts into a novel entity that may become more than the sum of its component parts), analogy (taking a property or properties from one entity and transferring them to another entity) and metaphor (describing something in a literary way that symbolises an aspect of it) (Nicholl, McLellan, & Kotob, 2008).

It is the relationship between professional design practice and the designing carried out by pupils that will be considered next.

RELATING CREATIVITY TO DESIGNING

Nigel Cross published extensively on the nature of designing (Cross, 2002, 2007), and using his research informed descriptions of designerly activity, it is possible to show that designing is a creative activity as envisaged by Robinson (Barlex, 2007a). However, while it is likely that the activities of professional designers as described by Cross will be creative, this begs the question as to the nature of the tasks that will enable children, who are novice designers, to design in a creative way. The work of the Electronics in Schools (EiS) programme went some way to helping teachers tackle this dilemma. From 2001 to 2003, the EiS programme piloted a variety of approaches to improve pupils' engagement with electronics in seven parts of England: Devon and Cornwall, Humberside, Leicestershire, Lincolnshire and Rutland, North London, Nottinghamshire and West Yorkshire, with funding and support from the Department of Trade and Industry and the Department for Education and Skills. In these regions, the programme had a major impact on schools, teachers and pupils, and provided models of professional development, resourcing, support and curriculum development, which can be built on elsewhere. The programme has since been carried forward under the banner of the Electronics in Schools Strategy (EISS). The evaluation of the EiS programme provided evidence that explodes a number of myths about electronics. These include that:

- it is too hard for pupils and teachers;
- it is too expensive;
- there is insufficient space in the curriculum;
- pupils cannot cope with design in electronics;
- girls cannot or will not do it;
- electronics classroom projects cannot compete with High Street products;
- the top priority for teachers and pupils should be a working product; and
- teachers introducing a subject like electronics are likely to find themselves isolated and unsupported.

Stephen Lunn of the Open University produced a short document *Dispelling myths about electronics in school* that examined in more detail the evidence in each of these cases, outlined the first steps that schools and teachers might take to move forward on electronics, and noted some points towards an agenda for action at national and regional levels that would help electronics in schools to flourish and help young people engage positively with 21st century technology (Lunn, 2003). To enable teachers to describe the designing they wanted their pupils to carry out, the EIS programme developed an approach to auditing the design decisions that pupils would take in a designing and making assignment. The audit can be carried out using five key areas of design decision: conceptual (overall purpose of the design, the sort of product that it will be), technical (how the design will work), aesthetic (what the design will look like), constructional (how the design will be put together) and marketing (who the design is for, where it will be used, how it will be sold).

This approach can be represented visually as a pentagon diagram shown in Figure 3. This interdependence of the areas is an important feature of design decisions, hence the lines connect each vertex of the pentagon to all the other vertices. A change of decision within one area will affect some, if not all, design decisions that are made within the others.

Usually the teacher identifies the sort of product the pupils will be designing and making. This makes it very difficult for pupils to engage in conceptual design, particularly if they are required to make what they have designed. But even if the type of product is identified for the pupils, there are still many opportunities for making design decisions in the other areas (Barlex, 2007a). In terms of technical decisions that pupils may make, this will depend on the technical expertise they have at their disposal. If pupils are to show creativity through technical design decisions, then it is essential that the teacher takes steps to enable pupils to acquire such expertise. There is, of course, a tension here between two extreme pedagogic positions: one that sees design as primarily a strategic context for learning particular knowledge, skill and understanding; and one that sees learning to design as an end in itself with the particular knowledge, skill and understanding needed to be successful being acquired on an as needed basis depending on the design task at hand and the nature of the solution that is designed. The author adopts a pragmatic view that sits in the middle, arguing that for a particular design task there is some easily identifiable knowledge, skill and understanding that is likely to be useful and to which the pupils can be introduced. But I would not necessarily insist that this be used in the solution in a particular way, and I would also allow the use of other knowledge, skills and understanding a pupil might have in developing his/her response to the design task.

This approach of auditing the design decisions within a task is complementary to that espoused by Marion Rutland (2005) and Bill Nicholl (Nicholl, McLellan & Kotob, 2008) in that it allows teachers to develop tasks in which pupils are required

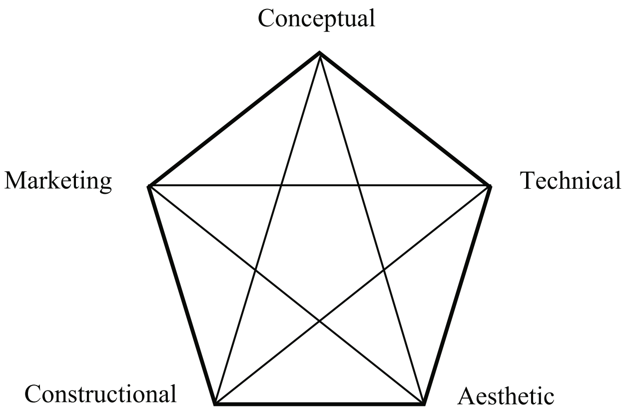


Figure 3. Design decision pentagon.

to make design decisions and then use the approaches recommended by these authors to support this decision-making, and hence enable the pupils to be creative through designing. It is important to reiterate that the design decisions in the key areas interact; all are important and the teacher's role in enabling pupils to be creative is much more than providing access to particular knowledge, skill and understanding.

ACHIEVING CREATIVITY THROUGH DESIGNING AND MAKING

A major feature of the design and technology curriculum in England is the designing and making assignment (DMA) in which pupils are expected to "combine practical and technological skills with creative thinking to design and make products and systems" (QCA, 2007).

The Nuffield Secondary Design and Technology Project developed pedagogy in response to the demands of designing and making that formed the core of the design and technology curriculum. This pedagogy consisted of three types of learning activity: Resource Tasks, short, often practical activities that taught specific skills, knowledge and understanding likely to be useful in tackling a designing and making activity; Capability Tasks, longer, more open designing and making activities as required by the National Curriculum; and Case Studies, true stories about design and technology in the world outside school to enable pupils to put their studies into a wider context. Through a careful combination of these types of learning activity across a number of years, a teacher could construct a learning experience that encouraged creativity through designing and making. Of course, in addition to providing opportunities for pupils to be creative, the sequence of Capability Tasks and the associated Resource Tasks and Case Studies must be devised in order to achieve: a) breadth across the different media with which pupils are required to design and make (in England this covers food, textiles, resistant materials, graphic media and technical components); b) balance in that there is a significant experience of designing and making with each of these media; and c) progression in that the demands of the designing and making increase over time. Overlaid on this progression are the content requirements as detailed by the National Curriculum. In this way, the learning intended through the designing and making can be planned for in some detail. The Nuffield Teacher Guide (Barlex, 2000) gives detailed guidance on how to devise such a sequence and is available on the www.secondarydandt.org website (see reference list).

There was concern that teachers had few, if any, strategies for managing the risks that pupils were taking in their attempts to be creative during Capability Tasks. This issue was also addressed in the revised edition of the *Teacher Guide* (Barlex, 2000). Ten points of teacher decision were identified through a set of key questions.

- How should I introduce the task?
- Do I link with other subjects?
- How open do I make the brief?
- How do I ensure good design ideas?
- How complex should the specification be?
- How will students model solutions?

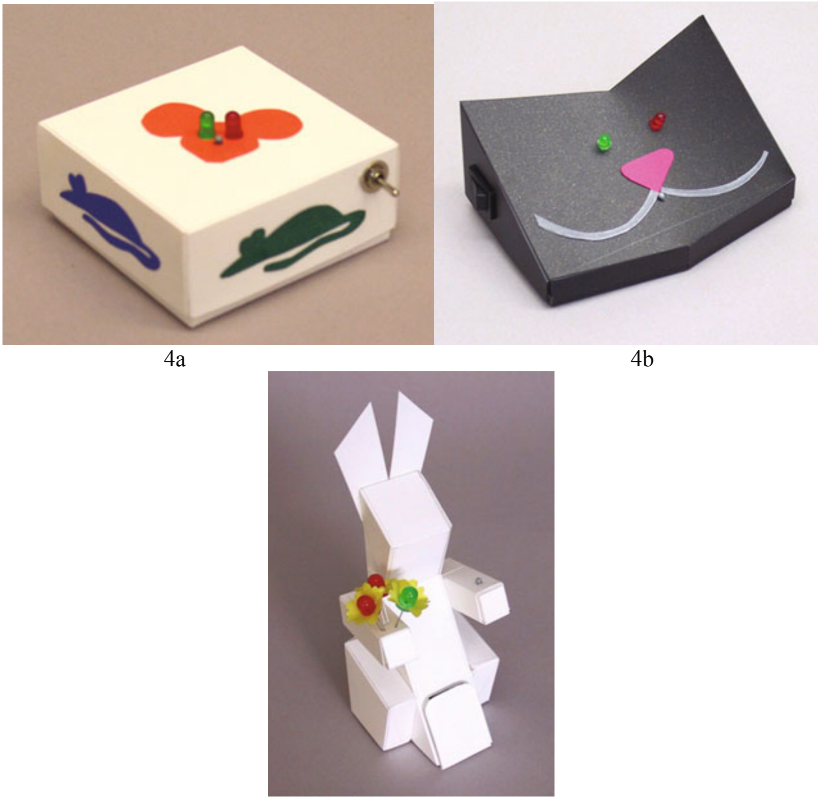
– How do I ensure students stay on track?
– What sort of written feedback do I give?
– How do I ensure quality making?
– How will I organise final evaluation?

By considering these questions when planning the teaching of the Capability Task, the teacher can develop strategies for dealing with the issues and use them flexibly according to the response of the class and individual pupils as the task unfolds. Detailed examples of possible strategies are given in the teacher guide and are available at the www.secondarydandt.org website (see reference list).

An important feature of the work that pupils carry out in response to a Capability Task is that there is variation in pupil response such that the individuality of their responses to the task is apparent. To exemplify possible variation in pupil response to a Capability Task, the Electronics in Schools commissioned an experienced designer maker to produce three levels of response to a brief requiring pupils to design and make a sensing device that would activate an alarm when the temperature in an animal's hutch becomes so low that it would be harmful for the animal to stay in the hutch. The first level of response was required to be modest, which could be achieved by a pupil who completed the task satisfactorily but without showing much in the way of visual flair or constructional/technical ingenuity. The second level of response was required to be intermediate in that it indicated some visual flair and constructional ingenuity. The third level of response was designated advanced and was required to show visual flair, constructional ingenuity and some technical creativity.

All responses involve developing a relatively simple sensing circuit and enclosing it in a housing that indicates the animal that is 'protected.' The most modest response is shown in Figure 4a and is in the form of a simple box decorated with basic images of the creature to be protected by the low temperature warning. The response shown in Figure 4b moves away from decorating the enclosure to show the creature protected by using the form of the enclosure to indicate the creature (in this case a cat). The most creative response shown in Figure 4c makes use of the enclosure to indicate the creature protected much further in creating the form of a rabbit through a combination of geometrical forms and providing additional electronics that give a low temperature warning through a set of flashing LEDs representing a bunch of flowers. In terms of creativity through design decisions, the technical design decisions are limited in the modest and intermediate responses, although even at these levels of response it is possible for the pupils to make technical design decisions in terms of choice of temperature sensor and components required to achieve a suitable potential divider in the temperature sensing circuit. At the levels of response developed in the modest and intermediate responses, more opportunities were taken for aesthetic and constructional design decisions. However, in the advanced response, the technical design decisions involving flashing LEDs provided the opportunity for more technical design decisions to be made, especially if the LEDs were required to flash in a particular sequence.

Those working on the Nuffield Secondary Design and Technology Project were aware of the difficulty in engaging pupils in creativity through technical



4a 4b 4c

Figure 4. Creative approaches for housing electronic products.

design decisions. The device they developed to deal with this difficulty was the chooser chart. There are three charts concerned particularly with technical matters – mechanical, electrical and electronic control. Such charts summarise areas of content in such a way that pupils can use the content to make decisions either unaided or with minimal support from their teacher. An able pupil can use such charts to make decisions, which he/she can then justify to the teacher. For a less able pupil, the teacher can ask questions, which engages the pupil with the content of the chart, thus leading the pupil to make his/her own decisions. These charts are readily available as free downloads at the Nuffield Secondary Design and Technology Project website.

ACHIEVING CREATIVITY THROUGH DESIGNING WITHOUT MAKING

Insisting that pupils should always make what they have designed can undermine pupils' autonomy especially if they have limited making skills. The Young Foresight project deliberately avoids this difficulty by requiring pupils to work collaboratively in designing but NOT making products and services for the future utilising new technologies as a starting point (Barlex, 2007b). The focus of the Young Foresight project was to enhance pupil creativity by improving pupil designing skills. The activity of designing without making was not intended to supplant designing and making or making as activities that may be used to enhance creativity, but as a complementary activity to these other learning approaches. Some of the products and services devised by groups of Year 9 pupils in response to the challenge of utilising the stress-sensitive conductor QTC (Quantum Tunnelling Composite) include the following (see Figure 5):

– Clothing that change colour as you dance
– Car tyres that sense their internal pressure
– An epileptic fit detector
– A self-weighing suitcase
– An arthritis treatment device
– Keep fit apparatus
– A depth-sensitive submersible
– An internal heart beat monitor

These ideas show the use of imagination, the pursuit of purpose, originality and value – the four features of creativity identified by the Robinson Report. If the pupils had been required to make what they were designing, it is extremely unlikely that they would have shown this level of creativity. Indeed, designing without making gives pupils the opportunity for conceptual design.

One feature of the project was to use an experienced illustrator to work with the pupils so that they could discuss their preliminary designs with him and then he could interpret them using his skill as an illustrator. This had two benefits. First, it showed the pupils that their ideas were being taken seriously and that when drawn by someone who could draw well, the worth of their ideas became more apparent. This is shown vividly in Figure 6, which juxtaposes the pupil's initial, quite primitive sketch with the illustrator's interpretation. Note that all the important design decisions are embedded in the pupil's sketch but are brought to life by the illustrator's interpretation as a sequence of 'comic book' style illustrations.

Second, it developed pupils' confidence and ability to sketch. The illustrator reported that on many occasions when he was discussing a pupil's ideas and drawing them, the pupil would take the pencil from him and make changes to what he was drawing. As the pupils watched the illustrator work and developed the confidence to intervene, it was noticeable that their confidence in sketching became much greater and they produced larger, bolder illustrations of their ideas.

Initially, the Young Foresight project was only available to teachers who attended a full one-day in-service session. Later, the approach was adopted by the National Strategy for Design and Technology in England (Department for Education and Skills, 2004) as an approach that enhanced pupil creativity through designing. The project website is still live, although inactive, and examples of the materials for teachers and pupils and pupil work are available at the Young Foresight website (see reference list). Trebell (2009) used the design without making approach to explore classroom interactions that support pupils' design activity.

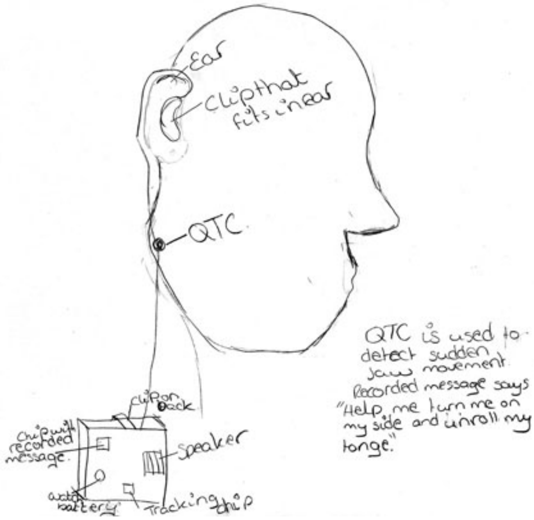


Figure 5. A pupil's initial annotated sketch of her design ideas.

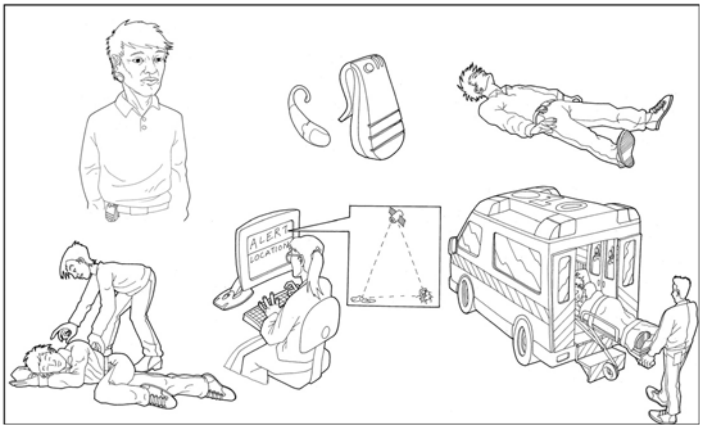


Figure 6. An illustrator's comic book style interpretation of pupils' ideas.

DEVELOPING A CURRICULUM FRAMEWORK THAT SUPPORTS CREATIVITY

Electronics in Schools Strategy (EIESS) and Electronics and Communication Technology (ECT)

The work of the Electronics in Schools project was extended by the Design and Technology Association to become the Electronics in Schools Strategy (EISS), and a curriculum framework for electronics and communication technology (ECT) was developed. This development manifested itself through the ECT curriculum website (see ectcurriculum in the websites list). In keeping with the view that it is through designing that pupils will be creative in design and technology, the framework describes designing in terms of activities pupils will engage in as they move through a designing and making task. According to the framework, pupils will need to determine, develop and implement their ideas, use maths and science, but not necessarily in that or any other prescribed order, often revisiting the different procedures several times in an order dictated by their progress in the task and the nature of the task. This framework uses the idea of 'starting points' for designing. A small working party of experienced electronics teachers in design and technology were tasked with developing an appropriate set of starting points. Through discussion, using their combined expertise and the idea from the Nuffield QCA research that tasks leading to creativity should be put in a context to which pupils can relate, the group identified six starting points. The starting points were also chosen on the grounds that they could lead to pupils designing and making electronic products of varying complexity depending on the sophistication with which the pupils responded. Hence, the starting points are not age- or key stage-specific. Once identified, the starting points were explored to ensure that they provided the opportunity for wide-ranging responses. The six starting points identified were:

– playtime
– keeping in touch
– keeping secure
– staying safe
– thinking machines
– other worlds

There are, of course, many other possible and valid starting points that the group could have identified, but for the purposes of this exercise, this number was felt to be sufficient and provided a sufficient variety across the set to be of interest and use to both teachers and pupils.

The framework provides different degrees of 'openness' for each starting point. The 'very open' starting points are visual brainstorms allowing the teacher and the class to explore the context for a wide range of possible briefs. The 'moderately open' starting points provide briefs that do not define the nature of the product to be designed and made. The 'closed' starting points provide briefs in which the nature of the product is defined. The framework supports the acquisition of the technical knowledge skills and understanding required to design and make fully functioning

Table 1. Features of progression in designing and making electronic products

Modelling and Simulating Circuits
Systems Thinking
Programming Systems
Understanding Technical Function
Sensing and Measuring
Communicating
Controlling power
Producing

electronic products by providing a growing list of focused tasks developed for this purpose. The framework describes how pupils might make progress in designing and making electronic products by listing a series of statements describing important features of knowledge and understanding. These are shown in Table 1.

Each feature is described at four levels of demand:

- Introducing
- Developing
- Enhancing
- Advancing

The statements for using scientific and mathematical concepts are presented such that they can be integrated into the other statements as appropriate. Some examples of statements concerning understanding technical function with regard to sensing and measuring are shown in Table 2. There are fewer statements at the lower levels of demand and these statements deal with simple concepts. The number and complexity increase on moving to the higher levels of demand. At the moment, these level statements are based on the experience and understanding of the ECT Framework working party. It remains to be seen whether these actually reflect the progression that pupils make as they become more adept at designing and making electronic products. The website warns that, in many cases, pupils will be between these levels of demand in their progress. Therefore, it is important to see these statements as indicators of difficulty and teaching sequence, and that it is not useful to see a hard boundary between these levels of demand.

A criticism of some approaches to creativity is that they enable pupils to be creative with form rather than function. This criticism could be levelled at the temperature sensing device described earlier. While the form of a product, realised through appropriate aesthetic design decisions, is of course an essential component of a product's appeal and ultimate success, the effective technical functioning is indispensible. Those responsible for the ECT curriculum framework believe that it provides a toolkit for teachers that will enable them to support pupils in designing and making functioning electronic products with visual appeal that meet purposes the pupils consider worthwhile.

Table 2. Level statements concerning understanding technical function with regard to sensing and measuring taken from the ECT framework website

Level 1: Introducing
– Know that a wide range of environmental signals can be sensed using electronic components (sensors) including temperature, light, moisture, sound, pressure, force, magnetism, movement/angle – Know that some sensors are switches (being either off or on)
Level 2: Developing
– Understand that switching sensors provide a digital signal (high or low voltage) – Know that many sensors respond to environmental signals by varying their resistance or produce a changing voltage – Sensors whose resistance varies provide an analogue signal; where the value varies between 0V and the supply voltage

Table 2. (Continued)

Level 3: Enhancing
– Understand that where sensors provide a changing resistance, a potential divider is used to convert this change into a varying signal (voltage) that depends on the ratio of the two resistances in the potential divider – Be able to use the potential divider equation to select appropriate resistors for a particular sensor – Understand that many electronic components only accept digital signals, so analogue signals may have to be converted into digital signals (analogue-to-digital conversion - ADC) – Be able to use a comparator for simple ADC. Understand that this provides a high signal when the input is above a certain threshold and a low signal when the input is below that threshold
Level 4: Advancing
– Understand matched pairs of IR or ultrasound emitters and receivers can be used to sense proximity and that light or IR sensors can sense surface colour – Know that pulses in digital signals can be counted electronically – Know that mechanical switches produce multiple pulses when pressed due to 'switch bounce' and that this must be accounted for in counting circuits either with a 'de-bounce' circuit or in a counting program – Know that the rate at which pulses arrive at a sensor can be measured as a frequency – Understand that a comparator provides one-bit ADC in which most of the information about the input signal is lost – Using multiple threshold values for digitisation allows more of the information in an analogue signal, to be preserved – Understand that each ADC threshold adds an input signal, e.g., four thresholds lead to four digital signals representing the value of the original analogue signal; know that ADC chips are used for this – Understand that measurement often requires complex signal conditioning, as most sensors don't respond linearly to changing conditions; some sensing devices provide measurement signal conditioning within an IC and therefore do give a linear response – Know that a wide range of modern electronic devices provide access to sense and measurement data that are relatively novel; these include location data from GPS and GIS systems, RFID data, data from accelerometers and Internet-based data
Science links
– Be able to calculate the value of resistors in series – Be able to calculate the signal value from a potential divider – Be able to use the resistor colour code – Be able to use Ohm's Law to select a resistor to achieve a desired current flow or to establish the current flowing through a resistor – Be able to calculate the time value for a simple RC network
Mathematics links
– Be able to read a range of scales in the context of measurement, interpolating effectively where appropriate – Be able to work with problems involving ratio and proportion – Be able to use and manipulate equations with three variables (e.g., Ohm's Law) – Understand the concept of number bases; be able to work with binary numbers up to 8 bits – Understand that a 4-bit binary number can be represented as a hexadecimal number (0-F)

DIGITAL DESIGN AND TECHNOLOGY TO SUPPORT CREATIVITY

In response to the need to modernise the design and technology curriculum, the Design and Technology Association has developed the Digital Design and Technology Programme (Design and Technology Association, 2010). This programme was formulated to bring together in a coherent manner those elements of design and technology that made strong use of information and communication technology. This involved amalgamating two very successful existing programmes – the CADCAM initiative and EISS. The result of this amalgamation was the establishment of four support centres in each of the government regions, creating 36 support centres across England. The support centres are required to provide professional development having a positive impact on classroom practice. A particular feature of the practice they promote is the use of microcontroller (PIC) chips in the designing and making of electronic products by pupils aged 11–14 years. Those responsible for the programme argue that it will have a great effect on the opportunities for pupils to develop creativity and autonomy. A typical and pervasive example of a traditional 'hard-wired' approach to electronic products in this age range is the designing and making of a 'steady-hand game.' This has been justly criticised for teaching very little electronics (pupils generally simply assemble a pre-designed board) and reducing pupil decision-making since the electronics are a given and pupil choice is often restricted to limited aesthetic and constructional aspects. The introduction of a microcontroller (PIC) as the core of the electronics completely transforms pupils' ability to work creatively with the project since features such as 'lives,' difficulty levels, scoring systems and a range of auditory signals can be implemented in the way the PIC is programmed to respond. Equally, the final product can be transformed from a simple game into, for example, training equipment for a stroke patient. The most innovative support centres are helping teachers move beyond simply incorporating microcontrollers into existing designing and making assignments. They support teachers in using the open starting points approach in the ECT Framework. In one case, a pupil responded to 'staying safe' by designing and making a fully functioning temperature sensor that an elderly person wears next to his skin and functions as a hyperthermia alarm.

To identify, celebrate and disseminate work such as this, each of the support centres has been asked to provide examples of good practice from one or more of the schools in their region. This will take the form of a large image board showing items that a class of pupils has designed and made as a result of the teacher having undertaken support centre professional development. The board should be accompanied by a brief commentary (five or six bullet points) that justifies the activity in terms of *some or all* of the following features of good practice:

- Teaching of knowledge, skills and understanding relevant to the designing and making activity (DMA)
- Provision of a stimulus that engages the pupils
- Placing the activity in a context to which the pupils can relate
- Utilises open starting points
- Involves pupils in making design decisions concerning some or all of the following: a) the nature of the product; b) how the product works; c) what the product looks like; d) how the product is constructed; and e) who the product is for

- Indicates creativity in that there is a variety of products showing particular responses of individual pupils
- Demonstrates effective use of digital tools in both design and manufacture
- Demonstrates effective use of traditional design tools

It is hoped that the professional development provided by the Digital Design and Technology support centres enables teachers to teach in ways that enable pupil creativity through designing and making using both digital and conventional design tools.

CREATIVITY THROUGH DESIGN AND TECHNOLOGY IN THE STEM CONTEXT

The fate of design and technology in England is to some extent entangled with the National Science, Technology Engineering and Mathematics (STEM) Programme. The National STEM Programme has its roots in the report to the Government by Sir Garth Roberts *SET for Success The Supply of People with Science, Technology, Engineering and Mathematics skills* (April, 2002), and the report by Lord Sainsbury of Turville *The Race to the Top: A Review of Government's Science and Innovation Policies* (October, 2007), both of which indicated the need for more pupils to gain qualifications in science and mathematics. In direct response to these reports, the government produced a report titled *The Science, Technology, Engineering and Mathematics (STEM) Programme Report* (DFES and DTI, 2006). As the following quote reveals, the government had decided to rationalise the range of STEM initiatives and initiate a national strategy.

> "However, at the current time we have far too many schemes, each of which has its own overheads. The original STEM Mapping Review in 2004 revealed over 470 STEM initiatives run by DFES, DTI and external agencies and subsequently, the STEM cross cutting programme examined around 200 of these. They are not, therefore, in total either efficient or effective and do not give a complete coverage of all schools. We need, therefore to rationalise those supported by the Government and build on the best ones. By doing so, we believe we can achieve a much better result for the same amount of money. Our proposals work towards a vision that aims to ensure that STEM support is delivered in the most effective way to every school, college, learning provider and learner. For the first time we will have:
>
> One high level STEM Strategy Group that will join up STEM across all phases of education and make recommendations to Ministers about national STEM priorities; and a National STEM Director who will drive delivery forward" (p. 3).

The report made sorry reading for the design and technology community: it had virtually ignored design and technology. The only reference to the subject was as follows:

> "It should be noted that engineering and technology are not typically considered as curriculum subjects in schools – though design and technology and ICT may count as such – but they are often college subjects" (p. 10).

John Holman was appointed National STEM Director. Under his leadership, an action plan for the national programme was developed and organised into five themes involving 11 action programmes overall, with each action programme supported by a lead organisation (National Science Learning Centre, 2008). This is presented in Appendix 1. Inspection of the individual action programmes that comprise the national programme reveals a dominance of mathematics and science. Some commentators have described the programme as a SM programme as opposed to a STEM programme. The complete absence of the phrase design and technology is an obvious cause of concern for those who believe that this school subject can make a significant contribution. Since the inception of the STEM National Programme, the role of design and technology has improved significantly through the work of the Design and Technology Association. From being ignored and invisible, design and technology is seen as the major contributor to the technology component and an important precursor to the engineering component (Barlex, 2009).

Maintaining the significance of creativity through design and technology within the National STEM Programme will not be a trivial task. To maintain its influence, it is likely that design and technology will have to demonstrate the effective use of science and mathematics in the teaching and learning of design and technology so that pupils a) experience the utility of these subjects and b) are motivated to continue studying them post age 16. The *Interaction Report* (Barlex and Pitt, 2000) and *Becoming an Engineering College* (Barlex, 2005) both revealed that the school subjects of mathematics, science, and design and technology tended to operate in isolation from one another in distinct contrast to the relationship between these activities in the world outside school, where a dynamic interaction exists with each area of activity contributing to and feeding from the interaction. There are signs that this is changing in some schools. The mood of cooperation and collaboration between STEM subjects has been enhanced by establishing the STEM pathfinder programme funded by the Department for Children Schools and Families (DCSF) and managed by the Specialist Schools and Academies Trust (SSAT). The programme enabled and supported networks of specialist schools to design and deliver integrated STEM activities through a programme of continuing professional development, and the provision of resources, consultancy and advice to schools. The driver for the path finder was the DCSF's interest in whether a STEM specialism could be manageable and advantageous (NFER 2009). The evaluation of the STEM Pathfinder programme identified the added value of integrated STEM activities on pupils as:

- "Awareness of the links between STEM subjects (e.g., maths skills and knowledge relevant to science, technology and engineering
- Ability and opportunities to transfer learning between subjects and reinforce learning
- Awareness of the relevance of STEM subjects to a broader spectrum of careers
- A sense of the interdisciplinary nature of many STEM careers and applications of STEM subjects" (p. 5).

On teachers, the added value included "Capacity skills and confidence to highlight the broader context of their subject and how it relates to other subjects and disciplines" (p. 5).

The evaluation noted that “The major challenges faced by teachers were finding time to meet together and plan activities, timetabling activities and getting other staff involved in the activities” (p. 6).

Ainley, Pratt and Hansen (2006) made the argument for the use of one subject informing purposeful activity in another subject with regard to the use of mathematics. It is easy to see how this argument could be extended to include the use of both science and mathematics for the purposeful and creative activities embedded in design and technology. Identifying practice that exemplifies the use- purpose argument has not been easy. Sharkaway, Barlex, Craig, McDuff and Welch (2009) carried out a literature survey designed to identify such practice, and reported that there were relatively few successful examples available and that these came from small case studies. However, recent and as yet unpublished work (Welch and Barlex, 2010) is actively pursuing this elusive goal of enabling pupils to use their mathematics and science understanding in making technical design decisions. Results so far indicate that the designing and making task must be structured to enable technical design decisions to be isolated to some extent from other design decisions so that the pupils can investigate technical performance and then optimise this using mathematics and science before integrating the resulting technical system into the consequences of the remaining design decisions. This approach does have some resonance with the one adopted by Zubrowski (2002), who developed an approach in which pupils are provided with an imperfect “standard model” where they are challenged to analyse its weaknesses and improve it, thereby enhancing their understanding of basic principles.

THE RELATIONSHIP BETWEEN ASSESSMENT AND CREATIVITY

The concerns raised by Jon Parker pertaining to the impact of terminal assessment schemes for pupils aged 16+ years were seen as a general criticism of the assessment required by the Awarding Bodies, which write the specifications and detail the methods used to assess the attainment of pupils at the end of a two-year general certificate of secondary education (GCSE) design and technology course. In 2008, QCA was required to undertake a review of the final specifications and sample assessment materials submitted by the awarding bodies for GCSE design and technology courses. This appeared to be an opportunity to significantly improve the situation. However, the introduction of a device called the controlled task that Awarding Bodies were required to use for the assessment of course work is now seen by some to severely limit the ability of teachers to provide the scaffolding necessary to support pupils as they work through a designing and making assignment (Gardener, 2010). A controlled task must be undertaken under conditions that allow the teacher to supervise the work and enable the work to be authenticated. If it is necessary for some assessed work to be done outside the centre, sufficient work must take place under direct supervision to allow the teacher to authenticate each candidate’s whole work with confidence. Some argue that such support is a natural part of the way course work should be tackled in design and technology, and that teachers have sufficient professional judgement to know what level of support is required to help pupils without giving so much support that the work is ‘taken over by the teacher’ and does not reflect the pupil’s true attainment (Steeg, 2010). Sim and Duffy (2004) argued that the act of designing is a learning process in which the designer learns about the design proposal as he/she is creating it. So, it is possible to see the designing and making assignment not simply as a means of assessment but at the same time as a means of learning. Vygotsky (1978) argued convincingly that a learner achieves more learning when assisted by a more able peer than when operating in isolation, and the role of the teacher in scaffolding pupil's creative endeavours in a controlled task can be seen as assistance from a more able peer, conducive to greater learning and improved performance. The examining bodies go some way to supporting this position, requiring that any assistance given should be provided in such a way that candidates have alternative possibilities to explore and make their own decisions about accepting or using the information or advice provided by the teacher.

One Awarding Body worked closely with the Technology Education Research Unit at Goldsmiths College to develop a model of assessment in which pupils were able to produce an e-portfolio by conforming to a scripted set of activities. The pupils used personal digital assistants (PDAs) to record their design activity in real time. The PDA could act as a digital sketchbook, digital note book, digital camera and or digital voice recorder. Note that since this preliminary work, advances in hand-held communication technology have made it possible for pupils to use other devices for this purpose such as sophisticated mobile phones. The evidence of activity is recorded digitally as pupils respond to the scripted instructions. The evidence is then automatically transferred to a database that contains similar work by many other pupils. Comparison between different pupils' work allows teachers to make valid and reliable assessment of pupil's attainment (Kimbell, 2007). This is a highly innovative approach to terminal assessment but is a one-size-fits-all approach, and it is here that I see a considerable weakness. Some would argue that one-size-fits-all is the price to be paid for validity and reliability. I argue that it is important, even essential, that pupil's individual approaches to designing should be both allowed and encouraged if we are to facilitate creativity. In fact, I propose that assessment should be minimally invasive (Barlex, 2007a). In such an approach, pupils would have control of and be responsible for the way they designed. All that would be required for assessment evidence would be that they use scripted probes at key points in the designing and making task to divulge and record their designerly thinking by revealing and justifying their design decisions. The teacher would be free to support the designerly thinking of the pupil, as suggested by Steeg, and be required to play the part of mentor and client in helping pupils use the scripted probes effectively. There would be no need for a class of pupils to adopt a lock-step approach. Different pupils could be at different stages in their designing and using different approaches according to the demands of their particular design task and their approaches to it. Of course, if pupils chose to use the PDA approach developed by Kimbell for terminal assessment as their preferred style of designing, there would be no objection.

THE ROLE OF COLLABORATION IN ACHIEVING CREATIVITY THROUGH DESIGN AND TECHNOLOGY

Achieving creativity in the secondary school design and technology classroom is not a simple matter. There is no magic bullet to provide the solution. The response will inevitably be complex and multifarious. There can be many manifestations of such creativity, each requiring in itself creativity and collaboration from those involved. Csikszentmihalyi (1999), an acknowledged expert on creativity, makes a strong case for building communities that nurture creative genius as opposed to developing highly gifted individuals.

> "... the occurrence of creativity is not simply a function of how many gifted individuals there are, but also how accessible the various symbolic systems are and how responsive the social system is to novel ideas. Instead of focusing exclusively on individuals, it will make more sense to focus on communities that may or may not nurture genius. In the last analysis, it is the community and not the individual who makes creativity manifest" (p. 333).

This resonates strongly with the idea of teachers taking responsibility for achieving the conditions for creativity in their classrooms such that they treat the class as a creative community and through this enable the creative development of individuals within that class. A single teacher, however gifted, working in isolation is unlikely to be able to maintain the energy and effort required achieving this; hence, collaboration will be an indispensible feature of success in this elusive quest. Vera John-Steiner has written extensively about creative collaboration (John- Steiner, 2000) and has developed a 'family' pattern as one possible means of achieving this. In this vision of creativity, a dynamic integration of expertise is achieved through a fluidity of roles fuelled by a common vision and underpinned by trust. This view of creativity is useful in considering the response of the design and technology community. There must be a shared vision of how creativity might be manifest in the subject, with contributors to this vision taking different and differing roles. Teachers wishing to establish their design and technology classes as creative communities will need to become dependent on the efforts of many different contributors: other teachers who have good ideas and are prepared to share them, curriculum developers who explore different possibilities for creative activity and professional associations who create opportunities for professional development. This will require trust. The whole complex of interactions creates a community of practice whose members are constantly contributing to and feeding from the overall endeavour in which their efforts depend on the efforts of others. As John Steiner reminds us "there is nothing to be ashamed of in such dependence. It is a dignified interdependence and the achievements of those who are dependent on each other in this way far out strips what they could achieve in operating independently" (p. 188).

DISCUSSION

The title of this book implies that it is natural for design and technology to define itself through the contribution it makes to the STEM agenda and play an important role in England in encouraging and enabling young people to take up technical careers that are seen as essential to maintain the country's competitiveness and success in the global economy (Sainsbury, 2007). This position has recently been questioned by Sir Christopher Frayerling in his valedictory speech as Rector of the

Royal College of Arts (Frayerling, 2009). He challenged the supremacy of STEM as the key player responsible for reinvigorating the economy, arguing that the creative media industries are of equal if not greater significance. This suggests that teachers would be unwise to neglect the relationship of design and technology to art and design in the school curriculum, and that it is important for the subject to look in at least two directions for co-conspirators in the education of young minds. In one direction, we see art and design and the possibility of encouraging interest and appetite for creative media; in the other direction, we find science and mathematics and the possibility of encouraging interest and appetite for STEM. Creative responses are essential in both arenas and it would be foolish to limit our contribution to education by looking just one way.

However, there is growing agreement that the T in STEM with regard to the STEM National Programme (DFES and DTI, 2006) is to a large extent represented by the school subject, design and technology. Implicit in the STEM National Programme is the belief that there should be links between science, mathematics, and design and technology that mirror the relationship between these areas of activity in the world outside school. This was reinforced by the report *S-T-E-M Working Together for Schools and Colleges* based on the outcomes of a workshop held at the Royal Society in May 2007 (Royal Society, 2007). Hence, it is likely that within design and technology, pupils will be encouraged to use their science and mathematics learning to inform their designing. This will be an important development as it will enhance the quality of the technical design decisions that pupils make. This has implications for creativity in design and technology in that there will now be the expectation that technical creativity should be demonstrated in pupil work. It is as yet uncertain how this will play out in terms of assessment, either in the controlled tasks, which could be designed to require a more technical response, or written examination papers, which might contain questions requiring in-depth technical explanation of design decisions. It remains to be seen whether the rise of the e-portfolio will allay the fears that Jon Parker voiced in terms of formulaic response (Parker, 2003) or help pupils make and record technical design decisions appropriately. The real-time evidence capturing embedded in the e-scape approach has yet to be focused on design decisions requiring significant scientific or mathematical reasoning. An important aspect of this technical creativity is the extent to which it can be achieved within design and technology seen as a component of general education as opposed to engineering, manifestly technical, which has become a school subject at 14 years through both an engineering GCSE course for pupils aged 14–16 years and an engineering diploma course for pupils aged 14–19 years. The relationship in the curriculum between design and technology and engineering has been articulated by Matthew Harrison (Head of Education at the Royal Academy of Engineering) at a recent STEM Advisory Forum event (Harrison, 2009). Matthew used a generative metaphor (Schon, 1963) to describe the roles of engineers and engineering in the curriculum for pupils under the age of 14 years as that of "an invited guest." Hence, engineering professionals visiting schools as part of STEM initiatives should be aware that they are there because they have been invited and should behave accordingly with consideration towards the hosts' overall intention for the design and technology curriculum as being to some extent in response to general education. At the same time, the teachers who invite engineers and engineering into the curriculum for younger pupils should acknowledge the authenticity of the engineering experience and treat ambassadors for engineering as guests with something well worth listening to. Matthew acknowledged that activities within design and technology that involve designing products of technical intricacy for manufacture embraced many aspects of engineering.

Curriculum developers are part of a wider community that contributes to pupil creativity. Individual teachers play an important part but their activities are dependent to some extent on those responsible for initial training and professional development. In addition the professional association for design and technology teachers plays a key role in promoting all aspects of the subject including the development of pupil creativity. Members of this community have the opportunity to work in synergy such that they promote creative communities as opposed to a minority of creative individuals (Csikszentmihalyi, 1999), and in being part of such communities are able to extend their influence and effectiveness through collaboration (John-Steiner, 2000).

This wider community faces some interesting challenges in maintaining and extending pupil creativity in design and technology. These challenges can be seen as a struggle between two competing requirements. On the one hand, creativity requires teachers and pupils to be adventurous in taking intellectual and practical risks in their designing and making, which requires operating in an environment of uncertainty. On the other hand, if pupils are to be creative it is important that they acquire a wide range of practical and intellectual skills that are usually taught in a didactic, though not necessarily an un-engaging manner operating in an environment of surety. It is achieving a balance between these competing requirements that is at the nub of the challenges. Neil Gershenfeld (2005) argues for a 'just in time' approach to learning as a way of finding the balance, and Torben Steeg (2008) argues that the approach developed by Gershenfeld in his fabrication laboratories (known colloquially as fablabs) is an important way for schools to respond to the issue of pupil creativity.

CONCLUDING REMARKS

To maintain and extend pupil creativity in design and technology in England, there is a wide range of activities in which members of the community of practice concerned with this endeavour can collaborate. The first is research that explores manifestations of pupil creativity in different design and technology classrooms. Here, collaboration between teachers, teacher educators and academics concerned with creativity would pay great dividends in providing examples of pupil creativity linked to the classroom conditions that enabled such creativity. An important extension of this research is to embed its findings in initial teacher education and professional development so that creativity is seen as a legitimate, widespread and achievable phenomenon in the way pupils respond to design and technology lessons. The Design and Technology Association has an important role to play here in promoting such activities and ensuring that the curriculum development it pursues gives strong consideration to pupil creativity and that this is valued by pupils, their parents and school administrators. All members of the community of practice will need to contribute to influencing government thinking such that it acknowledges the important and unique role that design and technology plays in the curriculum, with particular regard to developing creativity, essential at a time when the world is facing the biggest challenges in human history.

NOTES

[1] The GCSE (General Certificate of Secondary Education) is a public examination qualification in a particular subject, e.g., English, mathematics, science, design and technology, usually obtained by students aged 16 years after completing a two-year programme of study at school. The assessment procedures are administered by independent Examining Bodies that have to meet requirements laid down by the Qualifications and Curriculum Development Agency *(QCDA)*.

REFERENCES

Ainley, J., Pratt, D., & Hansen, A. (2006). Connecting engagement and focus in pedagogic task design. *British Educational Research Journal*, *32*(1), 23–38.

Barlex, D. (2000). *Nuffield design and technology 11-14 teacher's handbook* (2nd ed.). Harlow, Essex: Longman.

Barlex, D. (2003). *Creativity in crisis? Design and technology at KS3 and KS4* (seminar discourse). Wellesbourne, UK: Design and Technology Association.

Barlex, D. (2005). *Becoming an engineering college. A report describing emerging and developing good practice*. London: Specialist Schools Trust.

Barlex, D. (2007a). Assessing capability in design and technology: The case for a minimally invasive approach. *Design and Technology Education: An International Journal*, *12*(2), 9–56.

Barlex, D. (2007b). Creativity in school design and technology in England: A discussion of influences. *International Journal of Technology and Design Education*, *17*(2), 149–162.

Barlex, D. (2009, August 24–28). The STEM Programme in England - help or hindrance for design and technology education? In A. Bekker, I. Mottier, & M. J. de Vries (Eds.), *Proceedings of the Pupils Attitude Towards Technology PATT-22 conference* (pp. 42–53). Delft. Available at http://www.iteea.org/Conference/PATT/PATT22/ToC.pdf

Barlex, D., & Pitt, J. (2000). *Interaction: The relationship between science and design and technology in the secondary school curriculum*. London: Engineering Council.

Cross, N. (2002). The nature and nurture of design ability. In G. Owen-Jackson (Ed.), *Teaching design and technology in secondary schools: A reader* (pp. 124–139). London: Routledge Farmer.

Cross, N. (2007). From a design science to a design discipline: Understanding deignerly ways of knowing and thinking. In R. Michel (Ed.), *Design Research Now* (pp. 41–54). Birkhauser, Basel: Switzerland.

Csikszentmihalyi, M. (1999). Society, culture and person: A systems view of creativity. In R. J. Sternberg (Ed.), *The nature of creativity* (pp. 325–339). Cambridge, UK: Cambridge University.

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

Department for Education and Skills (DFES) and Department for Trade and Industry (DTE). (2006). *The science, technology, engineering and mathematics (STEM) programme report*. London: Department for Education and Skills.

Design and Technology Association. (2010). *The Digital Design and Technology (Digital D&T) Programme information*. Wellesbourne, Warwickshire, UK: Author. Available at http://www.data.org.uk/index.php?option=com_contentandview=articleandid=911andItemid=717

Dow, W. (2007). Implicit theories and pedagogy. In D. Barlex (Ed.), *Design and technology for the next generation* (pp. 252–265). Whitchurch, Shropshire, UK: Cliffeco Communications.

Frayerling, C. (2009). Cited in Barlex, D. (2009). The advantages of being two-faced! *D&T News*, *18*. Wellesbourne, UK: Design and Technology Association.

Gardener, P. (2010). Private communication with the author; Paul Gardener is a highly experienced design and technology teacher, regarded as a national expert and runs the West Midlands Digital Design and Technology Support Centre.

Gershenfeld, N. (2005). *Fab: The coming revolution on your desktop – from personal computers to personal fabrication*. New York: Basic Books.

Harrison, M. (2009, November 12). *Science, technology engineering and mathematics in key stage 3*. London: STEM Advisory Forum Event.

Hildebrand, G. (1999). *Con/testing learning models*. Paper presented at the AARE and NZARE conference, Melbourne, December. Available at http://www.aare.edu.au/99pap/hil99582.htm

John-Steiner, V. (2000). *Collaborative creativity*. Oxford: Oxford University Press.

Kimbell, R. (2007). E-assessment in project e-scape. *Design and Technology Education: An International Journal*, *12*(2), 66–76.

Lunn, S. (2003). *Dispelling myths about electronics in schools*. England Department for Education and Schools. Available at http://www.ectinschools.org/pdfs/EiS_myths.pdf

Murphy, P. (2003). Cited in Barlex, D. (Ed.), *Creativity in crisis? Design and technology at KS3 and KS4* (seminar discourse). Wellesbourne, UK: Design and Technology Association.

National Science Learning Centre. (2008). *The STEM framework*. York, UK: Author.

Nicholl, D., McLellan, R., & Kotob, W. (2008). *Understanding creativity for creative understanding*. Cambridge, UK: Faculty of Education, University of Cambridge.

Parker, J. (2003) Cited in Barlex, D. (Ed.), *Creativity in crisis? Design and technology at KS3 and KS4* (seminar discourse). Wellesbourne, UK: Design and Technology Association.

Qualifications and Curriculum Authority (QCA). (2007). *National curriculum for design and technology*. Available at http://www.qcda.gov.uk/25.aspx

Roberts, G. (2002). *SET for success. The supply of people with science, technology, engineering and mathematics skills*. London: HMSO. Available at http://www.hm-treasury.gov.uk/ent_res_roberts.htm

Robinson, K. (1999). *All our futures: Creativity, culture and education*. London: Department for Education and Employment.

Royal Society. (2007). *S-T-E-M working together for schools and colleges* (unpublished document).

Rutland, M., & Barlex, D. (2008). Perspectives on pupil creativity in design and technology in the lower secondary curriculum in England. *International Journal of Technology and Design Education*, *18*(2), 139–165.

Rutland, M. (2005). *Fostering creativity in design and technology* (unpublished doctoral dissertation). School of Education, Roehampton University, University of Surrey.

Sainsbury Review of Science and Innovation. (2007). *The race to the top: A review of government's science and innovation policies*. London: HMSO. Available at http://www.hm-treasury.gov.uk/sainsbury_index.htm

Schon, D. (1963). *Displacement of concepts*. London: Tavistock Publications.

Sfard, A. (1998). On two metaphors for learning and the dangers of choosing just one. *Educational Researcher*, *27*, 4–13.

Sharkaway, A., Barlex, D., Craig, N., McDuff, J., & Welch, M. (2009). Adapting a curriculum unit to facilitate interaction between technology, mathematics and science in the elementary classroom: Identifying relevant criteria. *Design and Technology Education: An International Journal*, *14*(1), 7–20.

Sim, S. K., & Duffy, A. H. B. (2004). Evolving a model of learning in design. *Research in Engineering Design*, *15*, 40–61.

Steeg, T. (2008). Makers, hackers and fabbers: What is the future for D&T? In E. W. Norman & D. Spendlove (Eds.), *Designing the curriculum - making it work. Proceedings of the Design and Technology Association International Research conference* (pp. 65–73). Wellesbourne, UK: Design and Technology Association.

Steeg, T. (2010). Private communication with the author; Torben Steeg is a highly experience design and technology teacher, regarded as a national expert and is the head of the Bolton Science and Technology Centre.
The National Foundation for Educational Research (NFER). (2009). *Evaluation of the 2008-09 DCSF-funded specialist schools and academies trust STEM pathfinder programme*. Slough, Berkshire: Author.
Trebell, D. (2009). Studying classroom interaction during a design-without-make assignment. *Design and Technology Education: An International Journal*, *14*(3), 58–71.
Vygotsky, L. S. (1978). *Mind in society. The development of higher psychological processes*. Cambridge, MA: Harvard University.
Welch, M., & Barlex, D. (2010). *Unpublished results from an enquiry into the design decisions made by grade 7/8 pupils when designing and making a moving toy*.
Zubrowski, B. (2002). Integrating science into design technology projects: Using a standard model in a design priocess. *Journal of Technology Education*, *13*(2), 48–67.

WEBSITES

www.ectcurriculum.org/
The website produced by the Design and Technology Association to support the electronics product dimension of the Digital Design and Technology Programme. Accessed 18 April 2010
http://www.digitaldandt.org/index.php?option=com_contentandview=articleandid=48andItemid=58
The website produced by the Design and Technology Association to provide information about the Digital Design and Technology Programme. Accessed 18 April 2010
www.secondarydandt.org
The website designed to support the Nuffield Secondary Design and Technology Project. Accessed 18 April 2010
www.youngforesight.org
The website produced to support the Young Foresight Project. Accessed 18 April 2010

David Barlex
Formerly of Brunel University
School of Sport and Education
UK

APPENDIX 1

The STEM National Programme

Action Programme	Lead Organisation
Getting and training the right teachers and lecturers of STEM subjects in the first place	
AP1 Improving the recruitment of teachers and lecturers in shortage subjects	Training and Development Agency for Schools (TDA)
Providing the right continuing professional development for teachers of STEM subjects	
AP2 Improving teaching and learning through CPD for mathematics teachers	National Centre for Excellence in the Teaching of mathematics (NCETM)
AP3 Improving teaching and learning through CPD for science teachers	National Science Learning Centre (NSLC)
AP4 Improving teaching and learning by engaging teachers with engineering and technology	Royal Academy of Engineering (RAEng)
Providing the right activities and careers advice that bring real world context and applications of STEM into the classroom	
AP5 Enhancing and enriching the science curriculum	SCORE[1]
AP6 Enhancing and enriching the teaching of engineering and technology across the curriculum	Royal Academy of Engineering (RAEng)
AP7 Enhancing and enriching the teaching of mathematics	Advisory Committee on Mathematics Education (ACME)
AP8 Improving the quality of advice and guidance for students (and their teachers and parents) about STEM careers, to inform subject choice	The National STEM Careers Co-ordinator (at Sheffield Hallam University)
Getting the STEM curriculum in the classroom right	
AP9 Widening access to the formal science and mathematics curriculum for all including access to triple science GCSE	Department for Children, schools and Families (DCSF)
AP10 Improving the quality of practical work in science	SCORE
Getting the STEM education support infrastructure right	
AP11 Programme to build capacity of the national, regional and local infrastructure	Department for Children, schools and Families (DCSF)

[1] Science Community Representing Education is convened by the Royal Society. The other founding partners are the Institute of Physics, the Royal Society of Chemistry, the Institute of Biology, the Biosciences Federation, the Science Council and the Association for Science Education.

JOHN M. RITZ AND JOHNNY J. MOYE

8. USING CONTEXTUALIZED ENGINEERING AND TECHNOLOGY EDUCATION TO INCREASE STUDENT MOTIVATION IN THE CORE ACADEMICS

INTRODUCTION

Education can be used to change human behavior. It can enhance one's ability to perform verbally, quantitatively and analytically. Much of one's early education takes place within the family and in school. Motivation is essential for enhanced learning. Motivation was conceptually defined by Lewin (1938) using the formula of $B = f$ (P,E), where B is behavior and it is influenced by the function of interaction of the person (P) in his/her environment (E).

These concepts can be used to exemplify the value of engineering and technology education in schooling. Engineering and technology education content and activities can be used to motivate students to master verbal, quantitative and analytical concepts in our classrooms and laboratories, but they can also be used to motivate and enhance learning in the core academic areas of the school curriculum. The authors will review how motivation contributes to self-efficacy, individual and subject matter goals, student interests and values, how teachers using the contextual nature of engineering and technology education can assist students in learning, and how contextualized engineering and technology education can be used to assist teachers in all school subjects.

MOTIVATION

The field of psychology has analyzed people and their development and actions for many years. Researchers have developed a wide variety of theories for motivation. Each researcher approaches motivation from differing perspectives, including ones such as self-efficacy, interest, goals, social cognition, etc. (Eccles & Wigfield, 2002). From these theories one may conclude that motivation relates to people doing what they want to do.

Self-Efficacy

Bandura (1997) considered self-efficacy to be the foundation for motivation. Self-efficacy is a perception of one's ability to perform a task or change a behavior; a belief one can do. This is a very important concept in learning. If a person feels good about performing a task, he/she probably has learned this behavior. This is so

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 131–151.

important for learners. How do they perceive they can perform? The concept of self-efficacy has importance in the classroom, laboratory, military, business and industry, and life. If a learner in engineering and technology education has developed self-efficacy when working with tools and resources, then he/she is able to apply these to solve problems, e.g., assemble gearing on a model lunar rover so that the vehicle can move along and still have the torque to climb over rocks. Through the development of self-efficacy, learners feel they are able and have the ability to overcome nature using technical means.

How might one develop this competence and feeling using the above example? It could come about by learning about gears and ratios (observing a teacher demonstration then student reading, applying salient mathematics and science knowledge, using previous principles and skills learned in engineering and technology education, and then problem-solving through design, development (tinkering) and assessment). Students can learn about new applications where gears and simple machines might be used, and with their motivation, due to the self-efficacy that they developed, not be afraid to try and solve new problems. By having the resources offered through an engineering and technology education laboratory, students can experiment to solve problems and become motivated to work in these areas.

Can the same be accomplished in other courses, such as physics and history? Yes, teachers can learn these strategies and collaborate with engineering and technology teachers to plan and use available resources. Engineering and technology education teachers can assist other teachers in developing the competence to use these types of instructional strategies and resources to assist students when studying these concepts. So engineering and technology education can contribute beyond the confines of the teacher's laboratory. Through cross-planning and academic integration, knowledge and teaching strategies can be transferred or shared for the improvement of learning.

Bandura (1997) believed that there were four sources for forming self-efficacy. These included mastery experience, vicarious experiences, social or verbal persuasion, and physiological and affective states. All contribute to a student's motivation in a learning environment.

Mastery experience implies the learner can perform. These learners have overcome obstacles and have assembled knowledge in their minds that comes together so they can master the experience. How do educators provide the environment so that students can master the experience? Teachers of engineering and technology education need to provide environments where appropriate content is taught and experiences allow students to apply and test the knowledge gained. After positive experiences with the new knowledge, learners gain ownership of the knowledge and can then use it to solve problems and answer questions. This type of mastery experience is the basis for the design experiences that occur in engineering and technology education laboratories – learn it – apply it – master the experience – transfer the knowledge to new situations. Teacher and curriculum designers have an enormous challenge in selecting the concepts or standards important for learners to master. There is limited time in the curriculum. If several standards can be set into the same contextual learning activity, this can make teaching more efficient. A key judgment is determining the concepts or standards that will best be taught even though they might not remain within a teacher's comfort zone.

Vicarious experiences are another way of forming self-efficacy. This includes learning by watching others perform (Bandura, 1997). Often for school-aged children, this can happen in our laboratories. The teacher demonstrates how to problem-solve using technical processes and resources, e.g., computers, simulations, tools and materials, etc. One learns to do the process by observing and then using the new knowledge and skills to solve similar and other problems. Bandura (1997, p. 87) believes: "More often in everyday life, people compare themselves to particular associates in similar situations such as classmates, work associates, competitors, or people in other settings engaged in similar endeavors." Industry apprenticeship programs are based on this model. For the reader, how many construction processes were learned by watching people work at construction sites? Other forms of vicarious learning come from reading books and watching media on technical topics. Those of us who teach probably began our career trying to practice as we saw more successful teachers perform. In contemporary society, many vicarious experiences are established through the media and via computer games. Players can create avatars and role-play with them. Students model what they observe.

Social or verbal persuasion is another way that one can develop self-efficacy. One can learn by the instruction and compliments of others. Coaching is a form of persuasion. Many parents provide for this type of development in the home. It is also important to use these techniques in the classroom or on the sports field. Teachers can persuade learners to perform tasks correctly through verbal instruction. The person who taught you to drive an automobile used these techniques. Important parts of this self-efficacy development are the compliments given to strengthen certain performances and to remove negatives by verbally correcting the learner. Again, in an engineering and technology education learning environment, social and verbal persuasion should be natural for teachers. Teachers can use these self-efficacy motivational techniques while teaching students to use technical resources such as computer design software, modeling materials and other contemporary laboratory equipment, including machines, Lego™, robots and other educational kits. One can point out strengths and correct weaknesses using social and verbal persuasion related to self-efficacy.

According to Bandura (1997), physiological and affective states are personal feelings about one's performance. Again, this is another component of self-efficacy. Betz (2004) refers to this as emotional arousal. Individuals develop feelings about their ability to perform. Some students in engineering and technology education may become anxious with the thought of using laboratory equipment, making choices on final problem designs, or making presentations on students' teamwork. They become tense, nervous and can actually experience physiological effects, sweating, etc. Educators can enhance student physiological and affective states and contribute to their self-efficacy. Educators, if teaching well, can make learners feel good about themselves.

Teaching environments created through engineering and technology education can provide positive contributions to the motivation of learners. Through the content and activities of these programs, learners can approach technological problems, use their knowledge and skills to perform to their maximum, and persist until they can provide answers to solve problems in the most efficient ways. Self-efficacy is enhanced when young people can see themselves matching their abilities to what they see people do in the real world as citizens and working professionals. Can engineering and technology and academic educators create contextual learning environments that mirror business and industry today? Remember the technology that young people have grown accustomed to during their lifetimes will be the technologies that they will use in their futures. Educators need to reduce the importance of older industrial-era technologies and bring their learning environments into the digital age. Young people have grown up in a digital age where most inventions and products used in business and industry rely upon microelectronic technologies.

Goals

Individuals are motivated by the goals that they set. Goals are used to put interest into action (Collins, 2010). Each of us has set goals for ourselves in engineering and technology education. For some, it is to become a good teacher. For others, it may be to become a great teacher trainer. Others may establish goals related to research.

Engineering and technology education is a great school subject for young people to explore career interests and establish goals. Some goals are short-range motivational goals, while others are long-range. Students may enroll in an age 12 engineering and technology education course to determine if they might become industrial designers. They know they can draw well but are unsure about using computers to create a CAD drawing or work with materials to design and make a prototype. They set a short-range goal to try these tools and functions to see if they have success. Students may meet with their counselor to explore the needs for a career in designing and determine that there is a high school course in engineering and technology education where they can further explore design and making. If students continue to experience success, then they might set a long-range goal to get the education and training needed to be an industrial designer, architect, technician, or engineer. A longer range goal may be to design a product that will lead to world recognition. By setting or re-setting goals, motivation is present to have the individual persist in achieving those goals.

Interests

A prime factor in establishing motivation is an individual's interests. Peoples' motivations change as a result of their interests. Some are interested in football, so they participate as players, coaches, or spectators. These same individuals may not have the same interest in table tennis. The situation causes the level of interest to change, thus increasing or reducing motivation. This is referred to as situational interest (Hidi & Renninger, 2006).

Engineering and technology classrooms or their types of activities in other school subjects, such as science (e.g., designing roof structures that reflect heat in a physics class) or social studies (developing a social program where students design temporary shelters for those who have been displaced from their homes by natural disasters), can increase students' interest and thus increase their motivation to improve participation and learning in these subjects. Through engineering and technology education, action-grabbing activities can be used to reinforce content in these subjects. These activities must balance students' level of knowledge and skills with the activity level. If students are not interested in a challenge, or it is too difficult for them to achieve, they will not be motivated to participate in engineering and technology education-based activities. Their self-efficacy to feel good about their abilities would decrease. These ideas of interest are also aligned with contemporary thought of differentiated instruction and understanding by design (Tomlinson & McTighe, 2006). Educators should assess their learners and design instruction to take learners from where they are toward the goals established for the instructional program.

Values

What people value affects their self-efficacy and consequently their motivation. Just like interest, people value activity differently. Some learners, especially those who withdraw or drop out of academics, do not value school or certain subjects offered in school. Many times not valuing school stems from lack of interest, personal goals and self-efficacy. If students do not see value in performing in an area, they can withdraw from the area. If students do not value school subjects or their assigned activities, their interest levels in these tasks declines and they do not perform well in them. Their expectancy-value (Eccles & Wigfield, 2002) is either high or low. Through the activities associated with the content of engineering and technology education, learning value can be enhanced through the contextualization of activities. Activities in a school subject can be contextualized to create interest and values, thus increasing motivation to participate. Examples could be activities that bring in the contexts of energy and the environment, helping peoples of the world, extreme sports, Internet applications such as Twitter and Facebook, etc. Engineering and technology education provides ample opportunities for creative curriculum designers and teachers to highly motivate learners through contextual learning activities, e.g., taking book work types of learning, placing it into a context that would create interest and having students build through hands-on activities that can be used by their peers, families, or greater society.

CONTEXTUAL LEARNING

Context is very important for learning new knowledge. The word contextualize can be defined as to "place in or treat as part of a context; study in context" (Trumble & Stevenson, 2002, p. 501). Karweit (1993) sees contextual learning as an instructional strategy where activities and problems are designed so students can approach these as though they are real world situations. Research supports that students learn more effectively when knowledge is placed into meaningful contexts (Carraher, Carraher, & Schleimer, 1985; Lave, Smith, & Butler, 1988). According to contextual learning theory (CORD, 2010):

> "…learning occurs only when students (learners) process new information or knowledge in such a way that it makes sense to them in their own frames of reference (their own inner worlds of memory, experience, and response). This approach to learning and teaching assumes that the mind naturally seeks meaning in context, that is, in relation to the person's current environment, and that it does so by searching for relationships that make sense and appear useful" (p. 5).

These ideas also build on the principle of advanced organizers for individual learning that Ausubel (1960) provided to the field of learning theory, i.e., when one encounters new information he/she tries to connect it with what is currently understood.

Contextual Learning and Cognitive Development

Engineering and technology education plays a role in contextualizing core disciplinary concepts. Engineering and technology education uses the same theories, principles and information taught in core discipline subjects (ITEA, 2007), such as using fractions during an age 13 middle school model bridge building activity or defining Ohm's or Watt's Law in an energy or power age 15–17 high school activity. When referring to any area of engineering or technology, the applications of the disciplines of mathematics and science might come to mind. What may not be so obvious is how the fields of psychology and sociology are also associated with engineering and technology education. Brandt and Perkins (2000) explained:

> "Cognitive science has many branches and variations, and no simple description applies to them all… cognitive scientists gradually expanded their attention to include a remarkable array of human activities: the formation of judgments, decision-making, creativity, critical thinking, and even emotions" (p. 165).

Joseph (2010) identified how "students' metacognition may be overlooked in the classroom because most instruction focuses on the content rather than on the strategies used to learn the content" (p. 100). *Metacognition* can be defined as "the high-level cognitive operation involving reflection on the thought processes through which human beings gain knowledge; the capacity to think about thinking" (Sroufe, Cooper, DeHart, & Marshall, 1996, p. 415). Engineering and technology teachers present students with contextual environments that challenge their abilities to think, reason and solve problems, thus theoretically improve their metacognitive development and skills. In many instances, teachers become facilitators of learning via a teacher of instruction (Doolittle & Camp, 1999; Plaza, 2004). Students learn more than just how to do something; they learn how to resolve problems while completing problem-based learning activities (Rogers & Rogers, 2005).

Engineering and technology education teachers can encourage students to use scientific and mathematical principles to solve real-life problems. The use of language arts is also very important. At every opportunity, teachers should integrate reading and writing into their activities. The International Reading Association/National Council of Teachers of English states:

> "Students use language every day to solve problems and grapple with issues that concern them. To respond to these situations and demands, students need to be able to use language to pose significant questions, to become informed, to obtain and communicate information, and to think critically and creatively" (IRA/NCTE, 1996, p. 13).

Contextual Learning and Social Development

Elias (2009) stated that there is an "inextricable connection of academic learning with students' social-emotional and character development" (p. 831) and that "failure to address this piece may contribute strongly to continued underperformance in education" (p. 832). People understand concepts when the concepts are put into context. Effective teachers are aware of contextual learning strategies and present students with connected information. "Regardless of whether we are reading or writing, speaking or listening, viewing or visually representing, a context always surrounds any activity" (IRA/NCTE, 1996, p. 16). Explaining how context influences social interaction, the International Reading Association/National Council of Teachers of English states:

> "Perhaps one of the most influential aspects of context is the social dimension. Many illustrations of reading and writing show one person alone, looking intently downward at a text or a paper, deeply immersed in thought. But we are coming to realize how fundamentally social the process of becoming literate is" (IRA/NCTE, 1996, p. 16).

Murray (2004) stated that putting mathematics vocabulary in context "is a developmental process that honors the individual characteristics and needs of students" (p. 169). If this is true, by putting mathematics into context, engineering and technology education could also play a greater role in how a student feels about him/herself, thus improving a young person's cognitive development and self-efficacy.

The National Council for the Social Studies (NCSS), creator of the social studies national education standards, discussed how "the problems of young adolescents and the changing nature of society are causing a reexamination of education" (NCSS, 1994, p. 3). Among many other issues surrounding middle school students, the authors discussed education's increasing role in the "development of self-esteem and a strong sense of identity" (NCSS, 1994, p. 21). The authors continued: "The teacher and the curriculum can address the concerns related to self-esteem, physical growth and change, and relations with peers, and other developmental qualities within the context of history, culture, the humanities, and parts of the social studies program" (NCSS, 1994, p. 22).

Drawing from empirical literature, Elias (2009) identified “teachable skills essential for educating students for sound character and seeing themselves and their learning as positive resources for their families, schools, workplaces, and communities. These skills are fundamental tools for citizens in a free and democratic society” (p. 834). The skills are:

- “knowing and managing one’s emotions;
- listening and communicating carefully and accurately;
- recognizing strengths in self and others;
- showing ethical and social responsibility;
- greeting, approaching, and conversing with diverse others;
- taking others’ perspectives;
- perceiving others’ feelings accurately;
- respecting others;
- setting adaptive goals;
- solving problems and making decisions effectively;
- cooperating;
- leading and also being an effective team member;
- negotiating and managing conflicts peacefully;
- building constructive, mutual, ethical relationships; and
- seeking and giving help” (Elias, 2009, p. 834).

Similar to Elias’ (2009) view of teachable skills, the National Council for the Social Studies (NCSS) (Schneider, 1994) identified how cross-curricular education can “prepare students to connect knowledge with beliefs and action using thinking skills that lead to rational behavior” (p. 160). Schneider (1994) identified the following four thinking skills:

- “acquiring, organizing, interpreting, and communicating information;
- processing data in order to investigate questions, develop knowledge, and draw conclusions;
- generating and assessing alternative approaches to problems and making decisions that are both well informed and justified according to democratic principles; and
- interacting with others in empathetic and responsible ways” (p. 160).

Elias’ (2009) and the NCSS’s (1994) lists provide detail and invoke much thought. Given classroom time constraints (Brandt & Perkins, 2000), a core academic teacher may wonder how he/she will cover course content and also address his/her students’ *other* needs. When an engineering and technology teacher reads this information, he/she realizes that all of these points have the potential to be addressed when his/her students are completing engineering design problems presented to them in real world contexts.

Why Do I Need to Know this?

Every educator has heard students ask this question. In past years, a teacher’s response could have been something like “you just need to know it” or “because it is in the curriculum.” Today, students are continuously bombarded with information that they deem relevant and important (e.g., blogs, social networks, texting, etc.).

Students must feel that what their teachers present them is equally important. By putting information into context, a teacher can easily explain how information will affect a student, his/her friends, family and society.

Students may or may not understand the relevancy of information they receive in their core academic courses. Engineering and technology education teachers may draw upon the content in different core academic areas to demonstrate this relevancy (Berentsen, 2006). A successful engineering and technology teacher should collaborate with core academic teachers, as well as be aware of the curriculum standards that drive academic content and use those resources to construct meaningful contextual lessons and activities. An example of one such collaborative effort is when middle school engineering and technology and science teachers combined their students/courses to solve a problem. The problem was that the students needed to check soil pH levels of a rain forest they had created. They did not want to contaminate the sample by walking on it. The engineering and technology and science students' challenge was to create remote-controlled robots that would enter the forest, retrieve soil samples and then deliver those uncontaminated samples to the science students. In a collaborative spirit, the engineering and technology and science students had to learn scientific, engineering and technological principles to solve the problem.

MOTIVATION AND CONTEXT FOR ENGINEERING AND TECHNOLOGY EDUCATION

This dialogue has underscored the need for the use of motivation (especially to use self-efficacy, goals, interests and values) and contextual learning to enhance teaching and learning. These concepts are particularly useful and have been practiced for years, consciously or sub-consciously, by people working in this school subject. These principles, along with activities from engineering and technology education, can also be applied to teaching core academic subjects.

Engineering and Technology Education

Engineering and technology education can apply the above motivational techniques and contextual environments to assist in student learning. Some teachers strictly lecture and demonstrate without the added value of using these principles. In the past, teachers taught the content, gave a demonstration and then students copied the projects that the teacher designed. These activities were motivational for many learners, but today many students could question projects presented to them in this fashion since they have grown up in the digital age where they want information presented quickly and then want to be able to do something with the new knowledge that they can see will make a difference to them, their families, or the greater society. They simply may not realize the relevance in what they are being asked to do. Doppelt, Mehalik, Schunn, Silk and Krysinski (2008) describe this approach as a "scripted inquiry" (p. 6) approach to teaching. Using a scripted inquiry approach, the teacher will set a goal, ask questions, identify tools and materials, explain procedures and discuss what he/she considers the correct result to a problem (Bonnstetter, 1998). "By contrast, Design Based Learning (DBL) provides a reason for learning the … content by engaging the student in design and using a natural and meaningful venue for learning both [content]… and design skills" (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008, p. 7).

As engineering and technology educators explored teaching and learning, they determined that additional design and contextual learning provided by project-based activities created additional motivation in learners (Frank & Barzilai, 2006). Today, design briefs contextualize problems and appear to be of more value to learning and development and the potential transfer of knowledge. Programs today are based on engineering and industrial design problem-solving strategies in the context of the technological world where one resides.

Following curriculum models based on motivational principles and contextual learning strategies, learners can be motivated to learn. These types of educational experiences can result in excitement and enhanced learning. Educators around the globe are taking notice of the value of engineering and technology education and the contributions it can make to the economic literacy and productivity of their homeland. Evidence can be found in PATT Conference Proceedings and the books available through Sense Publishers, among others.

Limited research exists showing that students who complete engineering and technology education courses actually perform better than their peers on tests assessing knowledge in the core academic subjects. However, some research is beginning to emerge. Frazier (2009) found marked differences in high school students who scored significantly higher on science, mathematics and social studies state standards tests after they had completed two sequential courses in technology education (program completers, e.g., Technology Foundations and Communication Systems, Technical Design and Introduction to Engineering, etc.). Hammons (1999) found that students' scores on eighth grade science standards tests were significantly higher if the students also studied technology education in a modular environment where students study such topics as simple machines, structures, flight, CNC machining, etc. High school students scored significantly better on standardized algebra and geometry tests after they had completed a course in drafting and illustration in an engineering and technology education environment (Dyer, Reed, & Berry, 2006). Settar (2006) found the same for students who completed a pre-engineering course of studies. Their scores on algebra II and geometry were significantly higher than students who did not have these educational experiences. These are additional illustrations of how engineering and technology education programs reinforce basic academic subject concepts to students.

Core Academic Subject

In the past, many academic subjects were taught using a transmission method. The teacher transmitted the content, students took notes and tests were given. Grades were primarily determined by the scores on tests. Some teachers used projects (forms of engineering and technology education) related to the content for students to pursue additional knowledge about a country, emperor, scientific principle, etc. Reading and hands-on projects were involved. Examples would be an illustrated paper on Shakespeare and his theater, a science project on chemicals found in coal, or a constructed project on the Roman Empire. Many times these projects allowed parents to work with their children at home. Parents would then have the opportunity to support a project's relevance and the significance of what the student was to learn.

These projects provided motivation if the learner had interest and abilities or received help from his/her parents. For others, the projects were disasters because of lack of interest or abilities. Most of these projects were completed outside the confines of the school; at times, their success depended on the resources that the family could devote to purchases of materials (economic discrimination).

Using engineering and technology education activities in class can assist students for better learning and create contexts to increase student motivation. In the next section, examples of applying engineering and technology education in the contexts of language arts, history, mathematics and science will be shown. These examples will be based on the standards that have been established for these school subjects in the US.

APPLYING ENGINEERING AND TECHNOLOGY EDUCATION IN THE CORE ACADEMICS

Academic leadership has created standards in their respective content areas. The list of these organizations and the standards they created are many. For the sake of brevity, this analysis will focus on four of the organizations and the academic standards they created. They are:

- American Association for the Advancement of Science (AAAS) – Benchmarks for Science Literacy (1993);
- International Reading Association/National Council of Teachers of English (IRA/NCTE) – Standards for the English Language Arts (1996);
- National Council for the Social Studies (NCSS) – Expectations of Excellence: Curriculum Standards for Social Studies (1994); and
- National Council of Teachers of Mathematics (NCTM) – Principles and Standards for School Mathematics (2000).

Making the connections between different standards is not a difficult task. Each list of core academic curriculum standards identifies individual standards (or strands), benchmarks (or applications) and grade level of each benchmark. For example, the science standards contain 12 benchmarks with 65 sections segregated into grade groups of K-2, 3–5, 6–8 and 9–12 (AAAS, 1993). The social studies standards contain 10 thematic strands and 240 performance expectations. Each strand is divided into early, middle and high school grade levels (Schneider, 1994). There are 12 English language arts standards. The standards do not provide specific benchmarks because "no single instructional method or sequence of lessons can serve all students or all situations" and that "adaptability and creativity are far more effective in the classroom than thoroughgoing applications of a single approach" (IRA/NCTE, 1996, p. 5). The mathematics standards contain 17 objectives within six mathematics standards and expectations (NCTM, 2000). Table 1 identifies the standards, benchmarks and grade levels for each national standard.

Table 1. National standards, number of standards, number of benchmarks and grade level categories

National standard	*Number of standards*	*Number of benchmarks*	*Grade level categories*
American Association for the Advancement of Science (AAAS) – *Benchmarks for Science Literacy*	12[a]	65[b]	K-2, 3–5, 6–8, 9–12
International Reading Association/National Council of Teachers of English (IRA/CTE) – *Standards for the English Language Arts*	12	None listed	Note[c]
National Council for the Social Studies (NCSS) – *Expectations of Excellence: Curriculum Standards for Social Studies*	10 thematic strands	240[d]	Early, Middle, High School
National Council of Teachers of Mathematics (NCTM) – *Principles and Standards for School Mathematics*	6	17[e]	K-2, 3–5, 6–8, 9–12

[a] Referred to as benchmarks (AAAS, 1993, p. XVI)
[b] Referred to as sections (AAAS, 1993, p. XVI)
[c] IRA/NCTE does not "attempt to specify levels of achievement corresponding to grade level or age (IRA/NCTE, 1996, p. 14)
[d] Referred to as performance expectations (Schneider, 1994, p. 30)
[e] Referred to as expectations (NCTM, 2000)

School divisions continuously research different methods to improve students' performance in science, technology, engineering and mathematics (STEM), social studies and language arts. However, it is difficult for educators to include more information in an already "packed schedule" (Brandt & Perkins, 2000, p. 171). Engineering and technology education teachers discuss core academic information in a *contextualized* manner during lectures and assignments almost daily. Academic teachers and curriculum designers can do the same as contextual integration has the potential to help students better understand information presented to them in all their courses. Examples of core academic standards at different grade levels are presented in the following section. The intent is to show how activities can be developed to teach standards using engineering and technology education in contexts of everyday problems facing students. These sample activities show how using engineering and technology to contextualize academic content can enhance student understanding and motivation.

CONTEXTUALIZED LEARNING EXAMPLES

Contextualized Standards for Science – Grades K-2

Very young students can understand scientific principles if these principles are placed into a familiar context. Science and engineering and technology teachers can use the following benchmarks/standards and activities to place a big idea into context. The following strands are examples of contextual learning in the areas of energy and environmental concerns for science.

The grade K-2 science benchmark states: “People burn fuels such as wood, oil, coal, or natural gas, or use electricity, to cook their food and warm their houses” (8C/P2) (AAAS, 1993, p. 193). Science K-2 benchmark 4E/P1 states: “The sun warms the land, air, and water” (AAAS, 1993, 2009, p. 83).

Teachers will create a realistic problem-based scenario that challenges students to use engineering and technological literacy to solve a problem. The scenario should be age appropriate and challenge students to troubleshoot and recommend a solution to the problem. Once students understand the scenario, they will realize the relevance of the lesson and become motivated to learn about and create a solution to a given problem (Frank & Barzilai, 2006; Loepp, 1999). The teacher could explain the basic concepts of energy and energy transformation as follows:

> Energy is produced naturally (e.g., the sun) or by humans (e.g., coal burning power plants). To explain the difference, the teacher could ask students to stand in a shadowed part of the classroom and then move them into a part of the room where the sun is shining through the window. Students will be asked if they can feel the energy (heat) created naturally by the sun. The teacher would ask students where they would like to sit on a cold day, a warm day. Next, the teacher could ask his/her students to hold their hand under a heat lamp and ask if they can feel the energy from the lamp. The teacher would ask the students to explain the difference between the two sources of energy. One source is natural (free), while there is a cost paid for the other by burning fuels.
>
> The teacher will then discuss the undesired consequences of burning fossil fuels – pollution. Burning fuels produces many forms of pollution and affects the environment and every person on Earth, a carbon footprint. The teacher could motivate students by asking them to describe how burning coal will affect people and explain the need to develop clean energy. A discussion such as this would occur as the anticipatory set for a project where students would use their knowledge of energy and energy sources to develop ideas such as conservation and the development of clean or green energy. As a possible project, students could design and construct a windmill or create a mock solar panel. Teachers could invite representatives from a local energy distribution company and discuss students’ findings and ideas.

Once the project and presentations are complete, students will realize the need for change and understand that *they* will be the generation that will help *save the planet*. Bandura (1997) indicated that self-efficacy was the foundation for motivation. People are motivated when they feel that they can help change the behavior of others. This kindergarten to second grade activity could easily serve as a motivator for these young people once they understand that each student could cause a positive change. This example illustrates that when using engineering and technology education strategies, a context can be created to enhance the learning of young students in science content.

Contextualizing Standards for Social Studies

Between the third and fifth grades, young students begin to "recognize that other people have needs and feelings of their own" (Nielsen, 1996, p. 111). A National Council for the Social Studies theme states: "describe instances in which changes in values, beliefs, and attitudes have resulted from new scientific and technological knowledge, such as conservation of resources and awareness of chemicals harmful to life and the environment" (VIII. C) (Schneider, 1994, p. 43). A second theme very closely related to life and the environment states: "suggest ways to monitor science and technology in order to protect the physical environment, individual rights, and the common good" (VIII. E) (Schneider, 1994, p. 43).

Today, there are few topics of greater interest than the materials that humans waste, in particular electronic waste (ewaste) (Gupta, 2009; Irving, 2010). Ewaste includes consumer products such as computers, computer peripherals, televisions, audio equipment, cellular telephones, etc. that have been discarded (US EPA, n.d.). Students at a young age will not understand these problems unless they are explained and put into context.

Irving (2010) identified that by 2020, ewaste is expected to increase by up to 500% in developed countries. Ewaste contains many toxins harmful to humans and the environment. Konrad Osterwaldet, the United Nations Under-Secretary General stated: "The challenge of dealing with e-waste represents an important step in the transition to a green economy" (as cited in Irving, 2010, para., 14). The United Nations Environment Programme (UNEP) created the *Green Economy Initiative (GEI)* which"

> "is designed to assist governments in 'greening' their economies by reshaping and refocusing policies, investments and spending towards a range of sectors, such as clean technologies, renewable energies, water services, green transportation, waste management, green buildings and sustainable agriculture and forests" (UNEP, n.d., para. 1).
>
> The teacher could use examples of young people standing around a mound of burning computer parts. The young people are there trying to earn money to buy food for their families. While burning these computer parts, the children inhale toxic fumes released from the burning materials. These fumes will eventually cause serious illness and even death!
>
> Prior to the lecture, the teacher could stage many different computer parts, such as keyboards, mice, circuit boards, etc. into a trashcan. While lecturing, the teacher could pull the individual pieces of equipment out of the trashcan, symbolizing that rather than just throwing away the ewaste, students were going to help "green the environment" and "save the children."
>
> The challenge would be to find a better way of disposing of ewaste materials. As an example, the teacher could inform students that gold from ewaste was actually used in the construction of the 2010 Winter Olympics gold metals (Irving, 2010). While lecturing, the teacher would give students the opportunity to view and touch the discarded electronic equipment and understand that in

its current state, ewaste is not dangerous. However, during the chemical process of burning, toxins are released into the air and soil.

Students would be asked to form small groups of two or three. They would be asked to produce a model simulating the procedures for an ewaste management facility. Groups would produce three products. The first would be a flow chart of the different processes electronic equipment could take from consumer purchase to when the consumer disposes of that equipment. The flow chart would indicate how equipment would be checked to see if it is still operational and usable. Once determined, the equipment would be segregated as usable or unusable then staged to be transferred to an appropriate organization for reuse or disposal. The second product would be sketches of receiving, storage and transfer bins that the organization would use to receive, store and then stage equipment designated for transfer. The third product would be presentations provided by groups describing their plan.

This activity addresses social, scientific and literacy principles, and might help students feel better about themselves as they begin to perceive themselves as capable of proposing solutions to societal issues. Students will understand that what they waste affects other people. They will feel good that they did their part to help people and the environment by properly disposing of ewaste. Again, strategies of engineering and technology teaching and contextualizing the situation will increase student motivation to learn such social studies content. Media news clips can be downloaded from YouTube to show children working in this toxic industry.

Contextualizing Standards for Language Arts – Grades 6–8

Engineering and technology education standards and activities can also be used to enhance motivation for students to learn in language arts. Following is a contextualized example for middle grade learners. It involves the use of International Reading Association (IRA) and National Council of Teachers of English (NCTE) Standards for the English Language Arts (1996). According to IRA/NCTE (1996):

> "Students use language every day to solve problems and grapple with issues that concern them. To respond to these situations and demands, students need to be able to use language to pose significant questions, to become informed, to obtain and communicate information, and to think critically and creatively. Purposeful language use demands all of these capacities" (p. 13).

To motivate learners, teachers could use the following contextual activity to increase interest and problem-solving skills. The activity could reinforce any of the following three language arts standards or integrate them through this contextualized activity. Select IRA/NCTE English language arts standards (1996) include:

– "Students apply knowledge of language structure, language conventions (e.g., spelling and punctuation), media techniques, figurative language, and genre to create, critique, and discuss print and nonprint texts.

– Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and nonprint texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.
– Students use a variety of technological and informational resources (e.g., libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge" (IRA/NCTE, 1996, p. 3).

Teachers may wish to only use one of these standards in a lesson, but the three can be integrated through the following activity. The activity is set in the context of students living in a technologically impacted world. They and their families purchase products that they want and need. They generally accept that the products they purchase will be safe for them and their pets.

> Students are interested in products that directly affect them and their families. Many companies have recently reduced quality standards with resulting products that could injure or make consumers ill. Examples include runaway Toyota cars, Chinese drywall with sulfur contents that deteriorate electrical circuits and cause sickening odors, lead paint on toys, children's jewelry made of cadmium, dog food and pet toys with lethal chemical substances added, tainted infant milk using powered plastics resins, etc. Companies producing these products have been unethical. Allegedly, they have known that their products were inferior but have been more interested in increasing profits at the expense of consumer safety.
>
> Divide the class into groups of three students. Have students select a recent product that has been produced to sub-safety standards. Have students research print and nonprint media (e.g., YouTube, network news stories, etc.) to investigate and gather information about their topic. Have them collect electronic photographs of the tainted products. Have students design a learning web (see Figure 1) of the technological product and the impacts that the product has, both positive and negative, on consumers. Have the students prepare a newsletter article on the product and a visual presentation they will make to a class assembly.

This activity involves writing, media techniques, inquiry, communication of student discoveries and the application of technological resources. It also integrates Standard 4 from Standards for Technological Literacy (ITEA, 2007) – Students will develop an understanding of the cultural, social, economic, and political effects of technology (Standard 4).

Through this type of activity, students can be sent into their current environment to analyze engineering and technological products. They will have interest since the products studied impact their families. This should enhance their interest to learn and apply language arts skills, and it should motivate them through engineering and technology and how it could affect them personally in their home environments.

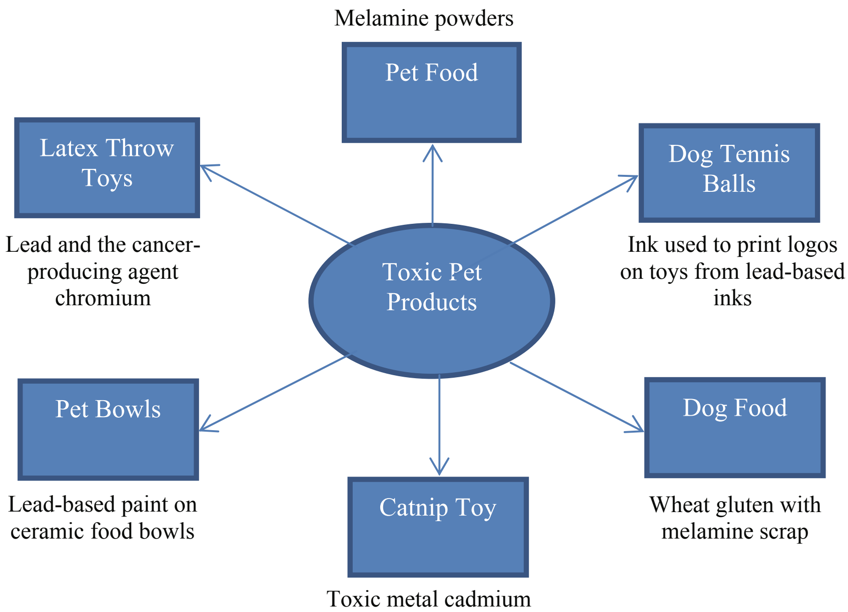


Figure 1. Language arts learning web of toxic pet products.

Contextualizing Standards for Mathematics – Grades 9–12

Most engineering and technology education teachers apply low-level (fractions, numbers, basic operations) mathematics concepts to their teaching practices. Legislation in the US (Brustein, 2006), requires that courses identified as career and technical education (technology education is under this classification) integrate core academic content into their presentation to students. In drafting and computer aided design (CAD), students must place drawings in the center of the page, so they need to measure, use scales and fractions, add, divide and subtract. Students need to use the same mathematics skills to process materials in a laboratory. Measuring angles is also very important, e.g., constructing. Algebra is used when working with the flow of electricity and fluids. Students can be helped to see the value and usefulness of mathematics when they apply mathematics to their work with materials in a laboratory environment. Other American engineering projects, such as Engineering by Design (ITEA, 2006; Moye, 2009) and Project Lead the Way (PLTW, n.d.) use American science and mathematics standards and incorporate these into their curriculum structures.

According to the National Commission on Mathematics and Science Teaching for the 21st Century (2000), “The future well-being of our nation and people depends not just on how we educate our children generally, but on how well we educate them in mathematics and science specifically” (p. 4).

> "However, growing numbers of teachers (especially those frustrated by repeated lack of student success in demonstrating basic proficiency on standard tests) are discovering that most students' interest and achievement in math, science, and language improve dramatically when they are helped to make connections between new information (knowledge) and experiences they have had, or with other knowledge they have already mastered" (CORD, 2010, p. 3).

This can be accomplished by using contextual learning, particularly in mathematics instruction. As an example, a teacher may use the National Council of Teachers of Mathematics, *Principles and Standards of School Mathematics* (2000), such as the geometry standard, which states, "use visualization, spatial reasoning, and geometric models to solve problems" (p. 97). This particular standard asks teachers to provide experiences where students use geometric principles such as those used by people who practice art or architecture.

Using contextual learning to motivate students and connect the principles they are learning to real world circumstances, a mathematics teacher could use the following activity:

> A new high school, community center, or recreational area is being planned for your community. To celebrate the new building, students will individually design and draw a monument to be erected at the entrance or in the courtyard of the proposed building/facility.
>
> Students will need to scale their monument to size. They will also need to consider artistic and architectural style. Teachers can have students construct a matt board model and consider actual construction costs. Students will research other print and nonprint materials on monuments and their design. After the models are constructed, local architecture or engineering firms could be invited to view and judge the models. The teacher could see if the community would be interested in building the monument. This could lead to a class fundraising project.

This activity involves the application of mathematics concepts. Formulas can be used to determine lengths and angles. Making of models will also require students to better visualize their geometric shapes. This engineering and technology education activity is also related to two *Standards for Technological Literacy* (ITEA, 2007) – students will develop an understanding of engineering design (Standard 9) and students will develop an understanding of and be able to select and use construction technologies (Standard 20).

Through this type of contextual activity, students can do a hands-on activity that can be personally related to their thoughts of good citizenship. They can develop interests in the application of mathematics and designing (tinkering) with materials to help them better understand the geometry and visualization of applications of mathematics to real world problems.

SUMMARY

Principles of motivation and learning can contribute to student performance in engineering and technology education and the core academic school subjects. If one analyzes curriculum and instructional techniques, content and activities could be used to increase student self-efficacy, goals, interests and values – motivation. Students can be motivated to want to learn and develop their problem-solving skills. Students can explore through the activities that scientists, engineers, designers and technicians use and the activities performed by sociologists, journalists, anthropologists, mathematicians and others. The learning environments of engineering and technology education can provide contexts and motivation for learning in all school subjects.

REFERENCES

American Association for the Advancement of Science (AAAS). (1993, 2009). *Benchmarks for science literacy: Project 2061*. New York: Oxford University Press.

Ausubel, D. P. (1960). The use of advance organizers in the learning and retention of meaningful verbal material. *Journal of Educational Psychology*, *51*, 267–272.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: W.H. Freeman.

Bonnstetter, J. R. (1998). Inquiry: Learning from the past with an eye on the future. *Electronic Journal of Science Education*, *3*(1). Retrieved from http://unr.edu/homepage/jcannon/ejse/bonnstetter.html

Betz, N. (2004). Contributions of self-efficacy theory to career counseling: A personal perspective. *The Career Development Quarterly*, *52*, 340–353.

Brandt, R. S., & Perkins, D. N. (2000). The evolving science of learning. In R. S. Brandt (Ed.), *Education in a new era* (pp. 159–183). Alexandria, VA: Association for Supervision and Curriculum Development.

Berentsen, L. W. (2006). Team teaching with academic core teachers: Using aviation concepts. *Journal of Industrial Teacher Education*, *43*(2), 7–19.

Brustein, M. (2006). *Perkins act of 2006: The official guide*. Alexandria, VA: Association for Career and Technical Education.

Carraher, T., Carraher, D., & Schleimer, A. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology, 3*, 21–29.

Collins, N. (2010). *A conceptual model of career development to enhance academic motivation* (unpublished doctoral dissertation). Norfolk, VA: Old Dominion University.

The Center for Occupational Research and Development (CORD). (2010). *What is contextual learning?* Retrieved from http://www.cord.org/contextual-learning-definition

Doolittle, P. E., & Camp, W. G. (1999). Constructivism: The career and technical education perspective. *Journal of Vocational and Technical Education*, *16*(1), 1–19.

Doppelt, Y., Mehalik, M. M., Schunn, C. D., Silk, E., & Krysinski, D. (2008). Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education*, *19*(2), 22–39.

Dyer, R. R., Reed, P. A., & Berry, R. Q. (2006). Investigating the relationship between high school technology education and test scores for algebra 1 and geometry. *Journal of Technology Education*, *17*(2), 7–17.

Eccles, J., & Wigfield, A. (2002). Motivational beliefs, values and goals. *Annual Review of Psychology*, *53*(1), 109–132.

Elias, M. J. (2009). Social-emotional and character development and academies as a dual focus of educational policy. *Educational Policy*, *23*(6), 831–846.

Frank, M., & Barzilai, A. (2006). Project based technology: Instructional strategy for developing technological literacy. *Journal of Technology Education*, *18*(1), 39–53.

Frazier, M. T. (2009). *The effect of technology education on student's state standardized test scores* (unpublished doctoral dissertation). Norfolk, VA: Old Dominion University.

Gupta, J. (2009). India prepares strictest rules on disposing of e-waste. *Thaindian News*. Retrieved from http://www.thaindian.com/newsportal/business/india-prepares-strictest-rules-on-disposing-of-e-waste_100234233.html

Hammons, J. (1999). *The effects of applied technology instruction on mathematics and science achievement of eighth grade students* (unpublished master's research paper). Norfolk, VA: Old Dominion University.

Hidi, S., & Renninger, K. (2006). The four-phase model on interest development. *Educational Psychologist*, *41*(2), 111–127.

International Reading Association/National Council of Teachers of English (IRA/NCTE). (1996). *Standards for the English language arts*. Urbana, IL: Author.

International Technology Education Association - Center to Advance the Teaching of Technology and Science (ITEA - CATTS). (2006). *Foundation of technology: A standards-based high school model course guide*. Reston, VA: Author.

International Technology Education Association (ITEA). (2007). *Standards for technological literacy: Content for the study of technology*. Reston, VA. Author.

Irvine, D. (2010). Can e-waste be turned to gold? *CNN International*. Retrieved from http://edition.cnn.com/2010/TECH/02/23/eco.ewaste.gold/

Joseph, N. (2010). Metacognition needed: Teaching middle and high school students to develop strategic learning skills. *Preventing School Failure*, *54*(2), 99–103.

Loepp, F. L. (1999). Models of curriculum integration. *Journal of Technology Studies*, *25*(2), 21–25.

Karweit, D. (1993). *Contextual learning: A review and synthesis*. Baltimore: Center for the Social Organization of Schools, Johns Hopkins University.

Lave, J., Smith, S., & Butler, M. (1988). Problem solving as everyday practice. In R. I. Charles & E. A. Silver (Eds.), *The teaching and assessing of mathematical problem solving*. Hillsdale, NJ: Erlbaum.

Lewin, K. (1938). *The conceptual representation and the measurement of psychological force*. Durham, NC: Duke University.

Moye, J. (2009). The foundations of technology course: Teachers like it! *The Technology Teacher*, *68*(6), 30–33.

Murray, M. (2004). *Teaching mathematics vocabulary in context: Windows, doors and secret passageways*. Portsmouth, NH: Heinemann.

National Commission on Mathematics and Science Teaching for the 21st Century. (2000). *Before it's too late: A report to the nation from the national commission on mathematics and science teaching for the 21st century*. Jessup, MD: Education Publications Center.

National Council for the Social Studies (NCSS). (1994). *Social studies in the middle school*. Retrieved from http://www.socialstudies.org/standards/introduction

National Council of Teachers of Mathematics (NCTM). (2000). *Math standards & expectations*. Retrieved from http://www.nctm.org/standards/content.aspx?id=4294967312

National Council of Teachers of Mathematics (NCTM). (2000). *Principles and standards of school mathematics*. Reston, VA: Author.

Nielsen, L. (1996). *Adolescence: A contemporary view* (3rd ed.). New York: Harcourt Brace.

Plaza, O. (2004). Technology education versus liberal arts education. *The Journal of Technology Studies*, *30*(1), 16–19.

Project Lead the Way (PLTW). (n.d.). *Project lead the way- our programs*. Retrieved from http://beta.pltw.org/our-programs/our-programs

Rogers, S., & Rogers, G. E. (2005). Technology education benefits from the inclusion of pre-engineering education. *Journal of Industrial Technology Education*, *42*(3), 88–95.

Settar, S. (2006). *The relationship between pre-engineering courses and increased success on the Virginia algebra II and geometry standards of learning examinations* (unpublished master's research paper). Norfolk, VA: Old Dominion University.

Sroufe, L. A., Cooper, R. G., DeHart, G. B., & Marshall, M. E. (1996). *Child development: Its nature and course* (3rd ed.). New York: McGraw-Hill.

Schneider, D. O. (1994). *Expectations of excellence: Curriculum standards for social studies*. Washington, DC: National Council for the Social Studies.

Tomlinson, C., & McTighe, J. (2006). *Integrating differentiated instruction and understanding by design*. Alexandria, VA: ASCD.

Trumble, W. R., & Stevenson, A. (Eds.). (2002). *Shorter Oxford English dictionary* (5th ed.). New York: Oxford University Press.

United Nations Environmental Program (UNEP). (n.d.). *The green economy initiative*. Retrieved from http://www.unep.org/greeneconomy/

United States Environmental Protection Agency (US EPA). (n.d.). *Wastes-resource conservation-common wastes & materials-ecycling*. Retrieved from http://www.epa.gov/osw/conserve/materials/ecycling/faq.htm

John M. Ritz
Graduate Program Director in STEM Education
Old Dominion University
Norfolk, Virginia
USA

Johnny J. Moye
Supervisor of Career and Technical Education for Chesapeake Public Schools
Chesapeake, Virginia
USA

THOMAS T. LIAO

9. ENGINEERING AND TECHNOLOGY EDUCATION

Toward 21st Century Integrated Skill Sets for Future Careers

INTRODUCTION

Careers in this century, whether white or blue collar, will require professionals who can use ETE-based concepts and tools to solve problems. ETE (Engineering and Technology Education) programs prepare future workers who can integrate skills sets for solving complex problems that involve the ability to apply STEM (Science, Technology, Engineering and Mathematics) concepts and use technological tools. This chapter focuses on a description of engineering concepts and tools that include applied science and mathematics examples in the context of 21st century careers. A case will be made that ETE programs develop technological literacy needed by all future workers and voting citizens if they are to be effective problem-solvers and decision-makers.

Technological Literacy (TL) refers to the understanding of modern technology: its capabilities and limitations, underlying STEM concepts, and societal impacts. TL spans the range from how specific technological hardware (machines) and software tools work, to the understanding of how more complex systems are designed to satisfy basic human needs and wants. Furthermore, TL includes not only the application of scientific and mathematical principles underlying engineering design, but also consideration of the human, environmental and societal impacts of technology (Liao, 1998).[1]

Part B of this book focuses on the discussion of core concepts and learning outcomes of ETE programs. In Chapter 5, Marc de Vries presents a concept-context framework for ETE curriculum and instruction. In Chapter 6, John Williams "proposes that ETE should focus on the development of dispositions." The authors of Chapters 7 and 8 focus on how ETE programs can enhance motivation and creativity. The preceding four chapters provide a solid foundation for making a case that ETE programs provide TL skill sets needed for 21st century workers.

The integration of skill sets that relate to technological design and decision-making is the central theme of this chapter. All of the elements of engineering design and decision-making will be discussed in the context of job requirements of modern workers. Modern technological design innovations will be used to illustrate various aspects of the design process.

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 153–168.

MATCHING SKILLS DEVELOPMENT WITH FASTEST-GROWING CAREERS

Career advisors are advocating the need for developing technological literacy, problem-solving skills that focus on the integration of STEM concepts and team collaboration on projects. They agree that most of the fastest-growing jobs require an addition of these skill sets to the more traditional ones. The following three citations from a magazine, book and a blog from an Information Technology (IT) professional argue for the need to provide ETE programs for all students. In an article in *Converge* magazine, Tanya Roscorda addresses questions about next generation skills and jobs that will be in high demand. (Roscorla, 2010):

> "*What kinds of jobs are in demand*?
>
> I can't sit here and tell you on a national level what kinds of jobs are really in demand. What we can do is help a region to identify what their talent pool looks like and identify skills, talent surpluses and talent deficits, and use that to invest in training and curriculum modifications.
>
> *What kinds of skills will students need to land a good job*?
>
> If I was going to summarize that, I would say initiative, problem solving and teamwork."

In the 2009 edition of *100 Fastest-Growing Careers*, Michael Farr identifies the following skill areas that today's students need to develop to qualify for 21st century careers that are growing the fastest:

- Artistic Skills
- Communication Skills
- Interpersonal Skills
- Managerial Skills
- Mathematics Skills
- Mechanical (Technology) Skills
- Science Skills

Notice that the last three of the seven skill sets are provided by ETE programs and directly relate to problem-solving that requires the integration of STEM knowledge and technological literacy. The need to ensure an adequate pool of workers with the proper skill sets is essential for innovation in our society (Farr, 2009).

In a global economy, in order for the USA to be competitive and continue to innovate, our companies must have employees who have up-to-date STEM skills. For example, IT companies such as Microsoft have launched programs to address this need. See the following blog, *Promoting Innovations to 21st Century Careers*, posted by Fred Humphries, Managing Director, US Government Affairs. (Humphries, 2010):

> "At Microsoft, we believe that equipping students and workers with the education and skills they need to compete in the 21st century global economy is critical to U.S. economic and national security. Indeed, despite the economic downturn and high unemployment rates, Microsoft and thousands of our

> partners continue to struggle to find workers with the knowledge and experience necessary to help our businesses compete and grow.
>
> These skill shortages exist despite significant investments by Microsoft and our like-minded partners to grow the pipeline of science, technology, engineering and math students through programs such as Partners in Learning, which provides curricula and class materials, and DreamSpark which offers students free software.
>
> But even if we succeed in developing a deep pool of highly skilled IT workers in the U.S., there will still be substantial workforce development needs to keep the U.S. economy evolving and growing long-term. For instance, there has been much talk in Washington, D.C., about the wave of new green jobs and health IT occupations that are likely to emerge over the next decade. Such occupations will also require that job seekers possess a basic platform of skills to prosper in a global economy."

One set of skills relates to the ability to model and analyze input and output systems, especially systems that use feedback to control their behavior. One hallmark of the 21st century technology is the automation of systems to replace routine human decision-making in both manufacturing and service industries.

AUTOMATION: FEEDBACK CONTROL

Both manufacturing and service industries in the 21st century use systems that are automated. Whether a worker is designing, servicing or simply using an automated system, a basic understanding of how sensing and feedback are used in an automated system to achieve decision-making capability needs to be part of the skill set of a modern worker. After a brief discussion of the role of feedback in the operation of an automated system, two concrete examples will be provided, namely, the cardiac pacemaker and barcode automation.

Automation is the use of machines to replace people in tasks that require decisions. At home, we use an automated system to flush our toilets and a thermostat to achieve comfortable temperatures. Because automation is used for decision-making, feedback is the central element. True automation must use feedback. Often, people think that using machines to make work easier is automation. However, this type of technology is simply mechanization because the human user of the technology is still making all the decisions (Truxal, 1989).

Feedback that is used to achieve desired outcomes is called negative feedback. Negative feedback systems such as home temperature control systems require a sensor and a comparison device to trigger the heating or cooling system when a difference exists between the desired temperature and the actual temperature.

A comparison device (thermostat) determines the difference between the desired output (temperature setting) and the actual output (house temperature). If the temperature difference is significant, a switch turns on the heating or cooling system. The temperature of the house changes until the desired temperature is reached. When the actual temperature is about the same as the desired temperature, the heating or cooling is automatically turned off.

Automation of Service Industry Systems

Recent statistics show most fastest-growing careers are from the service sector of our economy, especially in health care services. In the next section, a short history of the design and development of the artificial pacemaker for regulating the pacing of the heart is presented. Another important sector of service industries is retailing. The use of barcodes for automation of supermarkets and other retail stores is a second example that is presented to illustrate the application of STEM concepts.

Example #1: Cardiac Pacemaker

Of all the new medical devices that have come along since World War II, the cardiac pacemaker has probably been the most successful. In 2010, about 2 million Americans use pacemakers and 200,000 of the new highly automated devices are implanted in new patients each year in this country alone.

In the past 50 years, the design of the pacemaker has evolved from a simple mechanized device that sent a 70 pulse/minute signal to regulate the heart, even when the natural pacemaker was working, to a device with multiple feedback loops. The design improvement that changed it from being a mechanized to an automated system was the development of the demand pacemaker that only paced the heart when it was needed. In other words, a feedback loop was added to sense if the natural pacemaker was not working properly. The next sought-after design feature was a variable rate device. The modern pacemaker is the size of a small pocket watch and is able to regulate the heart with pacing rates to match a person's physical activity.

Despite all the advances made, pacing will remain a "halfway technology" that manages but does not cure the underlying disease. It has not evolved into something simple and inexpensive. High-tech prosthetic devices are complicated and expensive. As this chapter is being written in March of 2010, the debate is raging over how to provide health care for all at a reduced cost. All health care professionals and the public have to make very difficult decisions as to how best to provide cost-effective health care. Therefore, the example of the pacemaker can be a base not only for teaching concepts of engineering and technology, but also for discussing social dilemmas concerned with using new medical technologies.

Example #2: Barcode Automation in IT Systems

One of the most important skills that today's employers require are employees who can analyze a problem and make more cost-effective decisions to solve the problem. IT systems that use barcodes are being used in retailing and other applications, such the routing of mail for the purpose of replacing or enhancing human decision-making. In this example, we will discuss how the management of a supermarket and the routing of mail have been automated with the integration of barcode information and database information. We will study how the barcode for the postal mailing routing system is designed to check for errors.

Supermarket Automation: A customer brings his cart to the supermarket check-out counter. The checker moves each item across the counter so the laser scanner reflects off the barcode. The computer identifies the product purchased, instructs the electronic cash register what to ring up and prints out the customer's receipt. So, what is the automation? What decisions are being made by the machine?

The real automation is the computer use of the information for inventory control and reordering. In the computer's database, the store manager has a running record of the thousands of items in the store. When each sale is made, the computer subtracts one item from its record. The computer can then use the recent history of sales to predict when the store will run out of the item and reorder sufficiently in advance. Thus, the automation system handles all record-keeping, ordering and inventory control. It replaces the human manager in simple decisions and provides up-to-date information to enhance the manager's decisions. For example, the computer system can evaluate the effectiveness of coupons or special advertising campaigns to help the manager decide how best to promote sales.

Being able to analyze the design and operation of technological systems is an important TL skill that all future workers must learn and apply. Besides verbal descriptions, students also need to learn to describe systems graphically. Figure 1 presents a systems diagram depicting the design and operation of the supermarket automation system. The focus is on how the scanned barcode information about the manufacturer and food item is used in an inventory control system that re-orders store items automatically.

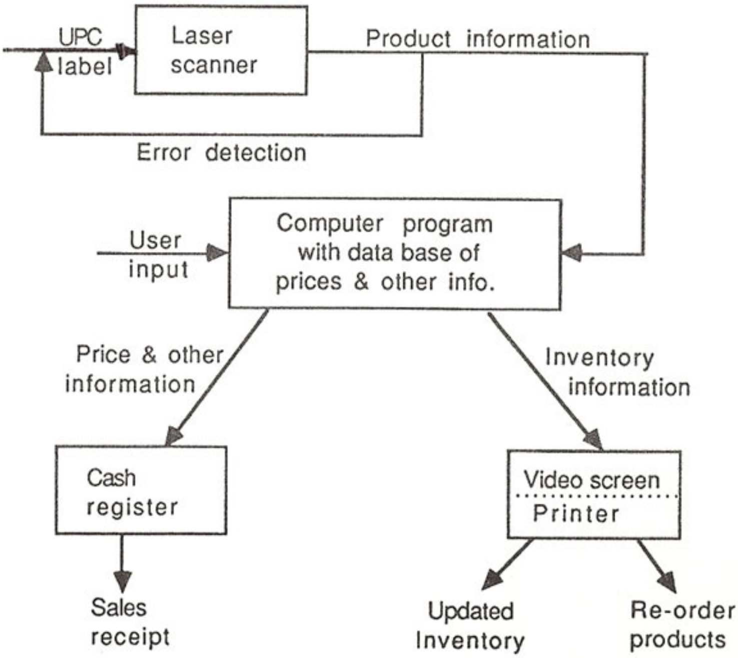


Figure 1. Supermarket automation system (Visich, 1990).

Using redundancy in barcode systems: An important design feature of all IT systems is using extra or redundant information to detect errors in transmission or decoding. In more complex systems, even greater redundancy is provided to correct the detected errors. In supermarket automation systems, digital barcodes are used to represent decimal numbers that identify the manufacturer and the specific product. It takes only four binary digits (bits, 0 or 1) to represent 10 decimals. However, seven bits are used. How are the three extra or redundant bits used?

In many IT systems, redundant bits are used to check if an odd or even number of 1s or 0s bits are scanned. In computer jargon, this is called an odd or even parity check. This type of error detection is used in both supermarket and postal service barcode systems. In addition, the supermarket system uses odd parity for the left-hand side of the barcode and even parity for the right-hand side. In this way, the scanning system knows which way the UPC (Universal Product Code) label is being read. This is an excellent example of good ergonomic design because the checkout person does not have to be concerned with the direction of the scan. The next example engages the reader in the exploration of the design of the US postal barcode system.

Cracking the US Postal Barcode

Another important problem-solving skill is the ability to study a system and figure out how it is designed. The US Postal Barcode system is one of the simpler barcode systems. You merely have pick up a piece of mail and analyze the barcode (a tall bar is a one and a short bar is a zero), which represents the ZIP plus four codes for the mailing address. The steps in the analysis are as follows:

1. Count the number of Tall and Short bars and confirm that there are 52 of them.
2. Notice that the first and last bars are both Tall. They are called protocol bars and are signals to a scanner to start or stop the scanning process.
3. We next have to figure out how the remaining 50 bars are used. We have nine decimal numbers (ZIP plus four) to code. So, how many bits are used to code each decimal number?
4. As discussed earlier, we only need four bits to code 10 decimal numbers (0 to 9). So we only need 36 (4x9) bits to code the ZIP plus four information. This means that we have 14 extra or redundant bits. How is the redundancy used to detect errors?
5. To achieve even parity (in this case, two ones), we need to represent each decimal number of the ZIP Plus four code with five bits. This means that the nine Zip Plus four numbers use up 45 bits. The remaining five bits are used as a check digit.
6. To complete cracking the code, label the first Tall bar as a Start bar and the last Tall bar as a Stop bar. Next group the remaining 50 into 10 groups of five bars. Now you are ready to decode. For example, if the first ZIP plus four number is a decimal 1, its code will be 00011. As you decode the remaining decimal numbers, notice that each binary code always has two ones (even parity). Thus, if the scanner reads an odd number of ones, an error has occurred.
7. The US Postal system also has a second way of detecting errors via the use of the check digit. The system adds the sum of the nine ZIP Plus four decimal

numbers to the check digit. If the final total ends in a zero, then there is no error. Otherwise, an error has occurred.

The above example illustrates how IT systems are designed to detect and correct errors via the use of redundant information. Future workers need to know how to use the concept of redundancy to better design or use systems to improve effectiveness. All human-machine systems can potentially benefit from the appropriate use of redundancy to enhance system performance. This is an aspect of technological literacy that is not emphasized or well understood.

Reasons for Automation: There are five main reasons for automating a system. The decision to automate supermarkets and the US Postal Service was based on three reasons. First, the simple decision tasks of the supermarket and postal workers were boring and sometimes degrading. Second, the worker decisions were so undemanding that the use of automation systems was cheaper. Third, the sheer volume of mail and products requires a system that can track and process information in a timely manner. The above three reasons relate to using automation to achieve more cost-effective performance of a system. However, there are many situations where human limitations and environmental conditions require automation. The fourth reason is that people are incapable of making the required decision due to human limitations such as reaction time. Finally, some environments such as a nuclear power plant are unfit for human beings.

Concluding comments about automation: The above examples of automation (pacemaker and barcode automation) are from what economists call service industries. However, most public discussions about automation focus on manufacturing industries such as auto manufacturing and assembly. Many of the concepts discussed about the automation of service industries also apply to manufacturing industries.

For manufacturing, there is a clear distinction between mechanization and automation. The industrial revolution was based on mechanization: machines replaced or assisted people by providing forces and energy to make work more doable and efficient. Automation includes, in addition, machines taking over some decision-making tasks. In an automated paint shop in a car assembly plant, the system measures the exact position of the car, determines the colors to be used, loads and aims the painting guns, and guides the nozzles precisely over the desired surface. This process is carried out in an environment so heavy with particulate pollution that it would be unsafe for human beings.

ASPECTS OF TECHNOLOGICAL DESIGN AND DECISION-MAKING

In the above discussion of concepts and examples that relate to automated systems, the idea of engineering or technological design and decision-making was introduced. In the second half of this chapter, the focus will be on modern examples of innovative design and the elements of decision-making.

New York Times Annual Year in Ideas: In 2001, to highlight new ideas for the year, the *New York Times* magazine launched a special issue that would be published at the end of that year and each successive year. On December 13, 2009, *The 9th Annual*

Year in Ideas was published. The magazine editors used the following 10 thematic areas to organize the new ideas or innovations:

1. Business
2. Design
3. Health
4. Social Science
5. Arts
6. Sports
7. Technology
8. Culture
9. Natural Science
10. Politics and Policy

Over 50% of the new ideas were related to the four themes pertaining to the STEM disciplines, namely, Technology, Natural Science, Design and Health. A more interesting feature of the articles was that all the innovations involved more than one theme. Many of the articles are examples of technological forecasting of what might be part of society in the near future. Five of the examples will be presented as a prelude to the discussion of the elements of design and decision making (*New York Times*, 2009).

1. Guilty Robots (Technology, Politics and Policy): A major application of automation technology is the use of robots to fight wars. Wars are increasingly being fought by automated machines. For example, from 2004 to 2009, the use of automated unmanned war machines increased from about 200 to 18,000. A new policy concern has arisen with the increased use of battlefield robots. Will these robots make ethical decisions?

   New software that uses "ethical architecture," which is based on international laws of war and rules of engagement, is being developed. The robots' behavior is literally governed by these laws. The software will also attempt to model guilt because it can be used to condemn specific behavior and generate constructive change. While fighting, the robots would assess battlefield damage and then use algorithms to calculate the appropriate level of guilt.

2. Artificial Car Noise (Technology and Social Science): When new technology is introduced, such as hybrid cars that use electric motors, unintended consequences often occur. It turns out that the new silent cars of the 21st century have a serious downside: pedestrians and bicyclists are less likely to hear hybrids and electric cars and are liable to be hit by them. The first element of decision-making is to ask: Is there really a problem?

   The National Highway Safety Administration recently released a study that revealed the full extent of the problem. At intersections, interchanges, and parking lots, hybrids proved far more hazardous, with pedestrians and bicyclists getting hit at up to twice the normal rate. So instead of trying to make cars quieter, manufacturers of hybrid and electric cars find themselves in the curious position of figuring out the best means of warning people with artificial car noise. This search for alternative solutions to the quiet car problem is an example of the second element of decision-making in a design problem.

3. Google Algorithm as an Extinction Model (Natural Science and Technology): Another important element of decision-making and problem-solving is finding appropriate models for studying the system that is relevant to the problem. To determine the relative importance of a species in an ecosystem, scientists design computer programs to model how the extinction of a given species would affect the other species in the system. Sometimes an approach or algorithm that is used to solve one problem can be used to study other systems.

   Two scientists, Stefano Allesina and Mercedes Pascal, had a hunch that they might be able to adapt the Google search approach to model the behavior of ecosystems. Google's search engine uses an algorithm called PageRank to identify the most important Web sites on a given topic by analyzing links. Allesina and Pascal modified the PageRank algorithm to model ecosystems and found that it was more efficient than existing models for studying the impact of the extinction of a species.

4. Good Enough Is The New Great (Technology and Culture): When searching for the best design to satisfy both criteria and constraints of a problem, some type of optimization process must be used. Often, the key question that needs to be addressed is: Is the design good enough? Robert Capps wrote an essay in *Wired* magazine called *The Good Enough Revolution*. He makes a case that the best technical product may not be the most successful in the market place. People are looking for cheap, fast and simple tools. So it seems for many people the criteria for selecting technology are changing (Capp, 2010).

   Even though HDTV has become the new video standard, many people are watching TV on their cell phones and microcomputers. CD players are being replaced by iPods. Lo-fi (low-fidelity) solutions are available for a range of applications that could not be solved by hi-tech tools. For example, music played from a CD is of higher quality than what comes out of an iPod. But you can't easily carry 4,000 CDs with you on a bus or to the gym. To a new generation of iPod listeners, lo-fi is good enough. When there are multiple criteria to a decision problem, then the final solution depends on the weight assigned to each criterion.

   This example demonstrates that design and decision-making in engineering and technology are always about choosing among alternatives and tradeoffs. It should be noted in Chapter 5, de Vries discusses how criteria need to be clearly established to determine which solution is preferred and that a solution's performance is measured against these criteria.

5. Man-Made Greenery (Design and Technology): When seeking solutions to environmental problems, designers look to mimic nature. A group of British engineers recommended building a forest of artificial carbon filtering "trees" to combat climate change. One proposed design is as follows:
   - The "trees" contain rows of filtration boxes that capture carbon dioxide.
   - An automated process lowers the carbon dioxide filled boxes underground.
   - The carbon is removed by a cleaning facility and stored.
   - The cleaned filtration boxes are returned to its slot in the artificial "trees."

Another designer, Samuel Cochran, proposed a set of leaf-like modules that harness both solar and wind energy. His modules are designed to be installed on building facades. The foliage shape is designed to capture oblique sunlight that hits the building facade. When a breeze rustles the artificial "leaves," tiny piezoelectric generators in the "stems" create a small charge.

The above five examples were selected from the 30 that appeared in the special Issue of the *New York Times* magazine to highlight the importance of technological forecasting and to introduce some of the aspects of the design process and the four main elements of decision-making (Criteria, Constraints, Models and Optimization). Next, all of the elements of the design process will be described and a concept map linking all the elements will be presented. Notice that the design process is an iterative process that hinges on the question: Is the design good enough?

CONCEPT MAP FOR ELEMENTS OF THE DESIGN PROCESS

The design process is an iterative cycle made up of many elements that are linked in many ways. The concept map (Figure 2) shows the connections between the elements or components of the design process:

1. Needs Assessment: What is the nature of the problem? How significant is the problem? What needs are being addressed?
2. Availability of Resources: What is the budget allocated to address the problem? Are there environmental or safety considerations?
3. Criteria: What are the design objectives in quantitative terms? What are the measurable performance outcomes?
4. Constraints: What are the limitations that the proposed design solutions have to satisfy? Are there human and environmental limitations that must be addressed?
5. Identification of Alternative Designs: Develop designs that satisfy the criteria and are within the constraints that are specified.
6. Optimization: Techniques for deciding which of the alternative designs is the best solution to the problem.
7. Models of Alternative Designs: Construct test models of alternative designs.
8. Selection of the Best Alternative: Use optimization techniques to test design models to determine the best alternative design.
9. Building a Prototype: Construct a working replica to test and evaluate its performance.
10. Testing the Prototype: Use optimization techniques to determine how well the prototype design satisfies the design criteria.
11. Is the Design Good Enough?: As discussed in one of the above examples, this is based on the optimization process. If the answer is yes, then the design is accepted. If the answer is no, then the design process must be repeated.

Concept Map

When a process or system has many elements that are connected in various ways, a concept map is a useful tool for describing and explaining the dynamics of the process

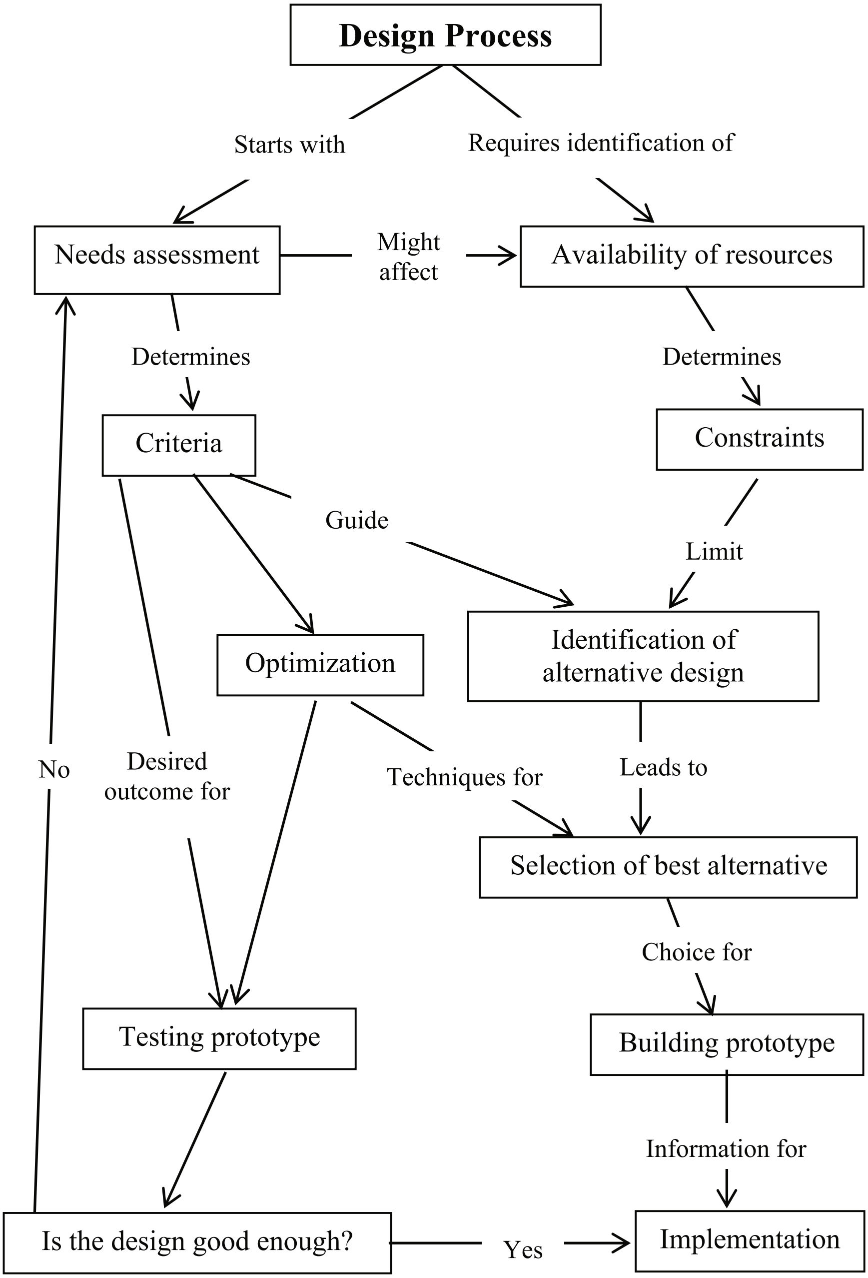


Figure 2. Concept map for the design process.

or system. A concept map for showing how the above 11 elements of the design process are linked is depicted in Figure 2. The arrow directions show the flow of the thinking process, and the words next to the arrows show how one element affects another element. The concept map also outlines the decisions that are involved in the design process (NYSED, 1995).

The design process concept map can be used in three ways:

1. To guide in the design of a product or system to address a need or problem.
2. To guide in the selection and purchase of a product or system to address a need or problem. For example, the selection and purchase of a car resulting in a "best buy" is more likely if the above process is used.
3. It can be adapted as a system for guiding decision-making in general. In this case, the four elements that apply to general decision-making are criteria, constraints, modeling and optimization.

ELEMENTS OF DECISION-MAKING

Both professional and personal decision-making require a systematic approach.

First, the decision problem must be clearly described in terms of criteria and constraints. What are the specific measureable outcomes? What are the limitations? Next, appropriate information in terms of the models must be used to study the decision options. Finally, optimization techniques must be applied to determine the best decision. Decisions relating to energy use will be used to illustrate how the following four elements can be integrated:

- Criteria: Desired outcomes
- Constraints: Limitations
- Models: Information related to the decision problem
- Optimization: Search for the best solution

Energy Decisions

Many personal as well as professional decisions relate to making more cost-effective decisions about the use of energy in homes, offices and transportation systems. As discussed in the previous section, the hybrid car and "man-made greenery" examples offer new technological options. Another interesting example from *Fortune* magazine about the design of energy efficient skyscrapers is as follows:

> "The holy grail of modern architecture is to design a zero energy building, or ZEB. ZEBs use solar, wind, and geothermal systems to produce at least as much energy as they tap from the grid" (Dumaine, 2010).

The above ZEB goal is an example of one design criterion for some architects. However, when designing homes or buildings, there are many other criteria that relate to the function of the living space. Some criteria may conflict, and compromises in design may need to be made that makes the ZEB goal not as attainable.

Depending on the location of the building, geographical constraints may limit what alternative energy systems can be implemented. For example, a new 71-story skyscraper in Guangzhou, China was designed to include a geothermal system. However, the site did not provide enough warm ground water for it to function properly. Even with this problem, this building is still 58% more efficient than conventional skyscrapers.

In order to decide whether ZEBs are cost-effective, much more information about construction and operation in the form of mathematical models would be needed to decide on the optimum solution. The selection of an optimum skyscraper design is much too complicated for this discussion. A simpler example, the selection of a cost-effective air conditioner, will be used in the next section as an example of how the four elements of decision-making are applied.

Selecting an Energy Efficient Air Conditioner

You are in the market for a window air conditioner. What criteria, constraints, models and optimization techniques relate to the decision to buy a cost-effective machine?

Criteria: What is the lowest life-cycle cost of the air conditioner? How durable is the air conditioner? How reliable is the air conditioner?

Constraints: What is the room size to determine required cooling power? What is the window size? Is a 230-volt line available?

Models: Information and calculations related to the energy efficiency of air conditioners. How are EER ratings defined? Cost of electrical energy?

Optimization Techniques: Determination of the efficiency of air conditioners, cost of operating the unit, purchase price, life-cycle cost.

Decision Question: How do you decide if a more efficient air conditioner is worth the higher purchase price?

Let's say that you are given a choice between two 10,000 BTU air conditioning units. One has an EER (Energy Efficiency Ratio) of 8.3 and requires 1,200 watts, and the other has an EER of 10 and requires 1,000 watts. Let's also say that the price difference is $100. To calculate what the payback period is for the more expensive unit, you need to know:

– Approximately how many hours per year the unit will be operating.
– What the rate of a kilowatt-hour (kWh) is in your area.

Let's also say that you plan to use the air conditioner in the summer (approximately five months a year, depending on where you live) and it will be operating around eight hours a day. Say that the cost of a kilowatt-hour in your area is approximately $0.10. The difference in energy consumption between the two units is 200 watts, which means that every five hours, the less expensive unit will consume 1 additional kWh (and therefore $0.10 more) than the more expensive unit. Assuming that there are 30 days in a month, you find that during the summer you are operating the air conditioner:

Time of operation = 5 mo. x 30 days/mo. x 8 hr/day = 1200 hours
Cost = ((1200 hrs x 200 watts) / (1000 watts/kW)) x $0.10/kWh = $24.00

Since the more expensive unit costs approximately $100 more to buy, it would take about four years to recover the additional cost. However, if your cost for electrical energy is 15 cents per kilowatt-hr, then it would cost $36 per year more to run the less efficient unit and it would take you only about three years to make up the $100 difference in the purchase price. The above mathematical model is based on simple physics and algebra concepts that can be manipulated to determine how the criteria and constraints that relate to the selection of an air conditioner can be optimized.

Conceptual Question: How Does the EER Number Determine the Efficiency of an Air Conditioner?

Your office air conditioner has an information label that has the following:
230 V 8.5 A 50 HZ [60 HZ for US Systems] 14,500 BTU/HR EER 8

The above data mean that the air conditioner runs on a 230-volt line, requires a current of 8.5 amperes, and uses an AC electrical energy system at 50 Hertz. The cooling system will remove 14,500 BTU of heat per hour, and the Energy Efficiency Ratio is 8 BTU per Hour of output for 1 Watt of input. Notice that in order to understand the above information, one must be bilingual in units of measurement. For example, the unit for power is Watt in the metric system but BTU/HR in the English system. So why did the federal government use a mixture of units to define the ERR efficiency rating? In the mid-1970s, the federal government initiated a series of steps to reduce US dependence on imported oil. One of the steps was to require labeling of air conditioners to indicate to buyers which models were more efficient so people would buy these even if the initial cost was higher. In the 21st century, the need to conserve energy is even more important so using more energy-efficient home appliances must be encouraged.

The first idea was simply to compare cooling power output to power input:

Efficiency = Cooling Power in Watts/Electrical Power consumed in Watts

The problem with the above approach is that the efficiency would turn out to be 200% or higher (See sample calculation). How is this possible? Did you not learn in science class that machines could not have efficiencies of 100% or more? The reason is that an air conditioner is a heat-removing pump and more heat is removed per hour than the electrical power needed to run the pump.

Sample Calculation

1. Converting the Power Output (cooling power) in BTUs/HR to Watts:

Power Output (cooling power) = 14,500 BTU/HR = 14,500 BTU/3600 Sec = 4 BTU/Sec
Since 1 BTU/Second ≈ 1 Kilo Watt
Power output ≈ 4 Kilo Watt

2. Calculating the Power Input (electrical power) consumption:

Power Input (electrical power) = Voltage x Current = 230 V x 8.5 A = 1955 Watts ≈ 2 KW (for power factor $\cos(\rho)=1$)

3. Efficiency = Power Output / Power Input = 4 KW/2KW = 2 or 200%

Government policy-makers were worried that the general public would be confused by labeling efficiencies of 200% or above, so they sought an alternative method for efficiency labeling. They came up with the EER (Energy Efficiency Ratio) rating, which is defined as:

EER (Energy Efficiency Ratio) = Power Output (Heat Removed in BTU/HR)/Power Input (in Watts) = 14,500 BTU/HR/1955 Watts = 7.4

Notice that the EER rating of 8 on the air conditioner label is an approximation.

The above example is provided to highlight the role that applied STEM knowledge is required in order to make more informed decisions. In this instance, if individuals are to make more effective decisions about energy, basic applied physics, mathematics and engineering concepts must be understood by everyone.

SOCIETAL IMPACT OF TECHNOLOGY

Future workers must also understand the numerous ways that technology can interact and have impacts on societal systems. Technology has both intended and unintended societal impacts. As discussed earlier, the intended design of hybrid cars is to build more energy-efficient vehicles. However, the lack engine noise was an unintended outcome. One way to identify impacts on outcomes is to carry out technology assessments. Two types of assessments exist: Technology-Initiated Assessment (TIA) and Problem-Initiated Assessment (PIA).

As new technological systems are being designed and developed, impact studies must be carried out to determine both the positive and negative outcomes of using the technology. A cost-benefit analysis should include both monetary and other costs to people and the environment. Benefits should be quantified, if possible. Public policy that relates to the development a new technology should be informed by TIAs.

We use technology to satisfy many human needs and wants. However, accompanying the benefits are problems. A PIA helps to identify potential solutions to the problems caused by technology. For example, the benefits of auto travel also results in thousands of people being killed or injured. A PIA would show that some auto safety measures prevent accidents while other measures reduce the severity of the accidents. There are three main approaches to prevent or minimize the severity of auto accidents. First, we can implement “technological fixes” to improve the cars and roads. Second, new laws and regulations can be implemented. Finally, education programs can be implemented to improve the quality of the driver.

This chapter concludes with a brief discussion of the notion of "technological overkill." This disturbing trend has two aspects. First, we often use more technology than necessary. For example, many cars are over-powered and waste energy. The current trend toward more efficient cars is a positive trend. The excessive use of computer games is another example of the over-use of technology. Second, sometimes new technological options are introduced that are frills and have little to do with the main function of the technology. The many new features or applications of mobile phones that have little to do with communication is a modern example of this societal impact of technology.

NOTES

[1] The author was an early advocate of the concept of technological literacy. About 40 years ago, he co-authored a paper with Prof. E.J. Piel that appeared in the *Physics Teacher*, Vol. 8 No. 2 entitled: *Let's Get Relevant: Toward Technological Literacy.*

REFERENCES

Capps, R. (2010). *The good enough revolution*. A Blog from wired.com. Available at http://www.wired.com/gadgets/miscellaneous/magazine/17-09/ff_goodenough

Dumaine, B. (2010, March 31). One cool skyscraper. *Fortune Magazine*. Available at http://www.energycode.com/?p=917

Farr, J. M. (2009). *100 Fastest-growing careers*. Indianapolis, IN: JIST Works.

Humphries, F. (2010). *Promoting innovations to 21st century careers*. Blog posted Microsoft on the Issues blog. Available at http://blogs.technet.com/b/microsoft_on_the_issues/archive/2009/08/04/promoting-innovations-to-21st-century-careers.aspx

Liao, T. T. (1998). Technological literacy: Beyond MST integration. *The Journal of Technology Studies*, *24*(2), 52–54.

New York State Education Department (NYSED). (1995). *Technology education: Principles of engineering, a curriculum guide*. Retrieved May 25, 2010, from http://www.emsc.nysed.gov/cte/technology/pub/home.html

Roscorla, T. (2010, February 13). Schools prime next generation for steady jobs. *Converge Magazine*.

The New York Times Magazine. (2009, December 13). *The 9th annual year in ideas*.

Truxal, J. G. (1989). *Feedback-Automation*. New York: New Liberal Arts (NLA) Monograph, SUNY Research Foundation. Available at http://www.math.dartmouth.edu/~mqed/NLA/FeedbackAuto/FeedbackAuto.phtml

Visich, M. (1990). *Bar codes and their applications*. New York: New Liberal Arts (NLA) Monograph, SUNY Research Foundation. Available at http://www.math.dartmouth.edu/~mqed/NLA/BarCodes/BarCodes.phtml

Thomas T. Liao
State University of New York at Stony Brook
Stony Brook
USA

PART III:
CULTURAL DIMENSIONS

JACQUES GINESTIÉ

10. HOW PUPILS SOLVE PROBLEMS IN TECHNOLOGY EDUCATION AND WHAT THEY LEARN

The Teaching-Learning Process for Transmitting Artefacts, Skills and Knowledge

INTRODUCTION

As is the case in several countries, the development of technology education in France involves a process of transmitting inter-generational knowledge aimed at children to develop their understanding of the technical world in which they live and to which they will contribute in structuring and helping to evolve. This process is, first and foremost, a cultural one; it is a matter of leading children to acquire knowledge that is socially shared by society. Beyond the social sharing of existing knowledge, gateways for children to enter into the adult world are also targeted. One of the roles of schooling is a social one that aims at educating future citizens by allowing them to build the knowledge they will need in order to be able to live and act responsibly within society. The notion of the school's social role exists from the moment that a society, using its political leverage, decides to hand the responsibility for conveying the social knowledge that governs it to a teacher, so that children use the learning of such knowledge to evolve socially. From this point onwards, studying different facets of the teaching-learning process becomes particularly meaningful in defining the cultural transmission of knowledge. The aim of this chapter is to describe some of these facets, notably with regard to the sharing of the tools, artefacts and knowledge that traditionally define engineering and technology education curricula in France.

FROM A THING TO AN OBJECT

The Subject and Object Relationship

First, we will discuss the cultural transmission of knowledge at school and by school in the anthropological sense using the idea that human society places objective value on the things within it. Understanding an environment carries with it the implicit need to establish relationships with the things comprising it, and it is the nature of the relationship that we establish that defines the nature of the object. Thus, a thing becomes an object from the moment that a person (subject) establishes a relationship with it (object): $S \rightarrow R \rightarrow O$. This relationship primarily involves constructing a meaning that will influence the subject's actions. From this point of view, learning

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 171–189.

is based on the process that involves forming relationships that will allow the subject to act upon and with objects built in this way. This being said, if the construction is an individual one (every subject forms its own relationships), it is equally true that objects are social constructions that fit into social meanings or contexts that are pre-established and shared within a given culture. From this perspective, school is the institutionalized place in which children will construct meaning about objects and about people's relationships to these objects that are generally shared by society. Hence, a link exists in this process between the pupil's individual actions in building his own knowledge and the social "togetherness" bearing the knowledge that gives meaning to the objects shared by the community.

As an example, let us examine the technical attribute that one normally accords to a class of objects (Andreucci & Ginestié, 2002). An object is technical from the moment it brings a technique with it, a way of doing something with a view to fulfilling a set objective (Séris, 1994). Put more simply, a technique can be defined as being an act that is traditionally effective (Haudricourt, 1988; Mauss, 1936, 1948), also underlining the fact that there is no technique without transmission (therefore without tradition) nor is there a technique without considerable (physical) effect (Sigault, 1990). The object's technical nature means that one is presumably going to view it as something manmade that is used in the right way by the subject without ambiguity (Simondon, 1989 This definition of the technical nature can be described as being external since it integrates the material nature of the object, the fact that it results from a human intention of manufacture and that it explicitly carries the goal for which it was designed. For example, in a given culture, a chair indicates a manufactured material object that is used to sit down on. However, this external definition is no longer operative (Cazenobe, 1987) the moment the three indicators of materiality (a material object), causality (a manufactured object) and finality (an object with a definite use) cease being interdependent on each other. For instance, certain designers scramble these codes by designing chairs whose function is not explicit – or from the moment that we refuse to detach the material object from the manmade context to which it belongs (Akrich, 1987). From a socially shared view, everybody knows that any object is technical whose function, structure, form or singular properties result in human intention expressed by the use of know-how; obviously, such a point of view is restrictive because it generalizes the fact that the nature of the object is related directly to the nature of the social relationship that a subject establishes with an object.

Technical Objects for Understanding the World

Technology education is compulsory in France for all middle school pupils (grades 6–9) following the study of an elementary school subject called science and technology initiation. From their early perception of the environment, children are invited to discover the world in which they live; school subjects are developed progressively through this social report to the school knowledge organization. Technology education at the middle school level is implemented in this global process of understanding the manmade world in which understanding the world of technical objects is one of the major aims by understanding their mode of existence and the social organisations that produce and use them (Andreucci & Ginestié, 2001; Ginestié, 2006a). Conveying knowledge improves pupils' knowledge in order to enable them to attribute a technical aspect to anything that fits one of the aforementioned criteria. Thus, we carried out a study on the attribution of technical characteristics by pupils of a range of familiar objects and how this attribution evolves throughout the course of their schooling (Andreucci & Ginestié, 2002). The study, based on a questionnaire, was carried out with 85 children (48 girls and 37 boys) aged between 12 and 15 years. The children came from three different schools and from four years of middle school in France; they were selected randomly from small groups working according to the problem-solving approach. The questionnaire was developed to characterize the technical or non-technical objects, as described in the following points.

The first part of the study asked the pupils to mention three non-technical objects. The results show that practically all of them think they know enough non-technical objects to be able to mention at least three. On the other hand, an analysis of the answers reveals that, regardless of age and gender, almost all pupils think that objects that are in fact technical are non-technical. They mention mainly (52% of all answers) objects belonging to the "school equipment" category (textbook, exercise book, pen, ruler, school bag, etc.). All other categories shown in these answers, such as furniture (approximately 16%), food products (6%), clothes (6%), manual labour tools (5%) and household equipment (5%), appear much less frequently.

The second question asked the pupils to mention three technical objects. Only five pupils failed to answer the question. The IT equipment category was the most common (48% of all answers), and the computer was the technical object most frequently mentioned. Audiovisual equipment (21%) along with mechanical and electronic tools (20%) were the two most common categories of those that followed. On the other hand, the categories of vehicle (5%), electrical appliances (4%) academic equipment 1%) or manual labour tools (1%) were rarely listed. As with the "natural" categories (Mervis & Rosch, 1981; Rosch, 1975; Rosch, Mervis, Gray, Johnson, & Boyesbraem, 1976), the concept of technical objects is fairly well represented.

The final question asked pupils to state whether each object in a list of 56 was technical or not. The results allowed us to define three categories: good, mediocre and bad representations of the concept of a technical object. The results bear witness to an established hierarchy, ranging from most technical to least technical: 1) electrical & electronic appliances or machines, 2) vehicles, 3) graphic tools or productions, 4) weapons, 5) artistic productions, 6) musical instruments, 7) buildings, 8) manual labour tools, 9) basic measuring or testing instruments, 10) cooking or decorating utensils, 11) clothes, 12) toys, 13) furniture and 14) foods.

The good representation category applies to objects deemed 'technical' by at least 67% of the pupils, the bad representation category is attributed to objects with less than 33%, and the mediocre representation category was situated between the two. The bad representation category is the most significant, since it includes 28 of the 56 objects (classified from "least poor" to "worst"): chimney, hand-made pullover, weather vane, statue, artificial flower, lipstick, pickaxe, saucepan, an edition of *La Provence*, liter of petrol, frozen ready meal, cathedral, bird's nest, Monopoly game, sugar, armchair, cherry tomato, teddy bear, packet of soup, aspirin tablet, jeans, igloo, soccer field, spider's web, hamburger, lettuce, bonsai, baguette. The mediocre representation category comprises 12 objects (from "least" to "most" mediocre): bicycle, satellite navigation system, photograph, technical drawing, mathematical theorem, artificial lake, tunnel, ruler, handsaw, pen, flute, and catapult. The good representation category comprises 16 objects (beginning with the most well represented): computer, electric drill, pocket calculator, video games console, electric fryer, sewing machine, telephone, motorbike, CD player, factory, tractor, compact disc, cinema special effect, circuit diagram, boiler, missile. There were two items on the list that few pupils termed to be technical objects: the bird's nest and the spider's web. This shows that pupils distinguish biological from technological things when categorizing things produced by animals. The fact that an object is a human production is not sufficient in homogenizing the technological order. The highly heterogeneous nature of the objects in the mediocre and bad representation categories bears witness to the frailty of the concept of a technical object, associating it with intentional human production. With the exception of cinema special effects, a technical object is apparently defined using mechanical and electrical structures to carry out a specific function. Mediocre examples of technical objects bring together objects that do not have "explicit" electrical structures, almost as if the "human production status" were reduced as a result. Familiar or traditional food products or clothes are "naturalized" by pupils who therefore reject their status as being "manmade." It is interesting to note that the children spontaneously do not connect the concept of a technical object to the fact that these objects result from a human intentionality; technological education should make it possible to build this significance, which is an element of our comprehension of our environment. We will examine this aspect in the next section.

An Increasingly Less Technical World

This study involved pupils of different ages corresponding to the four middle school grades in France. If we agree with the idea of spontaneity to connect the concept of a technical object as a result of a human intentionality for the pupils at the grade 6 level, we could imagine that the concept of technical objects would be broadened under the influence of technology education, which is compulsory for all of the pupils (grades 6–9). However, our results show that, contrary to this assumption, children instead tend to reduce the span of the concept gradually as they progress through school and through technology education. From grades 6 to 9, they "naturalize" objects more easily at the end of their schooling than at the beginning. This trend does not apply to the good representation category, which remains stable. Two objects in this category, the computer and the video games console, strengthen their status. The importance of certain objects (mathematical theorem, flute, artificial lake, electrical circuit diagram, boiler, ruler, hand saw, photograph, technical drawing, catapult, pullover, pen) significantly decreases (see status), resulting in their joining the mediocre or even bad representation category. Apparently ordinary technical objects whose usage does not seem to justify specifically learning about them in school end up being viewed in a bad light in comparison to objects requiring intellectual investment, and they are exposed to a real starting point for becoming instruments for a subject (pupil) to act upon (Rabardel, 1995, 2000, 2001).

This study provides evidence of middle school pupils' limited knowledge of the notion of a technical object. It also shows that the development of the concept tends to become increasingly restricted as pupils go through school. Pupils nevertheless seem to be able to differentiate between the nature of things produced by animals and by humans. This being said, the kind of material – synthetic or natural – used to create the object is not sufficient to be able to acknowledge such creations as technical objects. Thus, biological reference appears to take priority over technical characteristics, even if it is a matter of something being explicitly artificial (the plastic flower, for instance). The pupils seem to be relatively aware that one criterion for technical characteristics is linked to this notion of human creation or production, but that it appears as a progressive reorientation of the natural characteristics; something's being artificial is readily accepted from the moment a part of it uses electrical energy. Hence, one could almost measure how artificial something is by examining the amount of electricity used in defining a technical object's intrinsic functions: this aspect is far more significant than that of human creation. This is quite a surprising result, in contradiction to the aims of technology education in France. Technology education is based on the key concept stating that a technical object exists because it is designed and created to satisfy the user's needs; this led to the overstated link between design and manufacturing (Ginestié, 2002). But it could be concentrated on small objects that integrate elementary electronic functions into mechanical stands (i.e., a luminous key-ring). Successive evolutions of the various curricula (1985, 1992, 1996, 2002, 2008) testify to a first phase during which attention is focused on the procedures of the realization of the objects and not on the meaning borne by the articulation design-manufacture-use of the objects. The implementation of the procedures within a smaller class of technical objects is found in the reduction of the span that the pupils allot to the technical objects.

The strength of the relationship formed by pupils in class to technical objects clearly seems to be linked to the objects the teacher gives them to use, and the way that the teacher integrates them into the instructional tasks (Ginestié, 2006b). A study conducted with 191 pupils aged 12–13 years (7th grade) indicates that pupils have a primarily positive view of technology's position in society (Ginestié, 2005a). It fulfills an important role, makes life easier and plays an important part in our everyday lives. However, it remains a "subject for specialists" (which probably explains its strong links to science) - specialists who are unable to systematically solve all problems. Finally, technology is definitely modern and contemporary. This being said, when asked their opinions about technology, the pupils' answers vary considerably: technology lessons are, first and foremost, a place for doing things, be it manually with tools or using IT. The majority of pupils think that these classes serve no purpose for them in their daily lives; the teaching does not help them choose a job or gain a better understanding of technical objects. Neither are they completely fooled by disciplinary (subject) hierarchy; technology is a "secondary" discipline that comes after the "important" ones like mathematics or history. When asked to define the activities they undertake in technology classes, the vast majority of pupils consider such teaching to be based on a combination of manual work, IT, building or Do-it-Yourself (DIY) type tasks, as well as electronics to a lesser extent. These results confirm that technology teaching in France does not meet society's expectations – to understand the world of technical objects – and that this shortcoming, in terms of activities set with respect to a successful final outcome, is perceived by pupils who shy away as a result from this academic discipline, which is becoming "second rate" to them.

ACTIVITIES FOR ACTING AND UNDERSTANDING

Pupils' Activities and Academic Tasks

The construction of meaningful relationships is one of the main goals of school learning in general, and of engineering and technology education in particular. It is directly linked with activities undertaken by pupils to complete the academic tasks set for them by their teacher. The activity is organized based on what is to be done, how to do it and why; the task set by the teacher will serve as a starting point for organizing what pupils do, as well as a guide throughout the completion of the task. In order to act, the pupil must form an idea of the objective to be fulfilled, develop a strategy for solving the problem, and plan how he will proceed and implement a process to appreciate his progress in solving it. In quite simple terms, the pupil performs the job of being a pupil, meaning that he attempts to do what the teacher expects of him, and this result is not necessarily the learning of a concept (Ginestié, 2008). In other words, the teacher teaches, but are the pupils really learning?

In a somewhat dated study (Amigues & Ginestié, 1991; Ginestié, 1992), we showed how the way in which teaching scenarios were organized affected pupils' performance over short and slightly longer periods of time. Pupils aged 15–16 years (10^{th} grade) were asked to describe how an automated gantry crane, which moves pieces from one point to another, operates. The best solution was to organize the movement of the pieces by combining two movements (vertical and horizontal), picking up and holding the piece to be moved, as well as returning the gripping system or the point where the sequence begins. Creating a solution on this level requires the coordination of four "problem" spaces: time, space, logic and function. For example, movements from points A to B can be envisaged differently depending on the level of integration of the constraints linked to the coordination of these problem areas (see Figure 1). The optimum level consists of imagining simultaneous (horizontal and vertical) movements, without predetermining their duration. On the contrary, pupils at the lowest level are required to organize movements in sequence, vertically and then horizontally (or vice versa). Analysis of the task should provide all the constraints to be considered for a problem of this kind. It can also allow one to describe all possible solutions in order to consider each constraint, and how this series of possible "specific" solutions fits into the structure of the suggested overall solution. All pupils' work is then analyzed in conjunction with this chart: problems found (or not), specific solutions suggested for this part, and how these solutions considering specific constraints are linked to an overall solution. A pre-test allows us to appreciate inter-pupil differences; their performances are considered in a test immediately after the pedagogical scenario and in a subsequent test carried out six months later.

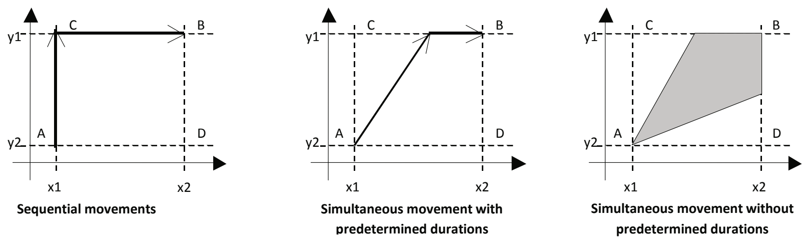


Figure 1. Different coordination levels for problem spaces.

Pedagogical Scenarios for Structuring Teaching

Five contrasting teaching situations were used to organize the sequence for learning to find solutions to this type of problem:

– The first one (GM: Guiding Method), which is used typically in French technology teaching, uses a system to guide pupils step-by-step towards the solution by describing procedures for taking action in completing tasks and the order in which they must be carried out. In this setup, pupils have no indication of what they have to do, how to do it, in what order, and why.
– The second one (EM: Expert Method), on the other hand, left the pupils in a completely open-ended situation. Pupils used resources describing the system, supplied specific information about how it operates, its structure, and described the jargon used to explain how the system functions; pupils had to collect all the elements necessary for finding a solution. In this case, pupils are left entirely on their own to complete the task, how to do it, in what order, and why.
– The third situation (ERM: Error Detection Method) structured the pupils' activity around tasks to detect errors to enable the pupils to identify them and create a strategy so that they will not make them again. In this setup, pupils' attention is focused on the difficulties linked to this type of task and ways of overcoming them. They have limited information about what they have to do and how to do it, but they know a lot about why they must do it.
– The fourth situation (OPM: Obstacle Problem-solving Method) revolved around a task for solving "local" problems linked to identified obstacles (simultaneity management, coordination of piece movement and transportation, return at the end of the cycle, managing the starting position). Breaking down the task into mini-problems limits pupils' knowledge of what they have to do, but also gives them a better idea of how and why to do it.
– The final situation (EOM: Error and Obstacle Method) brought together parts of the third and fourth scenarios by having pupils concentrate on the obstacles or problems identified, finding and identifying errors in the local solutions for each mini- or micro-problem. This setup gives pupils little freedom to do the task, but more scope to understand how and why to go about it.

Each of these setups was put into place under identical conditions in four classes of 16 to 18 pupils selected from schools that were varied enough to represent French academic diversity. The five groups of pupils comprised between 64 and 72 pupils working in pairs. The pupils had to submit a single solution, and to this end, they only had a ballpoint pen, a ruler and a packet of numbered white paper (to keep track of all their work) at their disposal. The experimenter conducting the sessions was requested not to answer any questions, explaining that he was not a teacher and that he understood absolutely nothing about the problem task.

Contrasting Performances

In the "immediate" test, the majority of pupils in the second situation (EM) did not progress past the level 1 solution (moving in sequence, no coordination of transportation of pieces, starting point fixed at point A). Pupils in the other scenarios all found solutions that leaned towards level 3 (simultaneous movement without predetermination of durations), without managing to solve all the parts relevant to this level; whatever it may be, the starting point is rarely taken into consideration. A solution of this kind for the majority of pupils (29 of the 35 groups) is only found in the fifth situation (EOM). By examining this in the context of the endogenous conditions for how teaching in France normally works – teaching followed by an evaluation test – organizing a flexible system for solving problems is insufficient in terms of pupils' performance, whereas the classic system of closely guiding pupils as they work allows pupils to perform well. These results serve as a means of reassuring teachers regarding their belief in the traditional method.

The subsequent test taking place six months later clearly highlights the differences between the categories. Solutions from pupils in the second situation (EM) are all limited to level 1 (sequential movements), and most of them (31 of the 34 groups) are largely incomplete. Pupils in the first situation (GM) join them at performance level 1; the high level they reached during the initial test did not stand the test of time. Pupils in the third (ERM) and fourth (OPM) situations falter slightly, all moving back to problem-solving level 2 (simultaneous movement with predetermined durations), nevertheless retaining overall solutions that tackle all the constraints but limit the effectiveness of some of the "sub-solutions." The majority of pupils (23 of the 35 groups) in the fifth situation (EOM) stay at level 3 (simultaneous movement without predetermined durations), with the 12 remaining groups being at level 2, with level 3 local solutions for piece movements (quite a number of them abandon any given starting point and fix it arbitrarily at point A).

These results are particularly interesting and meaningful with regard to the teaching-learning process. It is obvious that the organization of the teaching situations affects pupils' performances and one can appreciate their effectiveness. The first situation (GM) gives an illusion of efficiency if we appreciate it through the test immediately after the learning. But this situation does not allow pupils to consolidate suitably what they have learned in a viable way within the allotted time as do the third (ERM), fourth (OPM) and fifth (EOM) situations, with better performance in the latter one. These three situations are characterized by an organization of systems that accompany pupils as they progress in solving the task, without guiding them towards a pre-defined solution but making the obstacles that they must overcome in order to complete the task salient.

These three modalities clearly structure constructivist logic to learning by organizing the task as it is set for the pupils. The diversification of the situations (the five situations) allows pupils to reach a more stable, higher level of performance and to maintain this problem-solving level several months later. In other words, teachers have a direct influence on pupils' activities through the tasks and teaching systems that they propose by allowing or not allowing them to learn solid knowledge over time. The differences between these situations also highlight the influence of verbalization and formalization in this process. The first situation is centered exclusively on procedural logic in which pupils have no initiative to be able to question what they are doing, and it is this situation that is ultimately found to be lacking from a pedagogical point of view. On the other hand, situations that encourage pupils to formalize and verbally communicate as metacognition with regard to each problematic point were found to work extremely well.

THE OBJECT BECOMES A TOOL

Task Devolution

There is nothing systematic about pupils making an effort to complete a task. It is not enough to merely give a pupil a problem and ask him to solve it. The teacher must play a decisive role in pupils' efforts to become involved in the task as well as to supervise their activity. The kind of interactions put in place characterize the different teaching-learning systems (Amigues, Lataillade, & Mencherini, 2001; Bennacer, 2003; Bloch, 1999; Bonnet, 2003; Burton & Flammang, 2001; Chin, 2006; Delens, Carlier, Florence, Renard, & Scheiff, 1996; Dobinson, 2001). They determine whether or not devolution of the task occurs and whether or not pupils make progress in accomplishing it (Roux, 2003a). This process is one of the key elements in constructing knowledge (Weill-Fassina, 1979; Weill-Fassina, Rabardel, & Dubois, 1993) and the pupils' cognitive progress, notably through discursive episodes (Roux, 2003b; Trognon, Ball, Schwarz, Petrel-Clerraont, & Marro, 2006; Watson, 1995). The teacher plays a role of facilitator in building the knowledge.

The task must exemplify the importance of the knowledge that is targeted in teaching. It must make obstacles salient and offer the pupil a learning environment that can allow these obstacles to be overcome, while also supervising the pupils' learning activity. Pupils do things they have never done before – the set problem is an original one, and the pupils identify obstacles they will have to overcome in order to find the solution within the constraints that the problem incorporates. The pupils use the task-oriented environment to choose the available resources (or the means of accessing them). In order to overcome each obstacle, the pupils plan actions to structure their activity by defining a chronology for their actions on the one hand, and by anticipating the use of resources that may potentially be available on the other hand (Rabardel, 1993, 1995; Vérillon, 2000; Vérillon, Coué, Faillard, L'Haridonet, & Naji, 2005; Vérillon, Leroux, & Manneux, 2005; Vérillon & Rabardel, 1995). Going beyond the procedural descriptions detailed in the traditional system of guided learning, the pupils create instruments to be used based on procedural systems (the way of doing something) and semi-logical setups (the meaning or significance of their usage) (Vérillon & Rabardel, 1995). Linking these two types of "schemes" allows pupils to take in knowledge and enables them to act upon the learning environment in a lasting and viable way, as is the case with the third (ERM), fourth (OPM) and fifth (EOM) situations, but not with the first (GM) and second (EM) ones. In these two categories, monitoring pupils' activity is done by obtaining the result, whereas the other three are managed by pupils' activity in itself, which proves to be more successful.

Managing Pupils' Activity

In order to contemplate the management of pupils' activity, one must simultaneously create the conditions to allow analysis of the problem, description of the task, construction of a basis for planning out one's actions, and application of these choices in a problem-solving strategy (Leontiev, 1984; Roth, 2007; Roth, Tobin, & Ritchie, 2008). Structuring the situation must create the necessary conditions for every pupil to be able to apply an activity-based management system. Two pupils working on one identical solution allows their verbal exchanges to come to the fore, leads them to agree upon a solution, and above all on the problem-solving strategy, notably during the vital phase of the initial description. Restricting pupils to working together to produce a shared solution should lead pupils to present their points of view, clarify their positions, explain their strategies and justify their choices in order for their ideas to be taken into account by their partners. The efforts they will make to explain, describe and present arguments about their points of view on the problem, their descriptions of the task, and the way they approach it in order to reach a solution will lead the pupils to discover new aspects of the problem that they would not know about if they were acting alone. These conflicting points of view from pupils are based on the likelihood that not every pupil will describe the problem in the same way or see the same things, and therefore will not use the same problem-solving strategies and action plans. This discrepancy between pupils' initial descriptions should create the conditions for a debate in which each pupil will attempt to argue his/her point of view and convince the other that his/her own opinion is better (the most functional, the one that conforms, the most...). These differences of opinion lead pupils to negotiate, meaning that they will bring their own points of view closer to the other(s), therefore broadening their points of view at the same time. The fragility of this approach would indicate that there may well be confrontation among pupils, which was clearly the case in our experiment, but which seems fragile as soon as we move away from the experimental context.

Confrontation, Dynamics of Construction

In order for confrontation to exist, pupils must express points of view that are sufficiently different and manifest ideas that are clear enough to be able to be made explicit, debated and defended. As works on pupils' ideas have shown, at the same level of schooling they share the same overall level of thinking (Altet, Lessard, Paquay, & Perrenoud, 2004; Besson, 2004; Chaiklin, Hedegaard, & Jensen, 1999; Chartrain & Caillot, 2001; Da-Silva, Mellado, Ruiz, & Porlan, 2007; Dupin & Johsua, 1988; Mioduser, Venezky, & Gong, 1996; Ouarda & Ginestié, 2009; Tsai, 2004). It is highly probable that they adopt similar points of view, produce essentially the same task descriptions, discover the same constraints and suggest the same problem-solving strategies based on reducing the limitations found in “partial” and “local” solutions that are only specific cases.

Under such conditions, the debate, if it exists, will revolve around an explanation of the aim to be achieved in this scholarly context, meaning an attempt to find out what solution the teacher expects. This is what we discovered in a study about a description of how a two-axis system that moves pieces from one point to another functioned. This study was conducted on 24 pairs of pupils aged 15–16 years (grade 10) from three different classes in three schools. There is no special organization and these ordinary situations are coordinated by the homeroom teacher (Ginestié, 2005b). In this study, pupils saw the system carry out functions relevant to the transportation of parts. The displacement was still a simultaneous combination of the vertical and horizontal movements, with the transportation time for moving the parts being random (level 3 solution), meaning that the “journey” was never exactly the same. For practically all the pupil pairs (24 groups) that had to solve this problem, the description of the problem they submitted was based on sequenced movements (the system moved up and then moved forward): 23 groups never described simultaneous movements, even though this is what the system they were observing always did. In only one group did a pupil air a different point of view compared to the sequential solution that was suggested spontaneously. However, this element of doubt did not prove sufficient for creating a worthwhile debate with his colleague, as this extract of their conversation reveals:

– *E3: (The pupils write the first version of their description and pupil 1 re-reads what he has written. We see that he is struggling with a point that appears problematic to him. He restarts the system in a new cycle and watches carefully).*
– *E4: What are you doing? Why did you start it again? We’ve finished, haven’t we?*
– *E3: (concentrating very carefully on how the system operates) Watch.*
– *E4: (looking at his classmate with confusion) What is it? We’ve finished haven’t we? What are you doing?*
– *E3: Watch, you see the machine does this (he draws a small arc with his hand, moving from the piece’s starting point to its finishing point).*
– *E4: (looking more and more confusedly at his partner) Yeah, so what?*
– *E3: Yeah, but we said it was doing this (motioning his hand into a much wider arc, moving from the piece’s starting point to its finishing point).*
– *E4: (with a look of utter confusion) Well yeah, so what, isn’t it the same thing?*
– *E3: No. Since it does this and we said it did that (making hand movements, accentuating the differences, with both movements remaining in fairly tight arcs).*

The dialogue will continue in the same vain for a few dozen seconds (a very long time in this kind of exchange). Pupil E3 uses a ruler, pencil and eraser to attempt to simulate the movements so that his partner will understand them, but his demonstration is unconvincing:

– *E4: I’m telling you it’s the same thing, what we wrote and what the machine is doing. Don’t worry about it...*

- *E3: Well, no, not really. It's not really the same.*
- *E4: Yes it is, it's the same. We've answered the question, we shouldn't worry about it. Let's finish and get out of here.*
- *E3: Yeah, but that's not really it…*
- *E4: Yeah, but we're right. Come on, let's finish and go…*
- *E3 (stops all discussion, finishes filling in the answer sheet and begins to underline, putting things in boxes, tidying up his work, during which his partner talks to the group behind him).*

This exchange shows how the job of being a pupil – notably meeting the teacher's and the school's implicit and explicit expectations – plays a big part in the pupils' activities. Pupil E3 is clearly in the process of realizing that their solution only partially solves the problem they were given. He outlines the first parts of logic that allows him to question the problem-solving strategy they had adopted and with which he is not satisfied. The end of the session, the interjections from his partner who wants to end the session, the conformity of the solution in view of the other ones produced by other pupils in the class... a whole host of injunctions that bring an end to this stuttering criticism of the solution and the strategy they used in order to find it: a chance to construct something has been missed! Creating a situation that produces meaningful discussions and putting pupils into groups is not enough.

Constructing Instruments in order to Take Action

In a world of objects that are given meaning by society, the category of *tools* allows one to contemplate how each person possesses the potential to act. Tools determine the end result of one's actions, how to achieve this result, and how this result has come about. In our last example, pupils do not seek to exploit the potential of the tools available to them to solve the problem set by the teacher: they are preoccupied with producing an academic answer to the teacher's question, and the conformity of their answer to the majority of those offered by the rest of the class is a sufficiently strong validation to impose itself on any other way of thinking. Thus, the teacher's aims – setting a problem to lead pupils to build a problem-solving strategy that is effective from an epistemological point of view and not an academic or scholarly one – are not taken on board by the pupils, as they transform the task into an academic one, which involves producing a response that conforms to the teacher's supposed expectations.

Moving from a tool that is socially shared to an individual process of instrumental genesis or creation lies at the heart of the teaching-learning process. From this point of view, the teacher would organize academic scenarios that give pupils tasks to accomplish in systems where a certain number of tools are made available to them: for the pupil, learning could be said to consist of designing the instruments that are needed to accomplish this task within given constraints. This personal construction exercise relies upon the linked creation of procedural and semiotic setups (Andreucci, 2008; Rabardel, 2001; Vérillon, 2008; Vérillon & Andreucci, 2006), the simultaneous construction of a way of acting and its significance.

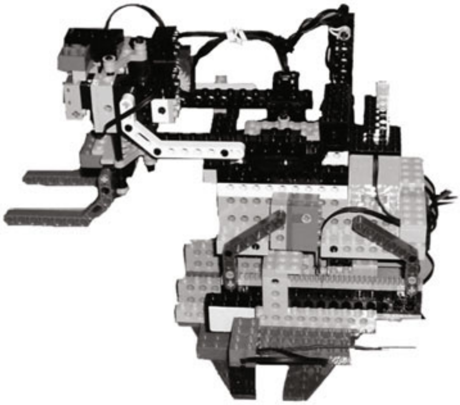
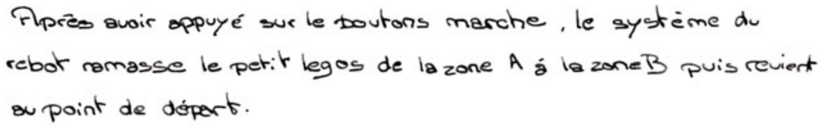


Figure 2. Lego carry lift.

This is what we analysed in another study on problem-solving. We observed two groups of 16 pupils aged 12–13 years (grade 7) coming from the same school in Marseilles classified as a priority education zone according to the school's difficulties of the great majority of the pupils. For this project, we used an automated system built from modular parts (Lego) and managed by ControlLab software (Aravecchia & Ginestié, 2008). Studying the carry lift in this system (Figure 2) allows us to see how pupils move towards finding a solution when asked to describe how the carry lift operates when we want it to move parts from a magazine to a conveyor belt.

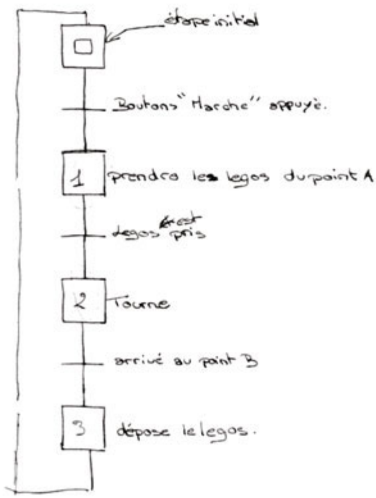
The results show that the type of tools made available to the pupils to complete the task has an effect on their success. Two graphic tools, GRAFCET (GRAPHe de Commande Etape-Transition, which is a sequential function chart) and a process chart were used to complete this description. GRAFCET is a term used to describe how automated systems work, organizing the phases in sequence from which the system produces one or several actions, and the transitions that define the conditions for shifting from one phase to another: phases are numbered based on the order in which they are executed. The execution of parallel sequences is done in an AND/ OR format (AND – parallel sequences are executed simultaneously; OR – a parallel sequence is carried out and the others are ignored depending on production of the transition conditions). The process chart applies the principles used by process maps or organizational charts, linking procedures, and conditional choices one after the other (right or wrong conditions). Two groups of 16 pupils working in pairs had to describe how this sub-system worked, one using a GRAFCET, the other using a process chart. Using the GRAFCET, five of the eight pairs produced a complete description that conformed, whereas only one managed this using the process chart. Analysis of one pair's work throughout the teaching scenario gives us information about how they form relationships with the available tools.

This first description in Figure 3 clearly describes the overall function of the combined parts. Figure 4 shows the first GRAFCET produced by these pupils using this description. Figure 5 shows the second description obtained from the same group.



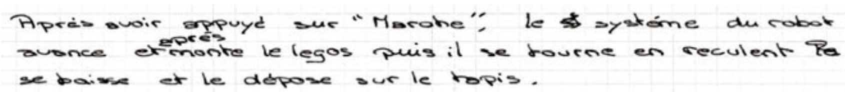
Après avoir appuyé sur le bouton marche, le système du robot ramasse le petit lego de la zone A à la zone B puis revient au point de départ. (After pushing the start button, the robotic system moves the little Lego piece from zone A to zone B, then returns it to the starting point).

Figure 3. First description from group 1A.



First phase
Start button pressed
Takes the Lego at point A
Picks up the Lego
Turns
Arrives at point B
Puts the Lego down

Figure 4. First GRAFCET from group 1A.



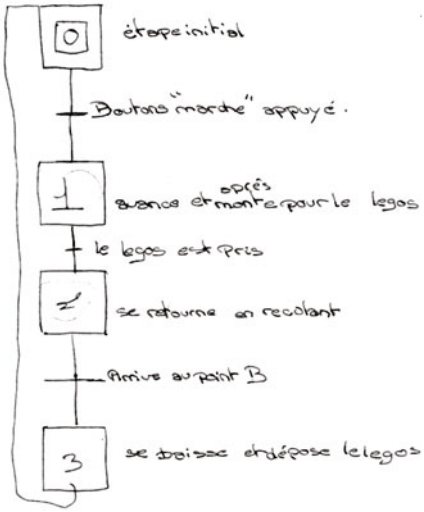
– *After pressing start, the robot system moves forward, picks up the Lego and then turns by moving backwards, lowers itself and places it on the conveyor belt.*

Figure 5. Second description from group 1A.

This description respects GRAFCET rules and the distinction between the actions taken and the transitions, but in this state, the description is too general to be able to give orders to the moving parts of the carry lift.

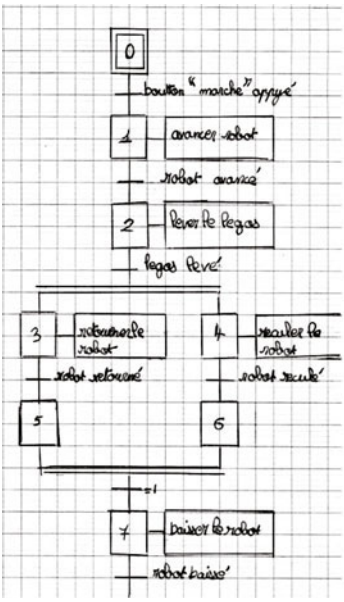
In this description, the actions are specified and the description is centered upon them. We note the linking of words for coordination (after, then, by, and) and the pupils abandoning certain qualitative terms (the small piece of Lego). This is the "sequence of events" that they rewrite in their new solution.

The implementation of this solution does not make the carry lift work. After several trial-and-error phases, literal descriptions and GRAFCET drawings, both pupils find this final solution quite quickly, as seen in Figures 6, 7..



First phase
Start button pressed
Moves forward and then upwards for the Lego
The Lego is picked up
Turns around moving backwards
Arrives at point B
Drops the Lego

Figure 6. Second GRAFCET from group 1A.



Start button pressed
Move robot forward
Robot moved forward
Lift the Lego
Lego lifted
Return the robot - Move the robot backwards
Robot returned – Robot moved backwards
Lower the robot
Robot lowered

Figure 7. Second GRAFCET from group 1A.

Strictly speaking, this solution is still not totally functional. Nevertheless, we see that the actions and transitions are clearly identified, as are the processes that occur simultaneously. However, the group abandoned studying the system's returning at the end of the cycle.

The succession of literal descriptions and translations into formal technical language is characteristic of the process of instrumental genesis shown here. Chronicling what is to be done – organizing the cycle in terms of actions that follow each other depending on the transitions – and the meaning or significance of what has to be done – for example, the actions characterized by use of an action verb whereas the transitions are defined using a condition to be met – is significant here in showing the manner in which the pupils move on to simultaneously construct the procedures for using the tool (the GRAFCET) and their importance. Generally speaking, the pupils' understanding of the system improves in this construction, which is both procedural and meaningful. Because of this, their knowledge of how the system works changes, they adopt a point of view that is closer to that shared by the automated systems professional, acquiring a few of the rules for describing a system. We can say that they have learned something and that this learning has allowed them to establish a meaningful relationship with an automated system, conforming to the knowledge brought by the social community that produces and uses these systems. The gaining of technical knowledge resulted from this teaching-learning process, and in this sense, the pupils have received a technological education.

CONCLUDING REMARKS

This chapter aimed at describing some of the facets of the teaching-training process concerned with the transmission of tools, artefacts and knowledge, which traditionally defines the curricula of technology education in France. Pupils do not allot easily or generally the technical character to the objects they meet in their environment because they do not recognize these objects spontaneously as manmade productions. This attribution even seems to be reduced under the effect of technology education between grade 6 and grade 9, which is compulsory for all pupils. Another study carried out among pupils aged 15–16 years (grade 10) confirms the influence of the organization of school situations on the pupils' performance in terms of learning. This type of study must, however, be moderate since one leaves the framework of the experiments for ordinary school situations. The third study presented shows how pupils' daily lives decrease their involvement in school situations they must deal with. It is possible to act on the processes of teaching-learning when the situations are designed and thus to improve their efficiency. This is the significance of the last study presented and of the outcomes obtained, including those of pupils usually failing in school. This research about the efficiency of organizations presents an important dimension of the work we carry out. Sharing knowledge in technology education is a major aim of evolution in modern societies. It is not enough to describe which knowledge is essential or only affirm that such an approach facilitates their acquisition. It is necessary to improve our understanding of the teaching-learning process, in particular, in order to be able to propose an evolution of initial or in-service teacher training.

REFERENCES

Akrich, M. (1987). Comment décrire les objets techniques? *Techniques et culture*, *9*, 49–63.
Altet, M., Lessard, C., Paquay, L., & Perrenoud, P. (2004). *Entre sens commun et sciences humaines. Quels savoirs pour enseigner?* Bruxelles: De Boeck.
Amigues, R., & Ginestié, J. (1991). Représentations et stratégies des élèves dans l'apprentissage d'un langage de commande. *Travail Humain*, *54*(1), 1–19.
Amigues, R., Lataillade, G., & Mencherini, N. (2001). Travail du professeur et activité de l'élève dans les dispositifs d'aide aux élèves en difficulté: un exemple, les groupes de consolidation. *Schweizerische Zeitschrift für Bildungswissenschaften*, *23*(2), 299–319.
Andreucci, C., & Ginestié, J. (2001). Approach of assessment and teaching meaningful in technology education in France. In M. De Vries (Ed.), *PATT Conference* (pp. 212–219). Haarlem (Netherland): PATT Editions.
Andreucci, C. (2008). The structuring role of artefacts in thought development. In J. Ginestié (Ed.), *The cultural transmission of artefacts, skills and knowledge: Eleven studies in technology education* (pp. 21–41). Rotterdam: Sense Publishers.
Andreucci, C., & Ginestié, J. (2002). Un premier aperçu sur l'extension du concept d'objet technique chez les collégiens. *Didaskalia*, *20*, 41–65.
Aravecchia, L., & Ginestié, J. (2008). Describing an automated system with the GRAFCET for understanding how it functions. In J. Ginestié (Ed.), *The cultural transmission of artefacts, skills and knowledge: eleven studies in technology education* (pp. 149–171). Rotterdam: Sense Publishers.
Bennacer, H. (2003). Prédiction de la performance scolaire: Étude de l'interaction entre l'élève et l'environnement social de la classe. *European review of applied psychology*, *53*(1), 3–19.
Besson, U. (2004). Students' conceptions of fluids. *International Journal of Science Education*, *26*(14), 1683–1714. doi: 10.1080/0950069042000243745.
Bloch, I. (1999). L'articulation du travail mathématique du professeur et de l'élève dans l'enseignement de l'analyse en première scientifique: Détermination d'un milieu: Connaissances et savoirs. *Recherches en didactique des mathématiques*, *19*(2), 135–194.
Bonnet, C. (2003). L'élève « tête À claques »: Une situation scolaire discriminatoire. *VEI enjeux*, *135*, 164–174.
Burton, R., & Flammang, C. (2001). D'une stratégie d'enseignement des sciences centrée sur l'enseignant vers une stratégie centrée sur l'élève: analyse des processus d'enseignement. *Les dossiers des sciences de l'éducation*, *5*, 53–65.
Cazenobe, J. (1987). Esquisse d'une conception opératoire de l'objet technique. *Techniques et culture*, *10*, 61–80.
Chaiklin, S., Hedegaard, M., & Jensen, U. J. (1999). *Activity theory and social practice: Cultural-Historical approaches*. Aarhus, Danemark: Aarhus University Press.
Chartrain, J.-L., Caillot, M. (2001). Conceptual change and student diversity: The case of volcanism at primary school. In H. Behrendt, H. Dahncke, R. Duit, W. Graeber, M. Komorek, & A. Kross (Eds.), *Research in science education - Past, present, and future* (pp. 265–270). Dordrecht, The Netherlands: Kluwer Academic Publishers.
Chin, C. (2006). Classroom Interaction in Science: Teacher questioning and feedback to students' responses. *International Journal of Science Education*, *28*(11), 1315–1346.
Da-Silva, C., Mellado, V., Ruiz, C., & Porlan, R. (2007). Evolution of the conceptions of a secondary education biology teacher: Longitudinal analysis using cognitive maps. *Science Education*, *91*(3), 461–491.
Delens, C., Carlier, G., Florence, J., Renard, J.-P., & Scheiff, A. (1996). Relation entre le portrait comportemental de l'élève et l'action pédagogique de l'enseignant. *Sciences et techniques des activités physiques et sportives*, *39*, 7–24.
Dobinson, T. (2001). Do learners learn from classroom interaction and does the teacher have a role to play? *Language Teaching Research*, *5*(3), 189–211.

Dupin, J.-J., & Johsua, S. (1988). Conceptions en électrocinétique. Permanences géographiques et évolution dans le temps. L'enseignement des circuits électriques: conceptions des élèves et aides didactiques. *TIP*, *VII*(2), 23–42.

Ginestié, J. (1992). *Contribution à la didactique des disciplines technologiques: acquisition et utilisation d'un langage d'automatisme*. Doctorat, Université de Provence, Aix-en-Provence. Available from Atelier National de Reproduction des thèses, Lille.

Ginestié, J. (2002). The industrial project method in French industry and in French schools. *International Journal of Technology and Design Education*, *12*(2), 99–122.

Ginestié, J. (2005a, mars). *Analyzing technology education through the curricular evolution and the investigation themes*. Paper presented at the Conference PATT 13: Overview on the 25 years of technology education, Harlem.

Ginestié, J. (2005b). Résolutions de problèmes en éducation technologique. *Éducation technologique*, *28*, 23–34.

Ginestié, J. (2006a). Analysing technology education through the curricular evolution and the investigation themes. In M. de Vries & I. Mottier (Eds.), *International handbook of technology education: Reviewing the past twenty years* (pp. 387–398). Rotterdam/Taipei: Sense Publishers.

Ginestié, J. (2006b). Teacher Training: preparing young people for their future lives. In C. Benson (Trans.), J. Ginestié (Ed.), *An international study in Technology Education*. Santiago: Éditions Los Salesianos.

Ginestié, J. (2008). 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.

Haudricourt, A.-G. (1988). *La Technologie science humaine: recherches d'histoire et d'ethnologie des techniques*. Paris: Éditions de la Maison des sciences de l'Homme.

Leontiev, A. N. (1984). *Activité, conscience, personnalité* (3eme ed.). Moscou: Editions du Progrès.

Mauss, M. (1936). Les techniques du corps. *Journal de Psychologie*, *32*(176), 279–327.

Mauss, M. (1948). Les techniques et la technologie. *Journal de psychologie*, n° spécial: Le travail et les techniques (dirigé par I. Meyerson et L. Febvre).

Mervis, C. B., & Rosch, E. (1981). Categorization of natural objects. *Annual Review of Psychology*, *32*, 89–115.

Mioduser, D., Venezky, R. L., & Gong, B. (1996). Students' perceptions and designs of simple control systems. *Computers in Human Behavior*, *12*(3), 363–388.

Ouarda, O., & Ginestié, J. (2009). Conceptions didactiques et épistémologiques de cinq enseignants tunisiens de sciences physiques. *Didaskalia*, *35*, 101–138.

Rabardel, P. (1993). Micro-genèse et fonctionnalité des représentations dans une activité avec instrument. In A. Weill-Fassina, P. Rabardel, & D. Dubois (Eds.), *Représentations pour l'action*. Toulouse: Editions Octares.

Rabardel, P. (1995). *Les hommes et les technologies; approche cognitive des instruments contemporains*. Paris: Armand Colin Éditeurs.

Rabardel, P. (2000). Influence of the development of knowledge systems and technological systems on cognition. *International Journal of Psychology*, *35*(3–4), 274–274.

Rabardel, P. (2001). Instrument mediated activity in situations. In A. Blandford, J. Vanderdonckt, & P., Gray (Eds.), *People and computers XV-interactions without frontiers* (pp. 17–33). Berlin: Springer.

Rosch, E. (1975). Basic objects in natural categories. *Bulletin of the Psychonomic Society*, *6*(NB4), 415–415.

Rosch, E., Mervis, C. B., Gray, W. D., Johnson, D. M., & Boyesbraem, P. (1976). Basic objects in natural categories. *Cognitive Psychology*, *8*(3), 382–439.

Roth, W.-M. (2007). Toward a dialectical notion and praxis of scientific literacy. *Journal of Curriculum Studies*, *39*, 377–398.

Roth, W.-M., Tobin, K., & Ritchie, S. M. (2008). Time and temporality as mediators of science learning. *Science Education*, *92*(1), 115–140.

Roux, J.-P. (2003a). Analyse interlocutoire, dynamiques interactives et étude des mécanismes des progrès cognitifs en situation asymétrique de résolution de problèmes. *L'orientation scolaire et professionnelle*, *3*(3), 475–501.

Roux, J.-P. (2003b). *The interlocutory logic analysis as a methodological approach in studying semiotic mediations: interest, difficulties, limits*. Paper presented at the XIth European Conference on Developmental Psychology, Milan.

Séris, J.-P. (1994). *La technique*. Paris: Presses Universitaires de France.

Sigault, F. (1990). Folie, réel et technologie. *Technique et culture*, *15*, 167–179.

Simondon, G. (1989). *Du mode d'existence des objets techniques* (Réédition ed.). Paris: Aubier.

Trognon, A., Ball, M., Schwarz, B., Petrel-Clerraont, A.-N., & Marro, P. (2006). Logique interlocutoire de la résolution en dyade d'un problème d'arithmétique. *Psychologie française*, *51*(2), 171–187.

Tsai, C. C. (2004). Conceptions of learning science among high school students in Taiwan: A phenomenographic analysis. *International Journal of Science Education*, *26*(14), 1733–1750. doi: 10.1080/0950069042000230776.

Vérillon, P. (2000). Instruments and cognition: Piaget and Vigotsky revisited in search of a learning model for technology education. *The Journal of Technology Studies*, *26*(1), 3–10.

Vérillon, P. (2008). The transmission of higher-order technological skills in technology education from a social constructivist point of view. In J. Ginestié (Ed.), *The cultural transmission of artefacts, skills and knowledge: Eleven studies in technology education* (pp. 101–122). Rotterdam: Sense Publishers.

Vérillon, P., & Andreucci, C. (2006). Artefacts and cognitive development: how do psychogenetic theories of intelligence help in understanding the influence of technical environments on the development of thought? In M. De Vries & E. Mottier (Eds.), *International handbook of technology education: The state of the art* (pp. 399–416). Rotterdam: Sense Publishers.

Vérillon, P., Coué, A., Faillard, J., L'Haridonet, A., & Naji, E. (2005). Contribution à l'analyse d'activités de conception et de fabrication en écoles maternelle et primaire. In P. Vérillon, J. Ginestié, B. Hostein, J. Lebeaume, & P. Leroux (Eds.), *Produire en technologie à l'école et au collège* (pp. 211–247). Paris: INRP.

Vérillon, P., Leroux, P., & Manneux, G. (2005). Activités productives et processus constructifs : les activités scolaires de production peuvent-elles être source de construction pour les élèves? *Aster*, *41*, 3–26.

Vérillon, P., & Rabardel, P. (1995). Cognition and artefacts: a contribution to the study of thought in relation to instrumented activity. *European Journal of Psychology of Education*, *10*(3), 77–101.

Watson, J. (1995). Teacher talk and pupil thought. *Educational Psychology*, *15*(1), 57–68.

Weill-Fassina, A. (1979). Guidage et planification de l'action par les aides au travail. *Bulletin de psychologie*, *XXXIII*(334), 343–349.

Weill-Fassina, A., Rabardel, P., & Dubois, D. (1993). *Représentations pour l'action*. Toulouse: Editions Octares.

Jacques Ginestié
Professeur des Universités
UMR ADEF – Gestepro
Aix-Marseille Université
Université de Provence – IUFM Aix-Marseille
France

LINDA RAE MARKERT

11. CULTURAL ASPECTS OF BECOMING TECHNOLOGICALLY LITERATE

"We are not going to be able to operate our Spaceship Earth successfully nor for much longer unless we see it as a whole spaceship and our fate as common. It has to be everybody or nobody."

– R. Buckminster Fuller, *Operating Manual for Spaceship Earth*, 1963

"From now on we live in a world where man has walked on the Moon. It's not a miracle, we just decided to go."

– Tom Hanks, *Playing the character of former NASA astronaut Jim Lovell in the film Apollo 13*, 1995

INTRODUCTION

About three or four years ago, my then teenage son called with great excitement to say that he and a friend had just finished navigating the most incredible corn maze! That telephone call, which today might likely have been a short text message, came at two o'clock in the morning and was totally out of context and disruptive to my sound sleep. Several days after that experience, my son discovered Google Earth® and managed to isolate a whole new view of this very same corn maze that was actually very close to our home in upstate New York (Figure 1). This aerial imagery confirmed his earlier perception that the course of the maze was quite challenging, and being able to claim he had found his way through it by the light of the moon was even more gratifying. His view of a small portion of his world had changed significantly by virtue of a technological device. Google Earth® maps the Earth by the superimposition of images obtained from satellites, aerial photography and GIS (geographical information system) onto a three-dimensional model of the globe (Google Earth, 2010). This geographic information program was originally named EarthViewer 3D and was created by a company called Keyhole, Inc. and acquired by Google in 2004.

Three other views of our planet Earth that have been around for decades (and centuries) longer than Google Earth® are depicted in Figure 2. These include the: Mercator Projection, Gall-Peters Projection, and Fuller Projection. Each of these maps is a device to help us visualize and comprehend our place (as human beings) in the world. However, as geographical information is transferred from a spherical globe onto a flat surface, the resultant projections reveal certain compromises. Stated differently, distortions occur in shape, size, area, distance or direction.

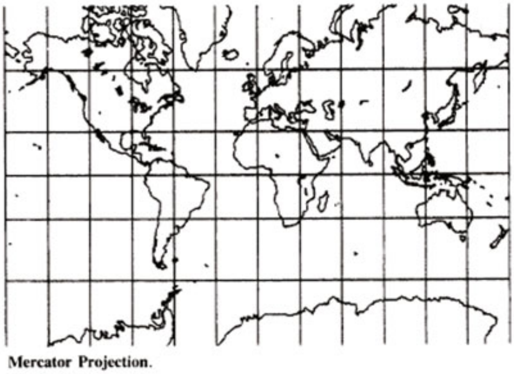
M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 191–206.

Figure 1. Aerial view of a 10-acre corn maze at Abbot's Farm in upstate New York.

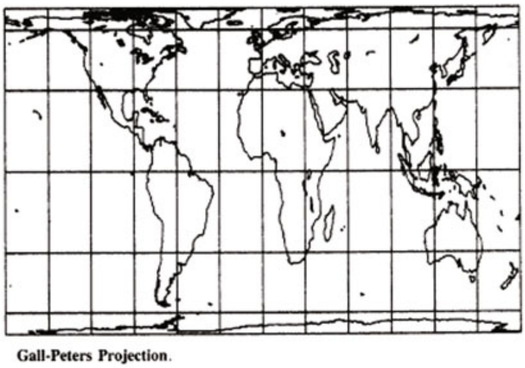
The **Mercator Projection** was developed by the Flemish geographer, mathematician and cartographer, Gerhadus Mercator, in 1569. He designed this map of the globe to support specific kinds of oceanic navigation and computational practices. Over the years, however, its use in classrooms to teach geography became controversial. Brewer and Dourish (2008) suggested that "the projection distorts representations of the Earth's surface area, exaggerating the **size** of countries which lie closer to the poles (largely first world countries and former colonial powers) while under-representing the land masses of those closer to the equator (often third world countries and sites of former colonial occupation" (p. 971).

Similarly, the **Gall-Peters Projection,** despite being promoted by the United Nations as an alternative to the Mercator, also encountered its share of criticisms. This two-dimensional depiction of our world was rendered in 1973 by Arno Peters, who actually blended his ideas with those introduced much earlier by James Gall in Scotland in 1855. Their resultant projection represents the world on an equal and consistent grid making it possible to accurately compare the sizes of countries, but their shapes appear to be vertically stretched (Snyder, 1988), giving new prominence to the continents of Africa and South America.

Interestingly, it was in the year that Peters introduced his new map projection that I had the great privilege of being introduced to Buckminster Fuller. Through that meeting in 1973, I ultimately became familiar with yet another world view – the Fuller Dymaxion world map. This is a truly unique representation of our world that Fuller first patented in 1946, and then published in 1954 with modifications as *The AirOcean World Map.* Adams and Carfagna (2006) explain that Fuller's map "shows the continents as nearly contiguous land masses with the least amount of visual distortion, thereby helping people to see the world as an interdependent network of relationships" (p. 154). This depiction is thought to minimize the visible distortion of the relative sizes (Mercator) or shapes (Gall-Peters) of the Earth's land masses.



Mercator Projection (John Snyder, 1988)



Gall-Peters Projection (John Snyder, 1988)

Fuller projection (Eric Gaba-Wikimedia commons user: http://common.wikimedia.org/wiki/user:sting)

Figure 2. Three line renderings of flat projections of the spherical Earth.

In many ways, Buckminster Fuller was the 20th century's Renaissance man, *a la* Ben Franklin. He was respected around the world as an architect, designer, engineer, poet, philosopher and writer. His world view portrays and emphasizes the relationships among all cultures of the world rather than highlighting the boundaries (real or imagined) between them. Since environmental and health concerns have become a central focus of our international political agendas, our contemporary view of the world must both enable and motivate us to recognize, nurture and preserve the resources that should unify us. Fuller's Dymaxion world map is a lens through which one's understanding of globalization becomes possible. "Bucky Fuller was the epitome of a world citizen" (Adams & Carfagna, 2006, p. 154).

The purpose of this chapter centers on an examination of the extent to which cultural orientation influences our capacity as individuals to become technologically literate. The term culture, from the Latin *cultura,* is used here to refer to the continuum of socially transmitted behavior patterns, beliefs and other products of human thought that are characteristic of a population. Cultural beliefs are formed over time, shared by many persons, and strongly influence our view of the world. When expressed as observable behaviors, cultural beliefs are often aligned with religious teachings and gender-ascribed roles in society.

In these opening paragraphs, four technological artifacts were introduced to illustrate a portion of the very complex concept of world view. We hope that subsequent segments of this discussion will stimulate our readers to think more seriously about: 1. how an individual's view of the world changes as she/he becomes technologically literate; 2. the degree to which gender roles, religious beliefs or cultural traditions affect an individual's capacity to become technologically literate; and 3. various ways contemporary engineering and technology education instructors should be practicing culturally relevant pedagogy in their classrooms and laboratories.

WORLD VIEW AND TECHNOLOGICAL LITERACY

It is nearly impossible to get through the day without hearing words like global, worldwide, globalization, or international at least once and most likely several times. Friedman (2005) asserting that the world is flat, surmised that we had entered the third era of globalization in around the year 2000.

> "Because it is flattening and shrinking the world, Globalization 3.0 is going to be more and more driven not only by individuals, but also by a much more diverse – non-Western, non-white – group of individuals. Individuals from every corner of the world are being empowered. Globalization 3.0 makes it possible for so many more people to plug and play, and you are going to see every color of the human rainbow taking part." (Friedman, 2005, p. 11).

The globalization of scientific and technological research and education has created a complex network of partnerships, linkages and joint ventures among numerous multinational enterprises. Ever-constant improvements in technological and scientific artifacts both allow and promote perpetual connectivity among human beings. The term "hand-held electronic or wireless device" has become ubiquitous in venues from elementary school classrooms to the airline industry. Middle school students routinely have online conversations with individuals around the country and citizens of the world whom they may never have met. High school students are learning to use sophisticated hand-held global positioning system (GPS) instruments to establish connections to distant geostationary satellites. Post-secondary students in an upstate New York college have become accustomed to working with their astronomy faculty members in order to operate a robotic telescope located thousands of miles away on another continent.

We commonly take these types of occurrences for granted, lending further credence to the assertion that we live in a global society that is intensely interconnected and therefore interdependent. On the other hand, the number of persons among us who have spent extended periods of time away from the United States to live among and learn from persons who live in other countries is certainly a minority. Even though we are aware “that our world is culturally and technologically diverse, very few of us are able to fully comprehend and articulate what life is really like and about in other places away from our homeland” (Markert, 2009, p. 27).

The 2006 Geographic Literacy Study revealed just how little young citizens who reside in the United States know about their world. Not a day passes without some amount of media coverage of the military conflicts in the Middle East and Asia; and the news reports about Hurricane Katrina (2005) and the World Trade Center terrorist attacks (2001) were intensive for months after their occurrences. Nevertheless, “six in ten (63%) cannot find Iraq or Saudi Arabia on a map of the Middle East, and nine in ten (88%) cannot find Afghanistan on a map of Asia. Moreover, half (50%) cannot locate New York State, slightly less than half (48%) cannot find Mississippi on the map, and a third (33%) cannot identify the state of Louisiana. Further, young adults surveyed across the nation reported limited contact with other cultures outside the United States – seven in ten (70%) have not traveled abroad at all in the past three years, nine in ten (89%) do not correspond regularly with anyone outside the U.S., and only two in ten (22%) have a passport” (National Geographic/ Roper Public Affairs, 2006, pp. 8–9).

Without question, these statistics are quite discouraging, and seem to tell us something about our world view. Adams and Carfagna (2006) confirm that “these results – and other studies similarly depicting our deficiencies – speak less to the intellectual capabilities of our students than to the alarming lack of emphasis on global learning in our educational system” (p. 169). In response, the authors of *Fostering Human Development Through Engineering and Technology Education* collectively postulate that engineering and technology education (ETE) can deliver elements of a global education, and possibly mitigate the insularity that seems prevalent among young adults in our country. We believe that as persons become technologically educated, their world view changes and improves in positive ways.

I believe that citizens of the world who are technologically literate should possess the knowledge, skills and dispositions to evaluate, select and apply appropriate technologies in an array of different contexts. Hodson (2003) argues that scientific (and technological) literacy also includes the ability and willingness to act in environmentally responsible and socially just ways. Thirty years ago, in an article about the dearth of female researchers in science and technology, Markert (1981) posited that "people who are technologically literate possess certain traits including: confidence and skill in the use of technical tools, equipment and machinery; an interest in technical research and inventions; an understanding of technical/scientific constructs and terminology; an awareness of the impact (both positive and negative) that science and technology can have on society; and an ability to project alternative futures in which technology has an influence" (p. 13). While this list of characteristics seems heavily weighted in the direction of technical skills and competency, it was forward-thinking in its early orientation toward sociopolitical action and civic engagement that protects the values and diverse cultures of our society.

Similarly, the authors of *Technically speaking: Why all Americans need to know more about technology*, tell us that a technologically literate citizen "asks pertinent questions about the benefits and risks of technologies, and participates in the decisions about the development and use of technology" (NAE/NRC, 2002, p. 17). It seems reasonable to expect that one's world view becomes less narrow-minded as these capabilities are acquired. Engineering and technology educators, who are not afraid to confront the political interests and social values that underlie the scientific and technological practices they teach, are in an excellent position in our schools and universities to foster technological literacy for all learners.

Hodson (2003) asserts that students must have many opportunities throughout their educational careers to tackle real world issues that have a scientific, technological or environmental dimension. Specifically, he writes "by grounding content in socially and personally relevant contexts, an issues based approach can provide the motivation that is absent from the current abstract, de-contextualized approaches that can form a base for students to construct understanding that is personally relevant, meaningful and important" (p. 654). Essentially, he is suggesting that science curricula can inform our understanding of contemporary technological problems, and it might also assist students in reaching tentative design solutions. More importantly, he also implies that it is both logical and useful to introduce current technology and engineering problems/issues to provide a realistic framework for the science curricula being taught in today's educational institutions.

It is entirely possible for engineering and technology educators to simultaneously improve geographic literacy as they work to foster technological literacy among their students. In so doing, we should expect these individuals to comprehend a more holistic and socially just view of their world. Science, technology and engineering are products of both time and place in the world and are closely aligned with social, cultural and institutional locations. Therefore, instructors around the world are challenged to prepare and educate students about the social processes used to generate, test and scrutinize technological innovations and scientific discoveries.

When instructors use case studies about both historical and contemporary issues, coupled with actual field-based exercises, they are able to deliver straightforward pedagogy that will achieve the goal of integrative learning. For many years, engineering and technology educators have been described as the faculty members who are able to provide meaning and applications for other academic subjects. As students experience inquiry-focused studies in engineering and technology, they are challenged to draw upon the skills and knowledge they have learned in science, math, literature and social science to solve authentic problems using an array of new tools and materials. When teachers focus their attention on topics that are both regionally and internationally relevant (e.g., agriculture, energy generation and consumption, land/water/mineral resources, transfer of information, human health), the resultant learning experiences for students can be structured around intercultural competence, real-world challenges, civic engagement and ethical reasoning (AAC&U, 2007).

GENDER, RELIGION & CULTURE AND TECHNOLOGICAL LITERACY

Both individually and collectively, gender, religious beliefs and cultural orientation affect our views and attitudes about technologies in our lives. In some cases, they have also achieved a level of importance that moves us to determine which technological options should be advanced and which should be curtailed. It may also be the case that one's gender, cultural traditions and religious perspectives can impact one's ability and/or desire to become technologically literate.

What is it about the fields of technology, science and engineering that students find appealing? More specifically, why do certain students gravitate toward these types of courses, while others approach them with apprehension or avoid them completely? Are girls (women) more technophobic than boys (men)? Are there unique features to applied technology and engineering classes that might actually be attractive to a multicultural and diverse student population, and perhaps more responsive to their learning expectations?

These types of inquiries have been in our minds for decades and have yielded a variety of opinions about the diversity dilemma in engineering and technology education (e.g., Brand & Markert, 1995; Erekson & Trautman, 1995; Flowers, 1995; Liedtke, 1995; Markert, 1981; Markert, 2003; Rider, 1998; Zuga, 1999). Together, these researchers have told us time and again that girls (women) and individuals from diverse cultural backgrounds are **not** broken – they do **not** need to be fixed! Brand and Markert's (1995) study revealed no significant statistical differences between men and women with regard to their tendency to be "technophobic." In their investigation among college-age students, technophobia was defined and measured as "a general tendency to shy away or refrain from using the artifacts of technology due to a: 1. lack of faith and/or trust in technological systems; 2. low level of personal confidence regarding the use and/or operation of technology intensive products; or 3. a self-perception that one is not technologically literate." Quite simply, in this study, women were not shown to be more technophobic than men. Shanahan (2006) seemed to agree with these findings, asserting that technical confidence can be increased through technical competence. Engineering and technology educators need to create a laboratory environment that is welcoming and appealing to all learners enabling them to be equally successful.

In almost all instances, students very much enjoy the applied nature of the problem-solving activities that they encounter in their science, engineering and technology courses. Teachers in many other disciplines now realize that authentic learning experiences, where there are obvious and meaningful links to their students' lives, are a much more powerful pedagogical approach than simple chalk and talk discussions. Engineering, technology and science educators have known this forever. Using real-world scenarios and project-based learning to challenge their students comes naturally to them. This notion of authentic or outcomes-based assessment is nothing new for this group of educators.

On the other hand, gender-friendly and ethnically diverse instructional settings in the engineering and technology professions are only gradually emerging. It is the case that the paucity of women and culturally diverse workers in science, engineering and technology disciplines represents a significant concern – one that potentially weakens our nation's economic power and intellectual competitiveness. Having said this, we need to be cognizant about how ETE educators promote and value diversity in their profession. Women and individuals with culturally diverse backgrounds must neither be viewed as tokens of success, nor expected to be stellar in their performance (Markert, 2003). Here is a metaphor to further illustrate this assertion: First, please envision a glass bowl of Hershey's® Kisses – all of which are wrapped in their signature silver foil. Next, imagine adding to the bowl several of these candies wrapped in red and blue colored foil. If, at this point, we perceive the red kisses to represent women, and the blue kisses to represent persons from culturally diverse backgrounds, then we are still singling these groups out as "different" or "special" by comparison to others in the collection. In reality, it is the new resultant mixture of kisses that represents diversity, and all of the candies taste equally sweet, regardless of their wrappers! Like the red and blue kisses, the contributions being made by women and persons of color in the ETE discipline must be applauded and celebrated alongside those being made by white males who are in the majority (silver kisses). I believe that it is far easier to emulate persons whose accomplishments are integrated into the discipline at large; therefore we should not idolize women and persons of color as surprisingly stellar (Markert, 2003).

Moving away momentarily from our focus on gender equity, let us direct our attention to another essential characteristic of human culture – one that also influences our view of the world, and attitudes about engineering and technology. Religion serves many purposes for individuals around the world and addresses their many needs and expectations. Religious beliefs and teachings propose a specific code of conduct that helps to bind men and women to their culture. It is therefore interesting to note that the word religion (like culture) is derived from the Latin word *religare*, which means to tie or bind. Rivers (2006) explained that "religions are bound to culture because they draw upon a common human experience, which uses rites, rituals, myths and taboos in order to be understood" (p. 518). Further, he asserts "religion depicts a world different from the world we live in, and after depicting this other world, it then attempts to explain the world we do live in" (p. 518).

For centuries, people from all ethnic and educational backgrounds, as well as all socioeconomic levels, have looked to their religious institutions for comfort and guidance during times of sorrow or confusion. Many individuals find solace in prayer, some may confess their sins asking forgiveness, and others may light a candle in memory of a loved one who has passed on. Pell and Smith (2003) posited that, at some level, all human beings have a spiritual dimension. This spiritual perspective is often very private and directs our search for meaning in our lives. According to Gross (2006), spirituality is generally thought to be motivated by a theocentric perception (religious), but it might also thrive within an anthropocentric perspective (secular). In a recent study, he offered “a new approach to describe spirituality in the modern world, an approach that conceives of secularity as a distinct autonomous entity, parallel to religiosity” (Gross, 2006, p. 54). Regardless of which vantage point our students are using, they believe in their beliefs.

Aspects of modern technology have, in many ways however, caused some individuals to question their beliefs, and to change their views about church (mosque, synagogue, temple), and their definitions of *God* (*Allah, Buddha*). As medical science, and contemporary engineering and technological breakthroughs continue to provide cures for previously incurable illnesses, people might feel they no longer need a Supreme Being who is all-knowing and everlasting. It may be true that hospitalized patients look to their medical doctors as a new type of priesthood or clergy.

Rivers (2006) says that “religion may be conceived as an attempt to understand ourselves and the world in relation to the forces beyond human control, but science gives us a more plausible explanation. We do not have to believe that the earth is a sphere, rather we know it is. Religion, on the other hand, cannot give us assurances of its beliefs because they are not based on fact” (p. 519). Overwhelming feats of engineering and technology might seem to challenge religion and threaten its traditional teachings (e.g., God is our creator who is all-knowing and all-powerful; live a life that is pleasing to Allah and you will gain Paradise; or, in the absence of any god in Buddhism, the soul will be reborn after death). Even still, hundreds of thousands of individuals across the planet continue to attend religious services as a regular course of living. Apparently, they find mutual comfort in viewing the world, making sense of natural phenomena, and understanding human-made artifacts through ***both*** a technology lens and a spirituality lens.

Another cultural perspective that emphasizes a world view based on natural phenomena, which Gross (2006) might easily be included as another form of spirituality, has come to be known as secular humanism. Secular humanists accept a philosophy called naturalism, in which the physical laws of the universe are not superseded by supreme beings, such as demons, gods, or other spiritual entities outside the realm of the natural world (Kurtz, 2002). They are committed to the use of critical reasoning and scientific methods of inquiry in the quest for truth and solutions to problems in society. Secular humanism encourages people to think for themselves and question authority, and suggests that the morality of our actions should be judged by their consequences in this world (Cherry & Matsumura, 1998). Stated differently, they focus not on eternal rewards in an ***afterlife***, but emphasize devoted concerns for the quality of ***this life*** through a respect for multiculturalism and better understanding of their fellow human beings. Diversity and dialogue foster learning and intellectual development.

Engineering and technology educators enter their classrooms and laboratories to work with men (boys) and women (girls) from a diverse assortment of ethnic, cultural, and spiritual backgrounds. Their ability to instill a desire among all learners to become technologically literate can be strengthened to the extent that they are able to safely navigate what might be considered controversial waters of technological and scientific breakthroughs. Some of the prevalent social, religious and ethical issues of contemporary life are rooted in the world of technological innovations and scientific experimentation. The dilemmas of euthanasia, the wonderment associated with alternative energy sources, the exciting new frontiers in stem cell research, the breathtaking design of new architecture in Dubai, the uncharted territory related to cloning, the unproven engineering reliability of hybrid vehicles, and the medical technologies of procreation are all legacies of a techno-scientific culture.

Technology in the medical profession might loosely be defined as the rational selection and use of devices and procedures toward the achievement of measurable, useful and relatively immediate human outcomes (Markert & Backer, 2010). There are both costs and benefits associated with the technological breakthroughs that we are making in health care. Generally speaking, technological progress in medicine often makes what can be done much clearer than what should be done. Stated differently, the numerous technical manipulations and procedures can be defined with much conviction. It is far more difficult to decide when and where such technological interventions should be utilized. And, these decisions are often heavily steeped in religious beliefs, cultural practices and moral convictions. We have reached a point where living longer may not necessarily mean living better. Quality of existence may not receive adequate attention when technological decisions are being made.

Quality of life is an interdisciplinary concept, with application and relevance in several areas, including medicine, law and philosophy. In legal settings, quality of life issues surface when it is necessary to make decisions about a person's life, especially in the context of withholding or withdrawing life-sustaining medical technology or other interventions. The machines of technology are often used to sustain life that many people would not deem worth living. Death is no longer viewed simply as part of the natural order of human existence, but as failure of medical technology. High-tech medicine may provide society with a reduced incidence of disease, but the costs are significant. Technology in medicine often alienates the patient from the health care professionals themselves. The beeps and squeals of the cardiac monitor, the printed output of a CAT scan, or the sound of a bedside respirator can obscure issues of human value. Major organ replacement is both technology-intensive and cost-intensive, and it is fraught with ethical challenges. Organ transplantation is unique among modern medical technologies because it is dependent upon human tissue obtained through consent. This reality places constraints on the use of this potentially lifesaving procedure when the supply of suitable donors falls short of the demand. The subject of technology and procreation also prompts an array of difficult legal and ethical questions. For example, when an *in vitro* fertilization team creates more embryos in the laboratory than can be safely implanted in the mother's womb, what should be done with those that are not used? Disposing of these surplus embryos or using them for further research purposes opposes the view held by some that an embryo is a human being who has a right to life. Others say that until the embryo develops to the point at which it is capable of experiencing something, it is not plausible to view it as a human being. Current stem cell research activities, coupled with the scientific feats in cryo-preservation, may lead to an increased practice of freezing embryos for later use. This area of study is laden with much debate and controversy. In each of these cases, high-tech medical procedures seem to interfere with the traditional cultural and/or spiritual support mechanisms that have historically served as a source of encouragement for a person's well-being and sense of self-esteem.

This brief discussion and short list of socio-technological dilemmas does not begin to scratch the surface of the multitude of study areas that engineering and technology educators might logically include in their K-16 curricula. And, while the religious, secular, cultural and ethnic beliefs/traditions of their students might be immediately apparent or visible, the reality of their existence cannot be ignored. Liedtke (1995) summed it up beautifully years ago when she wrote "to increase the participation of minorities and women in technology education as a profession, there must be an organizational culture which is attractive to these individuals and is consistent with the factors (values and norms) which these individuals can best identify" (p. 9). She continued to explain that the ceremonies, rituals, symbols and instructional strategies we use in our technology and engineering facilities must be gender-neutral, unbiased and accessible to all. The following section of this chapter provides a perspective about what some of these factors and possible pedagogical strategies might look like.

CULTURALLY RELEVANT TEACHING FOR ETE

Undeniably, our mission to educate a diverse society remains a critical and prevailing issue in all academic venues. Faculty members who teach in classrooms, laboratories and seminar lounges must have the dedication and competence to create and sustain high quality academic environments where respect is cherished and social justice flourishes. The "third millennium" generation is more diverse than any that preceded it, and the impact of immigration in the United States is often seen first in the classroom. A *New York Times* report in April 2009 informed its readers that enrollment of Hispanic and Asian students in American schools increased by more than 5 million since the early 1990s; of the nearly 50 million students attending P-12 schools in 17,000 districts across the nation, only 56% were white in 2006 compared to 66% in 1993 (Diversity in the Classroom, 2009). These students' teachers must therefore be equipped to teach in ways that respond to their diverse approaches to learning, different ability levels, varied cultural expectations, and widely disparate backgrounds. Further, they need to understand that racially diverse learners often bring cultural capital to the classroom that might very well be drastically different from regional habits or mainstream norms. Bourdieu (1977) suggests that individuals acquire cultural capital through the social structures where they learn norms, ideologies, customs, language and acceptable behaviors.

Educational institutions at all levels should routinely be asking themselves "what makes a safe, inclusive, equitable and academically rigorous environment for learning?" Adams and Carfagna (2006) tell us that, in our globalized world, a new type of citizen must be educated to celebrate good things, confront the bad ones and welcome all new challenges. “This new citizen must be able to balance the local identities that provide cultural distinctiveness and emotional sustenance with the global connections that make apparent our shared humanity and fate” (p. 13). I believe that engineering and technology instructors have a unique and essential role to play in educating this new citizenry. Among its many benefits, technological literacy in our world has the power to increase citizen participation and enhance social well-being (NAE/NRC, 2002). And, technological literacy as a definitive goal of engineering and technology education has great appeal “because it is multi-dimensional – it can be related to national economic performance of a literate workforce, ...and it can be used to relate to social responsibility in the context of a technological society” (Williams, 2009, p. 242). In other words, human development and social justice is fostered as citizens of the world become more technologically literate.

As previously stated, two key attributes of a technologically literate person are her/his: awareness of both the positive and negative effects that science, technology and engineering (STE) can have on our society as we inhabit Fuller’s (1963) Spaceship Earth, and insight into potential future states of various technologies in order to forecast their social (cultural) impacts. In countless ways, the products of STE have increased our capacity to control environmental forces and given us visions of an even more prosperous future. Unfortunately, STE breakthroughs have also increased uncertainties about the future, and created our overdependence on the innovations and inventions produced. Although we may have increased our capacity to understand, predict and control the natural environment around us (i.e., we are more technologically literate), we may have also lost the ability to manage the STE artifacts introduced in the process. Swearengen and Woodhouse (2001) surmised that “when negative consequences of technology are immediate, stakeholders sometimes can assess costs and negotiate remedies and compensations – although when the costs and benefits accrue (*unevenly*) to different communities and ethnic groups, analysis and remediation can be difficult (emphasis added)” (p. 15).

What does culturally responsive or culturally relevant teaching look like in engineering and technology education laboratories and classrooms? Ladson-Billings (1995) reminded us that we should not be attempting to insert culture into the educational experience, but rather, we should insert education into the culture. It is no secret that many students are afraid to be themselves in school classrooms. Behaviors and practices considered to be “acceptable” in these venues are quite different from those considered “normal or routine” in their homes. Many researchers have tried to isolate the source of disconnection between what students experience at school vs. what they are most comfortable with at home. They have studied strategies to develop a closer fit between students’ home culture and the school setting. Ladson-Billings (1995) argues that culturally relevant teaching “rests on these criteria or propositions: (a) students must experience academic success; (b) students must develop and/or maintain cultural competence; and (c) students must develop a critical consciousness through which they challenge the status quo of the current social order” (p. 160).

According to Ladson-Billings (1995), cultural competence encourages student to maintain their cultural integrity while also being respectful of others. Cultural competence also focuses on the idea of being able to thrive and respond appropriately/effectively in an ever-widening array of diverse settings. This necessitates a more expansive world view and sociopolitical consciousness that allows for individuals to address issues of bias, injustice and oppression within and beyond the walls of the classrooms.

The challenges today's engineering and technology educators must be prepared to address, as presented in this chapter so far, can be summed up in this way: Develop technological literacy to enhance geographic literacy, leading toward a more expansive world view, through improved cultural competence, devoid of gender bias – all of which ultimately will foster human development into a sustainable future. In their quest to respond successfully to these challenges and opportunities, they must be culturally responsive educators who acknowledge, value, and affirm diversity in ideas and people. Figure 3 presents a suggestion for the alignment of these ETE challenges with Ladson-Billings' (1995) delineation of the criteria established for culturally relevant teaching. You will note that cultural competence is common to both lists.

The oft-used phrase "one of the last best" continues to perplex me, but I find it quite appropriate as we near the close of this chapter. Quite simply, engineering and technology educators are "one of the last best groups of teachers" who can deliver culturally relevant pedagogy while developing the knowledge, skills and dispositions

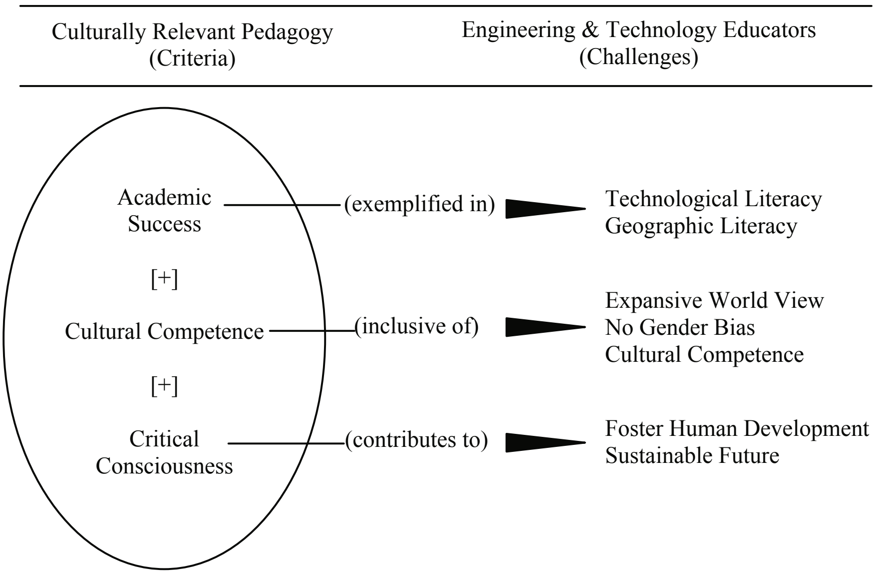


Figure 3. Criteria for culturally relevant pedagogy (Ladson-Billings, 1995) aligned with challenges confronting engineering and technology educators.

today's students need to become technologically literate. Ladson-Billings (1995) said it herself that "culturally relevant teaching is just good teaching – it's not some magic bullet or intricate formula" (p. 159). ETE instructors are often the ones parents identify as being exceptional, mainly because: 1. their children exhibit enthusiasm and excitement for the learning they experienced in applied technology courses; 2. they received a consistent level of respect and open communication from these teachers; and 3. the ETE teachers provided authentic assignments that enabled their sons and daughters to function successfully in the dual worlds of the academic setting and their home community.

Here are just a few examples (selected from hundreds) of ETE pedagogical excellence that give credence to my "last best" assertion:

– Thomas (2007) illustrated a variety of ways technology education can help break the cycle of poverty for low socioeconomic students. She highlighted the complex areas of agriculture, newspaper production and the trucking industry as arenas where field-based educational assignments are being deployed to complement school-based lessons and case studies. Her students are given opportunities to learn more about the ways that emerging technologies in these fields are determining the competencies they will need to be successful later in life.
– McCarthy (2009) asserted emphatically that we can no longer afford to leave more than half of our population out of the important science and technology decisions that affect our lives today and into the future. He gave his readers a glimpse of gender-neutral technology education at a middle school in Massachusetts where "girls and boys choose and test their own solutions to design challenges while learning how engineers and designers work through the universal problem solving method" (p. 16).
– Ikpeze (2009) introduced a comprehensive WebQuest checklist (p. 35) to support her belief that cultural competence can be positively influenced through the integration of new media and instructional technology across the curriculum. Information and communication technologies represent dominant tools that affect the way we live and think, and they should be used in our schools to allow youth culture and its varied literacies to flourish.
– iEARN (2010) is an acronym for the International Education and Resource Network, a non-profit organization that celebrated its 20th anniversary in 2008. Their network includes over 30,000 schools and youth organizations in more than 130 countries, enabling over 2 million students to be engaged in collaborative project work across the planet on a daily basis. One of the more than 150 teacher-created projects available is called "Positive Minds Interactive Media Literacy" – it like all the others is rooted in authentic real-world problems, international in scope and geared to students aged five through eighteen.
– Wiggins (2006) described a standards-based unit and lesson template called *Structures Around the World.* Designed for eighth graders, these activities promote technological and geographic literacy, and expand integrative thinking skills. Students draw upon their knowledge of history, earth science, physics and mathematics to explore, design and reconstruct models of architectural structures found in countries beyond the U.S. borders.

IN CLOSING…

Take a moment to re-read the two quotes that were cited to open this chapter. While one seems to be applauding national (US) technological hegemony, the other espouses the dire need for global cooperation and collaboration. Lynn and Salzman (2007) explain "the theory of comparative advantage postulates that countries gain when they concentrate on what they do best and trade that expertise to others. In collaborative advantage, mutual gain comes from the strength of interdependencies" (p. 13). Today's engineering and technology educators are already preparing a new class of STE professionals who will be expected to forge ahead through an ever-emerging framework and paradigm for globalized innovation and development. It is my anticipation that this diverse cohort of creative women and men, as teachers, are also helping to revise the operating manual we so desperately need to rescue and sustain our planet, well into the future!

REFERENCES

Adams, J. M., & Carfagna, A. (2006). *Coming of age in a globalized world: The next generation*. Bloomfield, CT: Kumarian Press, Inc.

Association of American Colleges & Universities (AAC&U). (2007). *College learning for the new global century*. A report from the National Leadership Council for Liberal Education and America's Promise (LEAP). Washington, DC: AAC&U.

Bourdieu, P. (1977). Cultural reproduction and social reproduction. In J. Karabel & A. H. Halsey (Eds.), *Power and ideology in education*. New York: Oxford.

Brand, P. A., & Markert, L. R. (1995). *Technophobia and gender*. Paper presented at the International Technology Education Association conference, Nashville, TN.

Brewer, J., & Dourish, P. (2008). Storied spaces: Cultural accounts of mobility, technology and environmental knowing. *International Journal of Human-Computer Studies*, 66, 963–976.

Cherry, M., & Matsumura, M. (1998). Ten myths about secular humanism. *Free Inquiry Magazine*, *18*(1). Retrieved 08:15, March 16, 2010, from http://www.secularhumanism.org/library/fi/cherry_8_1.01.htm

Diversity in the classroom. (2009). *The New York Times, April 22, 2009*. Retrieved 17:35, March 19, 2010, from http://projects.nytimes.com/immigration/enrollment

Erekson, T. L., & Trautman, D. K. (1995). Diversity or conformity? *Journal of Industrial Teacher Education*, *32*(4), 32–42.

Flowers, J. (1995). *Women and technology education*. Paper presented at the International Technology Education Association conference, Nashville, TN.

Friedman, T. L. (2005). *The world is flat: A brief history of the twenty-first century*. New York: Farrar, Strauss and Girous.

Fuller, R. B. (1963). *Operating manual for Spaceship Earth*. New York: E. P. Dutton.

Google Earth. (2010, 24 February). In Wikipedia, The Free Encyclopedia. Retrieved 07:55, February 25, 2010, from http://en.wikipedia.org/wiki/Google_Earth

Gross, Z. (2006). The construction of a multidimensional spiritual identity via ICT. *Educational Media International*, *43*(1), 51–63.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education*, *25*(6), 645–670.

Ikpeze, C. H. (2009). Transforming classroom instruction with personal and technological literacies: The WebQuest connection. *New England Reading Association Journal*, *44*(2), 31–40.

International Education and Resource Network (iEARN). (2010). Retrieved 10:40, February 24, 2010, from http://www.iearn.org

Kurtz, P. (2002). Secular humanism: A new approach. *Free Inquiry Magazine*, *22*(4). Retrieved 15:53, March 17, 2010, from http://www.secularhumanism.org/library/fi/kurtz_22_4.htm
Ladson-Billings, G. (1995). But that's just good teaching! The case for culturally relevant pedagogy. *Theory into Practice*, *34*(3), 159–165.
Liedtke, J. (1995). Changing the organizational culture of technology education to attract minorities and women. *The Technology Teacher*, *56*(6), 9–14.
Lynn, L., & Salzman, H. (2006). The real global technology challenge. *Change*, *39*(4), 8–13.
Markert, L. R. (1981). Women researchers in science and technology: Why so few? *Man, Society, Technology*, *41*(1), 12–14.
Markert. L. R. (2003). And the beat goes on: Diversity reconsidered. In G. Martin & H. Middleton (Eds.), *Initiatives in technology education: Comparative perspectives*. Technical Foundation of America and the Centre for Technology Education Research, Griffith University.
Markert, L. R. (2009). Ethics in a culturally diverse technological world. In CTTE Yearbook Planning Committee (Eds.), *Essential topics for technology educators*. CTTE Yearbook #58, Reston, VA: Council on Technology Teacher Education (CTTE).
Markert, L. R., & Backer, P. R. (2010). *Contemporary technology: Innovations, issues and perspectives*. Tinley Park, IL: Goodheart-Willcox Publisher.
McCarthy, R. (2009). Beyond smash and crash: Gender-friendly TechEd. *The Technology Teacher*, *69*(2), 16–21.
National Academy of Engineering/National Research Council (NAE/NRC). (2002). *Technically speaking: Why all Americans need to know more about technology*. Washington, DC: National Academy Press.
National Geographic/Roper Public Affairs. (2006). *Final report: 2006 geographic literacy study*. Washington, DC: National Geographic Literacy Study.
Pell, J. B., & Smith, T. B. (2003). The spiritual self: Toward a conceptualization of spiritual identity development. *Journal of Psychology & Theology*, *31*(2), 129–142.
Rider, B. L. (Ed). (1998). *Diversity in technology education*. CTTE Yearbook #47. Peoria, IL: Glencoe/McGraw-Hill.
Rivers, T. J. (2006). Technology and religion: A metaphysical challenge. *Technology in Society*, *28*, 517–531.
Shanahan, B. (2006). The secrets to increasing females in technology. *The Technology Teacher*, *66*(2), 22–24.
Snyder, J. P. (1988). Social consciousness and world maps. *The Christian Century*, *105*(6), 190–192.
Swearengen, J. C., & Woodhouse, E. J. (2001). Cultural risks of technological innovation: The case of school violence. *IEEE Technology and Society Magazine*, *20*(1), 15–28.
Thomas, D. (2007). Teaching technology in low socioeconomic areas. *The Technology Teacher*, *67*(3), 4–8.
Wiggins, E. (2006). Structures around the world: A standards-based unit/lesson template. *The Technology Teacher*, *66*(3), 28–30.
Williams, P. J. (2009). Technological literacy: a multiliteracies approach for democrasy. *International Journal of Technology Design Education*, *19*, 237–254.
Zuga, K. (1999). Addressing women's ways of knowing to improve the technology education environment for all students. *Journal of Technology Education*, *10*(2), 57–71.

Linda Rae Markert
Dean of Education
State University of New York at Oswego
Oswego, NY
USA

KARL M. KAPP

12. A CULTURAL PERSPECTIVE OF TEACHING AND LEARNING ETE IN A DIGITALLY CONNECTED WORLD

INTRODUCTION

The past millennium has brought forth unprecedented advancements in engineering and technology. Microchips have been invented and shrunk to the size of a pinhead, man has walked on the moon, great rivers have been dammed for irrigation, the Internet connects the globe through social networking, nanotechnology brings medical breakthroughs and Global Positioning Satellites (GPS) guide us to our destination. These advancements shape our social systems, our view of the world, how we interact with fellow humans and the quality of life. Each country's culture and how they live has been influenced by engineering and technological advancements, which continue to mold culture and influence a new generation of students. Yet, in many ways, educational systems across the globe have not integrated and joined the technological cultural influences of students with the technological advancements shaping the world.

This chapter looks at four key questions and examines how ETE is influenced by third millennial culture and how culture is influenced by technology:

- How is culture influenced by technology?
- What is the technology of the third millennium?
- What are the implications of integrating third millennial culture into educational curriculum?
- What are some examples currently employed of using third millennial technologies for education in ETE?

HISTORY LESSON

The anecdote below originally published in *Learning in 3D* by Kapp and O'Driscoll (2010) contrasts the difference between technological advancements in standards of living and culture, and the current educational system dominating the education of international youth.

The Smith family was excited about their visit to the Lost Colony in Manteo, North Carolina. Megan, just turning seven, had learned all about how 120 brave men, women and children established the first English settlement on Roanoke Island in 1587. Three years later, when Governor John White returned, the colony had

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 207–232.

vanished, leaving only one clue as to their whereabouts the word "Croatoan" carved on a post.

As they entered the Lost Colony, Megan was eager to solve the mystery of how they had vanished. In visiting the first building, brimming with curiosity, Megan asked *"Mommy, Mommy what did they do in here?" "This is a blacksmith's shop,"* answered her mother. *"This is where he made tools and horseshoes. That is called an anvil, and the blacksmith used it to shape the hot metal from the fire over there." What did horses need shoes for Mommy?* Asked Megan. *"Well back then people used horses to get around… they did not have cars back then," answered Mom. "But Mommy, horses poop and they go very slow, it must have been hard to get around back then… I am glad we have our minivan with a DVD player in it so I can watch movies when we travel."*

They strolled into the next building. Mom braced herself for the next barrage of questions. "*Mommy, Mommy, what did they do in here?*" asked Megan. *"Well this is where they made clothes Megan… Daddy will explain it to you, I need to change Connor's diaper." "Well Megan, over here is where they sheared the sheep to get wool to make clothes,"* said Dad. *"Ouch. Did that hurt the sheep Daddy?"* Megan asked, quite concerned. "*Not at all,*" said Dad. *"Then they took the wool and put it into this spinner to make yarn, they then took the yarn and put it on this machine called a loom to make cloth that they used to make clothes using this sewing machine over here." Wow*, said Megan, *"that looks like a lot of work just to get some clothes. I am glad that all we have to do is hop in the minivan and go to Wal-Mart when I need a new Dora t-shirt."*

As they went into the next building, Dad was prepared. Before she even asked, he began, *"Now Megan, this is a bakery. Over here is where they blended ingredients to make the dough. Over here is where they rolled the dough into loaves that they then put into this oven to cook."* Looking very concerned, Megan asked, *"Wait a minute Dad, don't tell me they didn't have Wonderbread back then?.... No wonder this became a Lost Colony….How can anyone go a day without Wonderbread … Wait, I figured out the Mystery Dad! Maybe Croatoan is olde English for 'We Need Wonderbread!'"*

As they waited for Mommy and Connor to come back from the restroom, Megan and her dad chatted about how things have really changed for the better over the last four centuries. Then they all headed towards a larger building over by the chapel. As soon as they entered the room, Megan didn't need to ask a single question. She spoke immediately, *"Mommy, Daddy, don't tell me, don't tell me… I know what this is… It is a classroom. This is where we go to learn."*

TECHNOLOGY'S RELATIONSHIP TO CULTURE

As the story above poignantly illustrates, a large portion of a civilization's culture is defined by its technology. Historical periods are often named for the influence of technology on the period. The Stone Age, Bronze Age, Iron Age, Industrial Revolution and Information Age are all closely related to the influence a particular technology or group of technologies had on livelihood, people and governments during that period in history. As technology evolves and changes over time, a culture will either change with the technology or disappear, or, in some rare cases, will shun the technology and remain isolated from the rest of the world.

One large group that has shunned technology and remained largely unchanged throughout hundreds of years is the Amish. This religious group, founded in the 1600s and living in the Eastern United States, refuses to incorporate modern technologies into their culture and way of life. They use horses to plow fields, bicycles for transportation and do not use electricity in their homes. The group has made a concentrated effort to maintain a culture untouched by technological advancements. Other groups are simply too isolated to feel the impact of technology. The Ayoreo-Totobiegosode Indians who live in a dense forest region stretching from Paraguay to Bolivia and Argentina are a group that has not adopted modern technologies because of their isolation and the remoteness of their region (Ayoreo, 2009).

What we can learn from these two examples is that isolating individuals from technology leads to a point of technological stagnation. While these are extreme examples, it is true that groups become isolated from technological advancements either through conscious efforts or neglect. As ETE educators, we cannot afford to allow our students to become isolated from the technologies used in our field nor can we isolate ourselves from the technology used daily by students in our classrooms. We risk the technological isolation of the Amish or the Avoreo-Totbiegosode Indians if we fail to integrate third millennial technology culture into our ETE curriculum.

Understanding the intricate relationship between culture and technology is critical in understanding how culture and technology support each other in the education of the youth of a culture. In Nieto's book *Affirming Diversity* (2004), the author describes culture as "The ever-changing values, tradition, social and political relationships and worldview created and shared by a group of people bound together by a combination of factors that can include a common history, geographic location, langaugae, social class, and/or religion, and how these are transformed by those who share them." To foster learning in the context of culture, we must understand that culture changes as the values, social relationships and worldviews of individuals change, and part of that change is a direct result of the influence of technology. Where is the change in a society more rapid or far-reaching than in the realm of technology? When groups fail to change their culture with the technology, they risk isolation.

Therefore, when examining how to foster human development through engineering and technology education, the cultural influences of teachers, administators and students must all be considered, with a special emphais on the culture surrounding the students. We know from a variety of research (Delpit, 1995; Gay, 2000; Nieto, 2004: Villegas & Lucas, 2002) that successful schools place their students' cultures at the center of their missions and curriculum. For ETE to be successful, elements of the culture surrounding the third millennium students must be carefully considered and integrated into the curriculum.

In the science discipline, great efforts have been made to shift schooling from the delivery of subject matter to inquiry-based learning. Technology education also underwent significant changes in many countries over the past few decades both in terms of content and instructional methods. Early curricula focused on hands-on activities primarily based on the apprentice/journeyman model, which was how early engineers and technicians were trained. As Hacker and Kiggens point out in Chapter 14, some teachers, trained as industrial arts teachers, are still teaching as they were taught; despite the overarching need for a technologically literate student body and workforce, some school programs are still rooted in crafts teaching.

But while some instructors remain rooted in tradition, other movements within the ETE educational environment have focused more on the abstract or conceptual basis of the fields of engineering and technology and less on the roots of hands-on activities. Curriculum materials have become increasingly more focused on the abstract concepts related to the field. The instructional emphasis has grown more conceptual and abstract with less focus on traditional skills such as craftsmanship and hands-on activities while still not fully addressing the technological needs of students and the field.

This is best highlighted by de Vries, who points out in Chapter 5 that as an educational structure grew around the ETE curriculum several different methodologies were advocated in the literature and applied for teaching concepts associated with engineering and technology. De Vries describes that early approaches focused on teaching abstract concepts at the beginning of an educational sequence. Eventually, this approach yielded to a movement in which it was hoped that students would be able to 'transfer' engineering and technological knowledge to other situations thorough a generalization process. And currently a more complicated approach is advocated in which the student is taken through a variety of situations, or contexts, in which different manifestations of the same general concepts are present. The idea is that the learner gradually begins to understand the communalities between the manifestations and acquires the general concept. All of these efforts mean that a standardized pedagogical base for constructing ETE curriculum has not yet been developed since the instructional approach and methods keep shifting.

Although the objectives of these reforms were only partially accomplished, we now have an opportunity to learn from experience and to introduce educational reforms that combine design-based methods, constructivist pedagogy and the technological acumen of the third millennium students to create instruction that is meaningful, impactful and capable of engaging students both within and outside of the four walls of the traditional classroom. In the past half century, the educational literature and research have emphasized the advantages of constructivist pedagogy over traditional teaching. We can assist students in constructing artifacts and systems aimed at solving practical needs and problems within the field.

We can't ignore the digitally connected culture or the reality of these digitally savvy youngsters. Instead, we need to examine their culture and integrate parts of this culture into our educational approach. Adopting all of their cultural nuances and quirks into a curriculum is just as ill-advised as the whole-scale rejection and dismissal of their culture and digital acumen. We, as educators, must strike the right balance of embracing elements of their culture with the instructional needs and requirements of engineering and technology fields.

TECHNOLOGY, CULTURAL INFLUENCES AND THE TEACHER

The influence of the third millennial culture must reflect more than content; it must impact methodology, approach and instructional activities. Yet, even today, instructional methodologies are heavily influenced by the instructional models and cultural influences of teachers and administrators, not the students. Much of the culture surrounding schools is based on the ideas, culture and influences of teachers and administrators during their formative years. As Knowles (1992) indicates, formative experiences of pre-service and beginning teachers influence the ways they think about teaching and subsequently their actions in the classroom.

Teachers teach in ways similar to how they experienced teaching during their own schooling and hold beliefs based on those experiences (Borko & Putnam, 1996; Thompson, 1992). Today's ETE educators grew up in a technological culture considerably different than the culture of their students, and they often have trouble leveraging the tools of the current culture. It can be difficult for teachers to adapt to technological influences that they themselves have not experienced during their formative years.

Instructors tend to teach in the same style and format that they have been taught. For the current generation of teachers, this included a linear step-by-step approach involving little technology in the classroom. In terms of pedagogy, much of the efforts during the current generation of a teacher's formative years were focused on the students as empty vessels to be filled with the wisdom of the instructor. Students were placed in rows of seats, and the teacher at the front of the room held all of the knowledge that they presented to students, who were assigned to memorize and repeat the information provided to them by their teachers.

In terms of technology, computers and even calculators were not available for much of the educational life of teachers today. Many current teachers remember using slide rulers instead of calculators. Affordable hand-held calculators didn't become widely available until the late 1970s and not until much later in many cultures and countries. While educational reforms since those formative years have had some impact, the overall effect has not been as widespread as expected.

As a result, the instructional paradigms employed for engineering and technology education across the globe have not fully embraced the technologies of video games, Internet, social media or mobile devices, or the associated teaching methodologies that must accompany the technology tools. Many teachers are unfamiliar with the opportunities afforded by technology-mediated methodologies and many curricula do not leverage the digital connectedness of students. The result is that technology tools are not fully utilized in the educational curriculum for engineering and technology education, and an exploratory, constructivist approach is not widely adopted.

The basic instructional paradigm for teaching students engineering and technology has not adapted to the explosive use of technology in the third millennial culture. This is not to say that technology tools haven't been introduced in schools; they have. But simply adding computers to a traditional classroom without a corresponding change in instructional delivery or strategy doesn't work. It highlights the disconnection between how third millennium students leverage technology for day-to-day communications and interactions with limited use of the technology within academic environments. And adding technology hardware is not enough. The next wave in engineering and technology education is to leverage the connectivity of the third millennium and its aptitude for creating content to share with others via web-based networking tools.

THE CHANGING CULTURE OF THE THIRD MILLENNIUM

For students in the third millennium, the Internet has always existed, video games have progressed far beyond the 1972 launch of Pong, and "smartphones" have replaced "land lines" for person-to-person communication. Kids are growing up with cell phones, video games, Internet access and a culture that rewards creating digital networks and online content. Today, the video game market is larger than traditional entertainment media. In the United Kingdom, the video game market has surpassed cinema, recorded music and DVD sales to become the country's most profitable purchased entertainment market (Rosenberg, 2009). In the United States, 67% of households play computer or video games (Industry Facts, 2010).

And the third millennium generation is not just consumers of content. They are content creators. Many people in the third millennium engage in highly creative activities on social networking sites, with the National School Boards Association in their *Creating and Connecting Report* (2007) indicating that about 96% of those with online access undertake activities like chatting, text messaging, blogging and visiting online communities, such as Facebook and MySpace.

The most ubiquitous device of the third millennium around the world is the cell phone. The first commercially automated cellular network (the 1G generation) was launched in Japan by NTT in 1979, and cell phone networks in the early 1980s were launched in Denmark, Finland, Norway, Mexico, Great Britain, Sweden and the United States. Today, six in 10 people around the globe use a cell phone, which totals over 4.1 billion people (Beaumont, 2009) In Japan, 24% of all sixth-graders own a cell phone, while 45.9% of second-year students in junior high school own one and over 95% of eleventh-grade students have a cell phone (GSM Association, 2009). Korean youth are among the youngest to begin using cell phones. The more the parents emphasize education, the earlier their children get their first cell phone. Moreover, Korean youth are more likely to trust in new media than they would in traditional media sources (GSM Association, 2009). Additionally, the nature of cell phone usage has shifted from voice calls to text messaging; the average American cell phone subscriber now sends and receives more text messages than voice calls (Reardon, 2008), and one of the fastest growing uses of mobile devices is Internet access.

Meanwhile, the Internet itself has changed dramatically since its early inception. The Internet morphed from a static, one-way communication network into a dynamic platform for the exchange of ideas, concepts and innovation. Over 90% of all children aged 12–17 are on the Internet daily, and this use results in the creation of new content and the posting of new information by these young people and others (Macgill, 2007).

So many people are creating their own content that in 2006, *Time Magazine* named "You" the person of the year because, as they put it: You are the person of the year for "seizing the reins of the global media, for founding and framing the new digital democracy, for working for nothing and beating the pros at their own game" (Grossman, 2006). In other words, the honor was bestowed upon "You" for creating content and exchanging ideas in an open forum where one does not need special access or expensive equipment to distribute thoughts or ideas. The only access required to post information on the Internet is the ability to log on. The widespread use of social media and web-based applications is allowing increased communication among students and is fostering relationships, collaborative exercises and working together at an unprecedented rate.

IMPLICATIONS FOR ENGINEERING AND TECHNOLOGY EDUCATION

Society and culture are responding to the needs of youngsters in unprecedented ways. Marketers, advertisers, video game companies and electronics manufacturers are focusing their efforts on pleasing youngsters in terms of design, visual appeal and functionality of new technology. The third millennium generation is shaping society and culture more than in any other time. They continue to push consumer companies for more connectivity, more ways to create their own content and more access to information. They demand expanded communication channels through instant messaging applications, social networking sites and place-based interactions. The use of smartphones as a communication platform for texting and video chatting has increased as "connectedness" through technology becomes common practice around the world.

Video game companies have responded by creating multiplayer versions of their once solitary products. Playing a video game is no longer done alone or with one or two friends in the same room; games are played across the world with hundreds of players who never physically meet one another. The widely popular multiplayer role play game, World of Warcraft, has over 11.5 million subscribers worldwide and shows no signs of slowing growth (Blizzard Entertainment Press Release, 2008)

But the growth of online games is dwarfed by the number of people connecting through social networking sites. The social networking site, Facebook, has over 500 million active users, with 70% of these users being from outside the United States. In the third millennium, friends are being made over digital networks and kids who have met once keep in contact for years via updates to Facebook, MySpace or other social networking pages. And they stay active within their social networks: the average Facebook user has over 130 friends (connections), is connected to 80 community pages, groups and events, and creates 90 pieces of content each month (Facebook Press Room, 2010).

The implication for educators in the subject areas of engineering and technology is that the technologies employed by the third millennial generation to communicate and stay connected must be integrated into the ETE curriculum. The obligation of ETE professionals to leverage third millennium technologies is even higher than in other fields. The fields for which we prepare students routinely use technology for transactions, creating designs, crafting digital "what if scenarios" and to drive innovation and advancement. The engineering and technology disciplines would not exist without technology, and preparing students to enter these fields requires that they understand and appreciate how the technology functions and the thought behind its use.

We must prepare students to design systems and apply mathematical, scientific and technical skills to solve problems while employing professional judgment in balancing issues of costs, benefits, safety and quality. We must prepare students to use technology to connect with end-users of the products they design, to test software applications and to debug hardware. The explosive growth of social networking software, smartphone hardware and other technological advances mean that an entire new generation of students must be well-educated, not just in the use of these new technologies, but in their creation, maintenance and troubleshooting.

Students can't learn to troubleshoot, design and develop the technologies in which they are immersed unless we integrate them into our ETE curriculum. Integrating these technologies into various parts of the curriculum provides the opportunity for students to experience the design and development side of the technologies they take for granted to communicate and play.

Preparing students to enter engineering and technology disciplines requires teachers in engineering and technology disciplines use technology to reach the students. The teachers of these topics can benefit tremendously from the intelligent convergence of learning strategies, pedagogy and technology matched to the cultural sensibilities of the connected third millennial students.

If we systematically ignore the technological cultural influences of the third millennium and pretend that they don't exist, or continue educating these youngsters as we have been educated, we risk, at best, being ignored, and, at worst, not preparing them to deal with the realities of the digitally connected world of technology and engineering awaiting them when they complete their educational experience.

EXAMPLES OF THE USE OF NEW TECHNOLOGIES IN ENGINEERING AND TECHNOLOGY EDUCATION

Elements of the third millennial digital culture have specific and unique applications to engineering and technology education. Using three-dimensional animation software to teach object-oriented programming, games to teach engineering concepts and social media to connect students with professionals in the field are all ways of engaging third millennial students with the technologies they currently embrace. ETE educators have the opportunity to reach students through familiar technologies and to apply the natural problem-solving approach of video games and computer software in using a constructivist approach to provide third millennial students with the educational foundation they need to design, develop and troubleshoot future technological advancements they will encounter in the fields of engineering and technology.

The integration of technology and a constructivist approach into ETE education is critical as teachers should be providing the hands-on experience with technology and a chance for students to create content with the technology. In ETE, we must help students understand and become familiar with the technology by having them use the technology to learn about the technology—this approach, reinforced with sound constructivist pedagogy, will lay the foundation for success in ETE.

Educators can seize the tendencies of the third millennium students and leverage their understanding and comfort level with technology to create engaging ETE experiences. Currently, there are already several examples of organizations combining third millennial interest in technologies with engineering and technology topics.

In this section of the chapter, we examine several techniques used to converge third millennial technologies with pedagogy and answer the question "What are some examples currently employed in using third millennial technologies for education in ETE?" This section will discuss a number of projects and tools leveraging third millennial technologies to engage students in engineering and technology subjects. Tools explored include:

- Game design software
- Simulations
- Video games
- Social media
- Smartphones

Game Design Software

A method of helping students gain an understanding of design and programming, and the underlying logic is to have them develop their own code and practice applying programming concepts to their own projects. This approach can be focused on problem-solving and on building knowledge and skills through various programming approaches and considerations. One such example of using software to teach programming is a computer program called Alice.

Alice – Alice is a computer software program developed at Carnegie Mellon University designed to teach students computer programming in a 3D environment. [www.alice.org]. The software is freely available and was created to be a student's first exposure to object-oriented programming. It allows students to learn fundamental programming concepts in the context of creating animated movies and simple video games. With the software, 3D objects (e.g., people, animals and vehicles) populate a virtual world and students create a program to animate the objects.

In Alice's interactive interface, students drag and drop graphic tiles to create a program. Within Alice, the instructions correspond to standard statements in a production-oriented programming language, such as Java, C++ and C#. Alice allows students to gain immediate feedback on how their programs are running, enabling them to easily understand the relationship between the programming statements and the behavior of objects in their animation. By manipulating objects in their virtual world, students gain experience with all the programming constructs typically taught in an introductory programming course. Figure 1 shows the object-oriented code from the program used to make an ice skater move.

Unlike traditional programming languages that require users to follow a rigid syntax, Alice couples a drag-and-drop editor with characters and animated actions to provide an open-source, object-oriented programming environment. Alice offers two major advantages for students learning to program. First, the drag-and-drop interface provides a method of program construction that prevents users from making

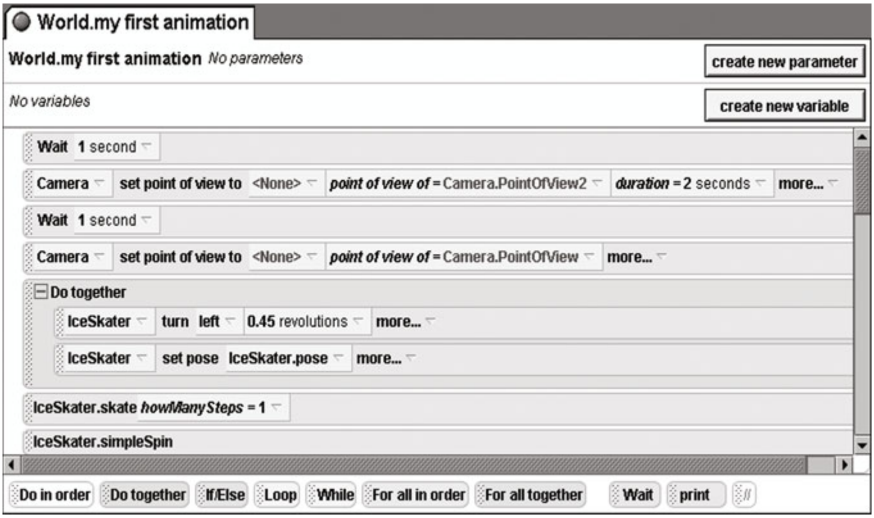


Figure 1. Programming code used to make an ice skater move in a 3D environment. Screen capture courtesy of www.alice.org. All rights reserved.

syntax errors, thus relieving much of the initial frustration. Secondly, Alice displays program sequences as animations so users can see their mistakes and more readily fix them. For example, if a character moves through a virtual world along the student's instructions but turns left instead of right at the end of the sequence, then the student can quickly pinpoint the problem. This leads to the development of good problem-solving skills (Kelleher & Pausch, 2006).

The pedagogy is that students "construct" or create the code necessary to make the animated figures function as they desire. Students can go through a basic tutorial to understand the screen and coding elements and are then given the opportunity to create their own animated sequence. As the students construct their sequences, they are able to see if they are getting the desired outcome by playing the animation to see if it functions as expected.

While students are constructing their code, the Alice software is teaching them basic programming concepts such as variables, if/then/else loops and parameters. Students learn about programming by creating short animation sequences. Students who gain more skills in using Alice can even create mini-video games that their fellow students can play and evaluate how much fun the interactions are. This is a strong incentive for many students and fully engages them within the learning process.

The goal of the Alice program is to combine the student's interests in video games with instruction in programming. Using this approach, students can see video game-like animations as a direct result of their manipulating object-oriented code. They learn technical concepts related to software development while having fun creating their own animations.

Simulation Software

A software simulation is the use of a computer environment to simulate objects or phenomena based on actual physical principles and constraints (Alessi & Trollip, 1985). In the ETE environment, software simulations can be used to create engineering projects not possible within a classroom. This might include building a roadway, designing an oil rig or designing and building a bridge to withstand the forces of a moving vehicle. Software developed at West Point to create a bridge provides an excellent example of using a software simulation in an ETE curriculum.

West Point Bridge Design – This is a constructivist-based engineering game designed to teach engineering concepts and skills related to the concept of building a bridge. The software was created by the US Military Academy, West Point, which sponsors the West Point Bridge Design Contest on the web (About the Contest, 2010.) The website contains software for creating a bridge crossing over a canyon. Students can create the bridge and then test it by driving a truck over the bridge. The software is also at the heart of the bridge design contest to encourage competition and engagement in an engineering task. The contest provides middle school and high school students with a realistic, engaging introduction to engineering.

In the contest, students download custom software and, using the software, design a virtual bridge to cross over a canyon. The contest has specific rules to guide the construction: the bridge must have no more than 120 structural members and no more than 50 joints, must pass a load test with no member failures, and no structural members may be drawn directly on top of one another. An example of a successful design is shown in Figure 2.

Figure 2. Successful bridge crossing. This image shows a student-designed bridge that crossed over the canyon successfully. Screen capture courtesy of http://bridgecontest.usma.edu/. All rights reserved.

The goal of the contest is to enable the students to learn about:
- Engineering through a realistic, hands-on problem-solving experience
- The engineering design process—the application of math, science and technology to create devices and systems that meet human needs
- Truss bridges and how they work
- How engineers use the computer as a problem-solving tool

The objective is to encourage students to think about the different variables and structures involved in creating a load-bearing bridge. The students receive instant feedback on the success of their design because the truck either makes it across the bridge or crashes into the river below. Again, the students are asked to conduct problem-solving processes, construct their own knowledge and build on past knowledge and skills to be successful.

Video Games

Another approach to engaging the third millennial generation is to create a video game environment in which students compete against themselves and others to accomplish specific goals, as described in Chapter 14 by Hacker and Kiggens. If well designed, these goals can be educational and beneficial to the students. Several projects have been undertaken to provide an educational, fun environment in which kids learn as they compete within a video game framework.

Several attributes of video games are useful for application in learning, including contextual bridging (i.e., closing the gap between what is learned in engineering or technology theory and its use): they provide high time-on-task and provide learners with cues, hints and partial solutions to keep them progressing through the subject matter (Federation of American Scientists, 2006) of engineering and technology. Below are two examples of applying video games to teach ETE.

Survival Master – The Survival Master game is a joint project of Hofstra University, Bloomsburg University and the CUNY Graduate Center sponsored by the National Science Foundation [http://gaming2learn.org/], described in depth in Chapter 14 by Hacker and Kiggens. The instructional and educational goals of the game are detailed more completely in Chapter 14 and provide a full description of the underpinnings of the game. This description will focus on the story created to support the educational goals of the game.

As indicated in Chapter 14, the project seeks to teach students engineering and technology skills through a video game designed for use in the classroom by teachers, covering topics related to engineering and math. The game involves teaching students concepts such as volume, heat flow, R-value and other information in the context of a video game where the learners must solve a series of obstacles or problems as they work to become a "survival master." The game teaches a variety of science, technology, engineering and math concepts while being fun and engaging for middle school students.

The instruction is designed to engage the student in an instructional process and in a story in a similar manner to many commercially available video games. Images from the game are shown in Figures 3–5.

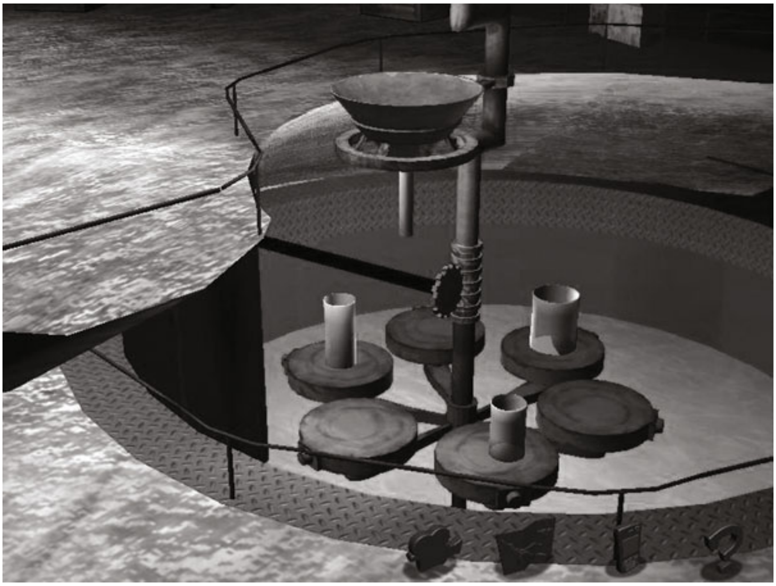


Figure 3. Inside the "Cave of Volume." Here students must calculate the volume of a shape and find the matching cylinder. Screen capture courtesy of "Survival Master." All rights reserved.

Figure 4. Inside the Labyrinth of Heat. This screen shows the player's viewpoint of an obstacle in the "Survival Master" educational video game. Screen capture courtesy of "Survival Master." All rights reserved.

Within the game, each subject or skill is performed in the context of the students training to become a “survival master” so they can teach others how to survive in a hostile environment. Students earn points for their accomplishments and unlock items such as power bars to boost their energy level throughout the game. The activities at each level contain common elements of commercially available video games, including unlocking chests having hidden surprises, shooting snowballs at targets and jumping from one platform to another.

Unbeknownst to the students playing the game, each level in the individual levels of the games prepares them for a group challenge to which they must apply the knowledge and skills learned individually into a group project. The second part of video game is a multiplayer game: the student must work in a group of four to build a shelter that will withstand extreme temperatures, a wind storm and snow load. The concept is that the skills learned by students playing individually in the first part of the game will be applied to the multiplayer game with the students working together to weigh trade-offs and develop reasonable compromises involved in building the shelter. Figure 5 shows a player orienting himself to the windswept wilderness.

As described in Chapter 14, the goal is to teach basic concepts related to engineering a structure while helping students think like engineers by considering trade-offs in terms of material usage, structure shape, structural integrity and cost

Figure 5. In the Wilderness. This screen capture shows a player navigating around the frozen wilderness during one of the Knowledge and Skill Builder activities related to heat loss. Screen capture courtesy of “Survival Master.” All rights reserved.

considerations regarding energy used by the players. The individual portion of the game ensures that all students have the basic skills needed to understand the broader engineering problem of building a shelter. The group portion of the game forces students to work together and think through the trade-offs involved in developing a shelter to withstand cold temperatures and wind and snow loads with each other and to create the right solution. The game has high-quality graphics, an interesting storyline and activities similar to commercially available video games. The goal is to combine the third millennial natural affinity for video games with educational content that teaches basic skills and knowledge, as well as more universal skills such as problem-solving and teamwork. The combination of entertainment and education leverages the cultural influences of the third millennial generation while providing a solid educational experience that will translate into the field of engineering.

Design a Cell Phone – Another game designed to focus students on the trade-offs and process of engineering a new product is simply called "Design a Cell Phone," created and made available at www.edheads.org. This educational game focuses on an engineering design project that requires the learner to design a cell phone that would appeal to individuals over the age of 65. In the game, the job of the learner is to help an engineering director called Elena design and manufacture a cell phone to help senior citizens get the most out of new technologies. The learner gets a chance to review research data, make design decisions, test the design for effectiveness and ultimately observe the results of his/her design decisions. Figure 6 shows the screen in

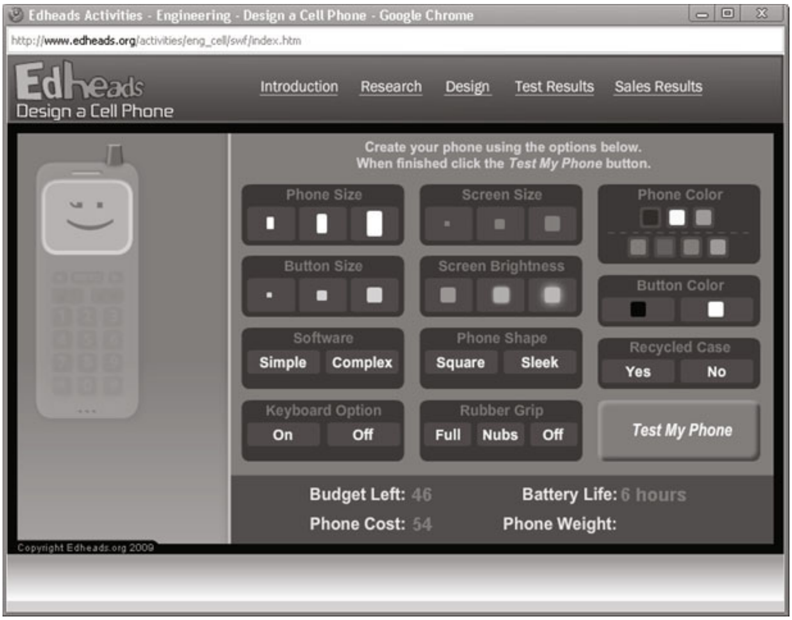


Figure 6. Design a Cell Phone. The design screen for engineering the features of the phone. Screen capture courtesy of www.edheads.org. All rights reserved.

which the player makes decisions about the phone design. Throughout the process, the game explains how engineers are required to make design and cost-benefit trade-offs, as well as the need to consider the target audience for whom the cell phone is being developed.

The pedagogy behind this game is constructivist-based. Students are given information in the form of "research" and during the process draw their own conclusions regarding the best design. The students are required to research the specifications of the new cell phone by conducting interviews, reviewing charts and graphs related to items such as desired battery life, button size and weight. Then they enter the design phase where they create a prototype by deciding on the size of the phone, the screen, the buttons and other key elements while trying to balance the cost of building the phone and the overall battery life.

Once a phone is designed, students test the results with a focus group of elderly individuals who provide feedback on what they like or do not like about the phone the student has designed, as shown in Figure 7.

Once the student has decided on the right engineering cell phone design, the phone is manufactured and the sales results are tallied. If the design meets the specifications and correctly balances the factors of cost, battery life, size and appeal to the target market, it will be a success. If the balance was not done correctly, the desired sales numbers will not be achieved and the student will be asked to redesign the phone and try again as shown in Figure 8.

Figure 7. Design Focus Group. A player can click on a member of the test group to obtain feedback about their cell phone design. Screen capture courtesy of www.edheads.org. All rights reserved.

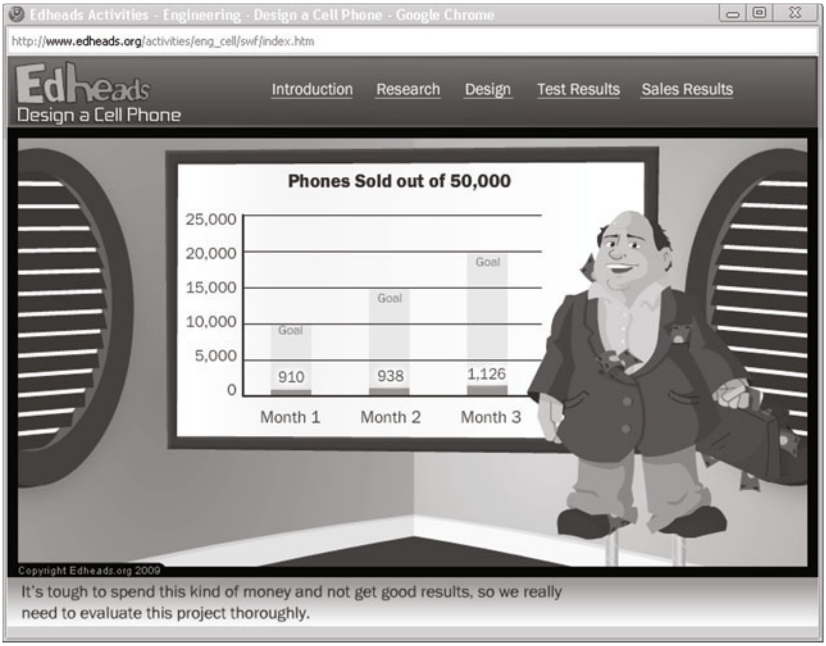


Figure 8. At the end of the activity, the learner is given feedback about sales numbers to determine if the phone was a success or a failure. Screen capture courtesy of www.edheads.org. All rights reserved.

Social Media

In addition to using video game technology to teach ETE topics, another technology that educators are just now beginning to leverage is social media. In fact, one of the most common topics of conversation on the social networks sites among middle school kids is education and schoolwork. Almost 60% of students using a social networking site talk about education topics and 50% talk specifically about schoolwork (Creating and Connecting, 2007). Social media is an umbrella term that refers to the ability of individuals to easily create and post information on the Internet in a manner in which others can view the materials and make comments on what was posted. Social media is about creating and sharing content online. The ease at which information can be uploaded to the Internet makes it attractive to students to create content and make it an effective instructional tool. “Central to the concept of Web 2.0 is that it involves connections and collaborations between people, and connections between ideas and hypermedia” (Finger & Jamieson-Proctor, 2009).

This section discusses two of the more popular social media categories. One is social networking as represented by the website known as Facebook and the other is the phenomenon of posting and sharing videos on the web through a video sharing site called YouTube.

According to Bozarth (2010, p. 55), "Facebook promotes conversation and can help to reduce the space and power issues between instructor and learners; it helps to 'level' the relationships and can support inter-learner interaction rather than just back-and-forth learner-instructor discourse often seen in traditional instruction." It is an easy-to-use website where each person can create their own profile and post text, video and pictures and then connect with others through the process of "friending" them.

YouTube is a software platform designed for storing and distributing videos. The videos are limited in length, and the free service allows individuals or organizations to establish a channel whereby all of your videos can be stored in one place. Visitors to the site can rank videos, make comments and even link to the videos from their own websites.

The social media represented by Facebook and YouTube can have the following three primary functions in the area of ETE education:

- Extending communication outside the classroom
- Encouraging design collaboration
- Creating an e-portfolio of student achievements, activities and work in the engineering and technology field

Social Media as a Communication Tool Beyond the Classroom

One of the first uses of social media in the ETE curriculum is to extend discussion and communications beyond the classroom. Social media allows students, instructors and industry to connect outside the four walls of the traditional classroom and to carry out discussions related to ETE, as shown in Figure 9.

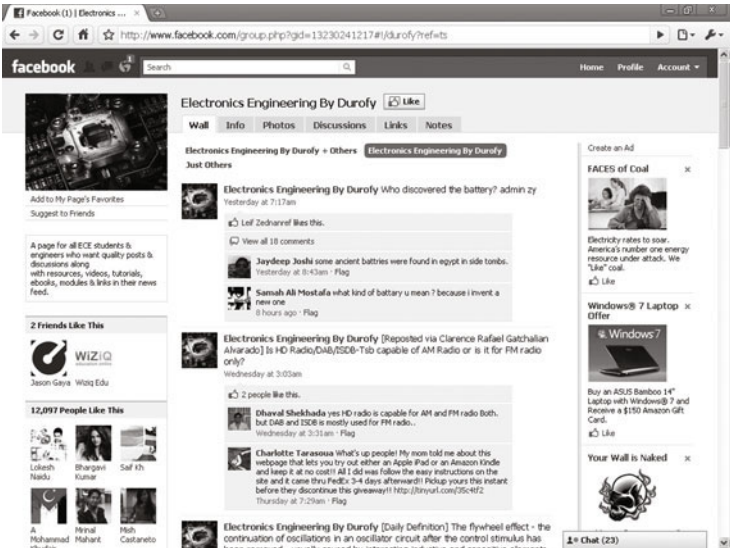


Figure 9. Facebook page. This page is used to post and react to engineering information.

One way to use Facebook is for an instructor to post comments and relevant information on a site set up to support his/her classroom's instructional activities, then encourage students to add their own comments on postings, add links and/or videos to the related information and post photographs. A Facebook site established around a class can be a central online site for sharing information with students and for students to share information with each other. It creates a conversation about ETE outside the typical constraints of a classroom. It provides the opportunity to extend the educational conversation. Its value is that it builds a community around the central theme of the class. Questions can be asked and answered, connections are made between people, and knowledge and ideas are exchanged freely. This taps into the third millennial use of Facebook technology and leverages the connectivity of the Internet.

The Web as a Source of ETE Video Content

Another example of using social media as a tool for learning is YouTube and its sister site TeacherTube. Both of these websites are video-sharing websites that literally contain hundreds of thousands of videos. The only difference is that TeacherTube is moderated to ensure that "school friendly" videos are posted while YouTube is more open in terms of the content it allows. On both sites, you can find video topics such as IBM experts discussing technology, virtual factory tours and even lessons on pneumatics. Both YouTube and TeacherTube provide interviews with experts, examples of engineering-related experiments and access to content only previously available in the classroom. The sites even contain videos created by students to show off their projects and work accomplished.

If you search YouTube for the term "engineering and technology education," you will find many examples of valuable educational information. One such example is shown in shown in Figure 10. You can also search for more specific terms such as "pneumatics," "manufacturing" or "CAD." Virtually any topic related to engineering and technology education can be found with the right amount of searching.

The idea behind using YouTube and TeacherTube is that ETE students can watch short videos in class, at home on the Internet or via their smartphones. YouTube allows for comments on the videos and creates a community around the content contained within the videos by allowing comments to be added. Additionally, the videos can be embedded on other websites and social networking sites such as Facebook.

The goal of leveraging existing videos found on the Internet is to provide access to content whenever the students have web connectivity. In the past, DVDs and VHS videos meant that when one person was viewing the content, a person across town or in another room was not able to access the content, but with web-based video content, multiple students in different locations can view the content simultaneously. Videos available on the Internet complete with social networking capabilities foster a network whereby students, faculty, alumni and industry professionals can share videos, comment on the content and exchange information in a networked environment regardless of their physical location.

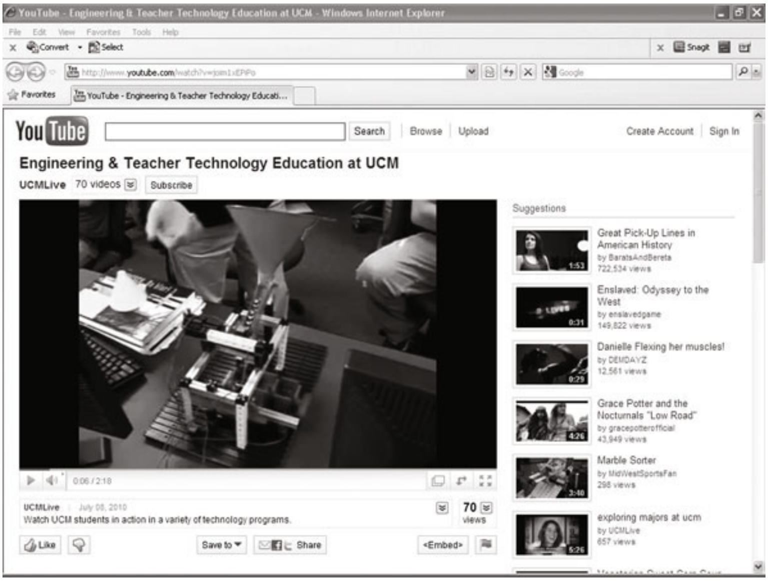


Figure 10. YouTube as a Resource. The page on YouTube, shows one of the many engineering and technology education-related videos available.

Encouraging Design Collaboration

While using social media as a tool to extend the classroom is a good first start with social media, many more opportunities exist to leverage social media within the ETE curriculum.

One innovative way of using Facebook is to post discussion questions that ETE students can answer focused around a design topic. The advantage is that students will have conversations with other students about their answers; Facebook provides students with the opportunity to post pictures or even videos related to answering the question. In answering a question, ETE students should be required to construct an argument, offering evidence and supporting resources, and apply sound design and logic principles for answering the question and creating a dialogue. The questions could include something like:

– Can you describe how a common household item was designed and manufactured?
– How can engineering and technology solutions solve the world's growing "clean water" problem?

As the students are answering the questions, the teacher can require them to post links to resources relevant to the topic, take a photograph of the item they are describing, and even post a video showing the item and discussing the design principles beyond its creation or behind the student's solution.

This approach could also be used in YouTube. Some ETE instructors have begun to ask students to record their meetings and thoughts around a design process undertaken when creating items such as a solar-powered car or a miniature wind turbine.

The students must not only design and build these items, but they must also record the process. This encourages the students to think about how they are designing and about the processes and procedures involved in their own thinking. In educational terms, this is called metacognition.

Metacognition is the state of being aware of one's own thinking (Marzano et al., 1988) and is a fundamental tool enabling learners to control their thinking. It has been revealed as an important skill in the fields of engineering (Case, Gunstone, & Lewis, 2001) and technology (Phelps, Ellis, & Hase, 2002). Rarely do students become self-aware of metacognition; instead, an instructor must point it out to the students as an important element in problem solving. By encouraging students to describe and narrate their project, an instructor can then review the video with the students, make comments about what they were thinking and observe how they approached the problem. This is one way in which third millennial technologies can be leveraged to increase the effectiveness of ETE curricula. It allows students to "watch" their own thought processes by requiring them to record and post the design project online.

Students can be asked to interview experts in the field and post the results on YouTube, providing them with the opportunity to meet individuals from the field and share these experiences with fellow classmates in a robust manner as opposed to a simple verbal or oral report. The videos can also show the products designed and built by the individuals being interviewed.

Creating an e-portfolio

Perhaps one of the most enticing aspects of social media is the opportunity for students to create a permanent and continually updated e-portfolio of projects, design thinking and online artifacts. e-portfolios are a way for learners to portray a story of their understanding of content at a deep level using a variety of media (Heinrich, Bhattacharya, & Rayudu, 2007). e-portfolios are a way for the concept of life-long learning to be incorporated into an ETE curriculum (Heinrich, Bhattacharya, & Rayudu, 2007).

In the early days of multimedia technology, e-portfolios required some knowledge of web development and an individual server on which a website could be housed. This was costly to maintain and usually the student portfolio disappeared or was placed onto a portable media when the student graduated. Today, with social networking tools like Facebook, educators and students can take advantage of free web resources that allow the portfolio to exist online indefinitely on the servers of the hosting software platform.

Using a social networking platform like Facebook, students can post information in a variety of formats and can augment the Facebook page by using other social media tools like YouTube for create videos.

The general characteristics of a portfolio as described by Meeus, Questier, & Derksare (2006) are:

- Student-centered
- Competence-oriented

– Cyclical with regard to action and reflection
– Multimedia-oriented

Online social networking tools leverage all of these characteristics to provide a permanent record of a student's accomplishment within the ETE curriculum.

Capitalizing on the affinity for social networking, an e-portfolio is networked, allows for feedback from the community, is constructivist in approach and allows for open standards. Tools like Facebook make it easy to update an e-portfolio and provide students with a low entry barrier (Heinrich, Bhattacharya, & Rayudu, 2007).

The accessibility of an e-portfolio created in Facebook or similar software provides the opportunity for peer-to-peer feedback, industry review of content and a level of professionalism by the students since they understand that their work will be viewed by someone other than just their teacher.

Incorporating e-portfolios using social networks into the ETE curriculum provides a linkage between third millennial technology and the content presented in class. It provides the tools for students to connect with others and to construct their own knowledge based on their interaction with the content online.

Smartphones

Taking advantage of the ubiquitous nature of smartphones extends the ETE classroom as students leverage the devices to assist them in learning.

As a platform, a smartphone provides easy access to applications required within the ETE curriculum. The most obvious use of a smartphone is as a scientific calculator. There are literally dozens of applications that can be downloaded that provide various versions of calculators, not to mention the fact that the hardware of many cell phones already have a built-in calculator that can perform some sophisticated calculations.

Already in the field, applications are being designed to provide formulas related to mechanical, electrical, chemical and civil engineering. Information is available for diverse topics such as brakes, elevators, metalworking, fluid viscosity, power demand, wiring, voltage drop, and many more.

As an example, one application used in the field determines the cost of a steam leak within a pipe. The application allows a person to approximate the cost of a leak and the potential savings involved by repairing the leak in a set number of days. On the calculator, you enter the steam pressure, the orifice/leak size and the cost of steam. The application then determines the steam loss rate and the cost of the leak per hour.

Figure 11 presents an example of an application showing geometric formulas. ETE curricula can include the use of such applications to familiarize students with the use of mobile applications to assist them in making calculations and using formulas just as professionals do in the field.

Smartphones also provide connections to instructors and other students. A student can use a smartphone to view teacher-created videos, text-message a request for help to a classmate or link to an important website online. Smartphones are another way of accessing social networking sites like Facebook and online videos through YouTube. Students can also use them to take photographs of design projects, post messages to a social network site about a design project and email information to an instructor.

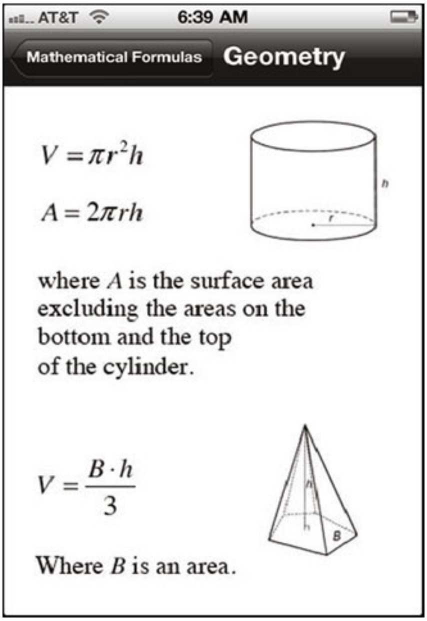


Figure 11. Formulas found in an ETE application designed for a smartphone.

Incorporating smartphones into the ETE curriculum extends the classroom and utilizes third millennial technologies to keep students interested and engaged in ETE subjects. A combination of using smartphones and a problem-based learning approach can foster facilitation, encourage students to talk with and teach each other, and create relevance for students by creating assignments that help them see the subject matter in the world around them outside of the classroom (Project Tomorrow, 2010).

CONCLUSIONS

It is clear from the examples above that third millennial technologies can be combined with sound pedagogy to create engaging and interactive learning experiences. As educators, we are obliged to examine the culture of the third millennium and compare it to our teaching methods and approaches in the classroom, and see if we can integrate elements into the ETE curriculum. This is especially urgent in the fields of engineering and technology because we are preparing students for fields in which technological acumen and a deep understanding of technological conventions is required for success. Engineers and technologists simply can't function without technology. Given this reality, one of the most effective ways of integrating technology intelligently into the ETE curriculum is to leverage the ability of third millennial technology tools to allow learners to construct their own knowledge.

The ease at which students can create knowledge, view the thoughts of others and apply learning within a simulation or game must be recognized. Tools are now available to allow students to literally construct knowledge in the form of digital assets that could not be done a mere decade ago. Curricula must be re-engineered to have students participate in the following manner through technology:

- Creating an online dialogue about design or manufacturing complete with images, videos and links to support or refute conclusions
- Working through an engineering challenge presented in the form of an educational video game
- Looking up formulas while on a field trip to solve an engineering dilemma presented by the instructor on a mobile device
- Teaching students to create their own video game using specially designed software
- Creating a life-long passion for engineering and technology topics by constructing an e-portfolio that shows the maturation of a student's thinking over time

These are just some of the ways the ETE curriculum can begin to be shaped by allowing third millennial communication technologies into the classroom. But this type of integration will not be without obstacles. As with any sweeping change within a discipline, there will be cries that traditional methodologies are "proven" to be sound and should not be changed, and that those new technologies are a distraction from "real" learning.

The truth is that smartphones, social networking software and simulation software are the business tools of today's engineers, technologists and technicians (Kapp, 2007). These tools have already worked their way into the practice of the discipline as "serious" tools. The field uses these tools and innovative companies are gaining a competitive advantage with these communication technologies. This same type of innovation must be applied to the creation and delivery of the ETE curriculum.

By relating to the third millennial culture and incorporating items from this culture into classroom settings, we can provide a bridge between the digitally connected world of the students and the current ETE paradigm. The next step in the evolution of the ETE educational system requires a convergence of constructivist-guided pedagogy with the advanced, third millennial communication technologies to teach them the design, thinking and problem-solving skills required for success.

This material is based partly upon work supported by the National Science Foundation under Grant No. 0821965.Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

About the Contest. (2010). *West point bridge design contest web site*. Retrieved September 19, 2010, from http://bridgecontest.usma.edu/

Alessi, S. M., & Trollip, S. R. (1985). *Computer-based instruction: Methods and development*. Englewood Cliffs, NJ: Pentice-Hall, Inc.

Ayoreo. (2009). *Survival: The movement for tribal people*. Retrieved August 10, 2010, from http://www.survivalinternational.org/tribes/ayoreo

Beaumont, C. (2009). Half the world's population owns a mobile phone, *UN study reveal. Telegraph. co.uk*. Retrieved August 10, 2010, from http://www.telegraph.co.uk/technology/news/4933263/half-of-worlds-population-owns-a-mobile-phone-un-study-reveals.html

Blizzard Entertainment Press Releases. (2008). *World of Warcraft surpasses 11 million subscribers world-wide*. Retrieved August 10, 2010, from http://us.blizzard.com/en-us/company/press/pressreleases.html?081028

Borko, H., & Putnam, R. (1996). Learning to teach. In R. Calfee & D. Berliner (Eds.), *Handbook of educational psychology* (pp. 673–725). New York: Macmillan.

Bozarth, J. (2010). *Social media for trainers: Techniques for enhancing and extending learning*. New York: Pfeiffer.

Case, J., Funstone, R., & Lewis, R. (2001). Students' metacognitive development in an innovative second year chemical engineering course. *Research in Science Education*, *31*(3), 313–335.

Creating and Connecting: Research and guidelines on online on social and educational networking. (2007). *National School Board Association*. Retrieved on September 19, 2010, from http://nsba.org/site/docs/41400/41340.pdf

Delpit, L. (1995). *Other people's children: Cultural conflict in the classroom*. New York: The New Press.

Facebook Press Room. (2010). *Statistics*. Retrieved August 10, 2010, from http://www.facebook.com/press/info.php?statistics#!/press/info.php?statistics

Federation of American Scientists. (2006). *Summit on educational games*. Retrieved August 29, 2010, from http://www.fas.org/gamesummit/Resources/Summit%20on%20Educational%20Games.pdf

Finger, G., & Jamieson-Proctor, R. (2009). Assessment issues and new technologies: ePortfolio Possibilities. In C. M. Wyatt-Smith & J. J. Cummings (Ed.), *Educational assessment in the 21 century: Connecting theory and practice*. (pp. 127–146). London: Springer.

Gay, G. (2000). *Culturally responsive teaching: Theory, research and practice*. New York: Teachers College Press.

Grossman, L. (2006). Person of the year. *Time Magazine*. Retrieved August 10, 2010, from http://www.time.com/time/magazine/article/0,9171,1569514,00.html

GSM Association and the Mobile Society Research Institute within NTT DOCOMO. (2009). *Children's use of mobile phones: An international comparison*. London: GSM Association. Retrieved August 10, 2010, from http://www.gsmworld.com/documents/Final_report.pdf

Heinrich, E., Bhattacharya, M., & Rayudu, R. (2007). Preparation for lifelong learning using ePortfolios. *European Journal of Engineering Education*, *32*(6), 653–663.

Industry Facts. (2010). *Entertainment Software Association*. Retrieved September 18, 2010, from http://www.theesa.com/facts/index.asp

Kapp, K., & O'Driscoll, T. (2010). *Learning in 3D*. New York: Pfeiffer.

Kapp, K. (2007). *Gadgets, games and gizmos for learning: Tools and techniques for transferring know-how from boomers to gamers*. New York: Pfeiffer.

Kelleher, C., & Pausch, R. (2006). Lessons learned from designing a programming system to support middle school girls creating animated stories. *Visual Languages and Human-Centric Computing*, *IX*, 165–172.

Knowles, G. J. (1992). Models for understanding pre-service and beginning teachers' biographies: Illustrations from case studies. In I. F. Goodson (Ed.), *Studying teachers' lives* (pp. 99–152). New York: Teachers College Press.

Lawanto, O. (2010). Student's metacognition during an engineering design project. *Performance Improvement Quarterly*, *23*, 117–136.

Macgill, R. (2007). *Parents, teens and technology. Pew Internet & American life project*. Retrieved from http://pewresearch.org/pubs/621/parents-teens-and-technology

Marzano, R. J., Brandt, R. S., Hughes, C. S., Jones, B. F., Presseisen, B. Z., Rankin, S. C., et al. (1988). *Dimensions of thinking: A framework for curriculum and instruction*. Alexandria, VA: Association for Supervision and Curriculum Development (ASCD).

Meeus, W., Questier, F., & Derks, T. (2006). Open source eportfolio: Development and implementation of an institution-wide electronic portfolio platform for students. *Educational Media International*, *43*(2), 133–145.

Nieto, S. (2004). *Affirming diversity: The sociopolitical context of multicultural education*. New York: Longman.

Phelps, R., Ellis, A., & Hase, S. (2002, December). *The role of metacognitive and reflective learning processes in developing capable computer users*. Paper presented at the 18th annual conference of the Australasian Society of Computers in Learning in Tertiary Education, Melbourne.

Project Tomorrow. (2010). *Students leverage the power of mobile devices through the Project K-Nect Mobile Learning Initiative in Onslow County*. Project Connect Evaluation Report. Retrieved August 29, 2010 from http://www.tomorrow.org/docs/Project_K-Nect_EvaluationReport_Final_Jul7.pdf

Reardon, M. (2008). *Americans text more than they talk: CNET News*. Retrieved August 10, 2010, from http://news.cnet.com/8301-1035_3-10048257-94.html

Thompson, A. (1992). Teachers' beliefs and conceptions: A synthesis of the research. In D. Grouws (Ed.), *Handbook of research in mathematics teaching and learning* (pp. 127–146). New York: MacMillan.

Villegas, A. M., & Lucas, T. (2002). *Educating culturally responsive teachers: A coherent approach*. New York: SUNY Press.

Karl M. Kapp
Department of Instructional Technology
Institute for Interactive Technologies
Bloomsburg University

PART IV:
PEDAGOGICAL DIMENSIONS

DAVID CRISMOND

13. SCAFFOLDING STRATEGIES FOR INTEGRATING ENGINEERING DESIGN AND SCIENTIFIC INQUIRY IN PROJECT-BASED LEARNING ENVIRONMENTS

INTRODUCTION

Project- and Problem-Based Learning are instructional methods that, although not identical, have been used to support learning skills in scientific inquiry and concepts in science, engineering and technology via the investigation of questions, solving of problems, and completion of projects that can sometimes involve design challenges. This chapter describes some of the unique capabilities related to using design tasks in project-based learning environments, and some challenges and controversies associated with using these approaches in K-16 classrooms. One controversy involves a dilemma of teaching (Wiggins & McTighe, 2005) that educators face when implementing project-based tasks: when to use direct instruction and when to opt for constructivist approaches. Two forms of design-based project support are then described that attempt to bridge inquiry and design. These include having students: (1) creating design rules-of-thumb that guide their decision-making based on “fair-test” experiments they conduct on prototypes; and (2) doing diagnostic trouble-shooting, where students focus on and analyze problems in design prototypes and improve them via iterative design cycles. Educational technologies that enhance these two approaches are also discussed, including an electronic portfolio system that uses digital audio and video recording to enable students to communicate their design-based work and learning. Finally, an alternative to the constructivist/direct instruction dichotomy is presented.

LEARNING STEM TOPICS THROUGH PROBLEMS AND PROJECTS

Predictions of Products and Pedagogies by Visionary Engineers

I currently live in Poughkeepsie, NY, a rather long-of-tooth industrial town in the mid-Hudson Valley, which on a good commute day is a 100-minute ride by train or car to New York City. I am completing the writing of this chapter in the summer of 2010. Poughkeepsie recently opened a pedestrian bridge for walkers, joggers and cyclists who can now traverse the Hudson some 212 feet above the river. I daily make a seven-mile circuit on my recumbent bicycle across downtown Poughkeepsie to the Walkway over the Hudson Park, where I gain access to the footbridge that

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 235–255.

was once a busy railroad line, and while riding to the western bank of the Hudson and back, enjoy the panoramic views of the nearby Catskill Mountains and tidal Hudson as it ebbs and flows down to the Atlantic Ocean.

My beautifully designed and well-reviewed recumbent is the Bike•E RX, which sports a dual chainwheel and chain transmission attached to the Bike•E's distinctive I-beam design, with handlebars that give this recumbent a familiar and inviting look to passers-by. As with all recumbents, the RX provides great exercise for my large muscle groups (read that as quadriceps and *gluteus maximus*), and an unimpeded view of the sky, since I am not hunkered down over drop handlebars of more ubiquitous racing-bike designs.

Besides me loving my Bike•E, so do many of the people I fleetingly meet while performing my constitutional. It is a rare day when at least 3-4 strangers do *not* comment on how much they like my bike, ask to take it for a ride, and in a few worrisome cases, just ask to take it. The lead designer of the Bike•E is the author, engineering professor and researcher, David G. Ullman, who uses the Bike•E as a case study in his undergraduate engineering design textbook, *The Mechanical Design Process* (1997). I have no other possession that garners such dependably regular praise. As people compliment the bike, I nod to acknowledge my having made a fine purchase, while thanking the even finer work of a gifted product designer.

In preparing to write this piece, I came across a chapter by Ullman (1992) in an early book of engineering design research entitled *Research in Design Thinking*. In his "imaginary retrospective," Ullman imagined himself writing in the year 2010 [my underline], and reflecting on technology that would then be available to support the work of engineering designers. What seemed to me remarkable and visionary in Ullman's chapter were his sketches and description of a "computerized assistant" that he coyly named DUDA, and which to my eye bore an uncanny resemblance, in appearance and more importantly in listed features, to Apple's iPad, which hit the world's markets by storm in April 2010 (see Figure 1).

While the DUDA's screen is a bit larger and slightly more squarish than the iPad's 14.5x19.5 cm screen, both DUDA and iPad: are mouseless; employ a flat screen; are touch sensitive and accept input via a stylus or finger; do voice recognition; and

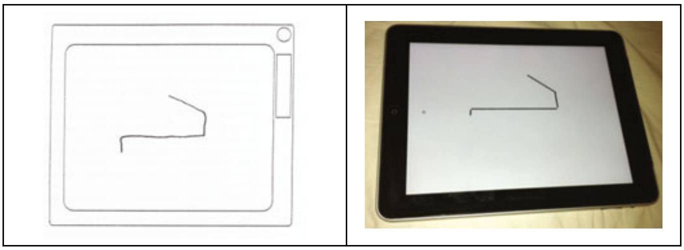


Figure 1. David Ullman's DUDA (left, 1992) was an envisioned digital assistant for designers living in 2010, and shows a half-completed drawing of a bent paper clip. The Apple iPad (right), was itself released in 2010 sporting another sketch of Ullman's paper clip.

have their memory contents updated regularly (Apple's *iTunes* program does this for the iPad). Both support sketching; Ullman's imagined machine runs a smart CAD program that anticipates strategies the designer might need to use, while the iPad currently runs rudimentary CAD software with a limited pallet of tools.

In my view, Ullman hit the mark with DUDA (even though his device's rather heavy reliance on artificial intelligence programming now is quite out of fashion), and with the line of Bike•E recumbents (even though the company that made them declared bankruptcy in 2002). In this chapter, you will read about another visionary engineer and educator, Robert Mann, whose work in engineering design education in the 1950s and 1960s I believe still impacts and has relevance in the world of ETE today.

The Three Flavors of PBL

Grounding students' learning within the contexts of solving problems and doing projects has been an approach favored by educators since the early 20th century (Barron et al., 1998, p. 272), and as far back as late 16th-century Italy (Knoll, 1997). Three recent variations on that theme have all been represented by the same acronym – PBL. The first form of PBL, called Problem-Based Learning, was developed by Barrows and others (Barrows & Tamblyn, 1980) and used as a method of instruction in medical education settings. Students learned disciplinary knowledge and rendered diagnoses of cases given to them by working in teams and distributing assignments among team members, who then gathered information and sought guidance on the problem. Subsequent later interest in collaborative and cooperative learning arose in part from PBL's use and emphasis on learning in groups that shifted the locus of control of learning away from the instructor and towards the students. Recently, PBL-styled courses have been offered in parallel with traditional engineering courses at McMasters University (Smith, Sheppard, Johnson, & Johnson, 2005).

After PBL became established in a number of medical, veterinary and business schools, and its methods were more clearly delineated and even "systematized" (Bereiter & Scardamalia, 2000), others began adapting and extending the boundaries of PBL. This next generation of problem-based learning, which some use lower-case letters (pbl) to refer to, still had students facing problems that needed resolving, but now emphasized learners developing mental models and theories from which new learning could flow rather than providing answers. Questions in pbl were not as strongly coupled to specific cases, but were more closely aligned with the abstractions from a discipline of study.

The last flavor of PBL, Project-Based Learning, which some abbreviate as PjBL, involves students in doing investigation or performance projects (Kanter, 2010) rather than solving problems or answering questions. Investigation projects could include monitoring pollution levels in a local body of water, or using data on conditions and life in the Galapagos Islands to disprove or validate explanations regarding the evolution of animal populations there (Reiser et al., 2001). Design challenges are performance projects, and have involved elementary children devising the layout and devices for a school playground (Cognition and Technology Group at

Vanderbilt, 1992), middle-school students devising a model for an extreme weather structure and habitat (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004), or learners creating a healthy and energy-balanced (no-weight-gain) lunch menu for a school cafeteria (Kanter, 2010). Within these contexts, students could learn science content while planning and conducting experiments that generated data useful for interpreting their explanations or evaluating their predictions. Here, designing served the learning of science: “Our goal in these units is not to instruct the students about Design; we want them to engage in Design in order to learn science” (Fortus et al., 2004, p. 1085).

Engineering and technology educators have followed a different instructional vector than science educators in their use of design activities. They wanted students to learn STEM ideas, but also gain competence in engineering design, and would emphasize ideas like optimization, reasoning about tradeoffs, troubleshooting and meeting criteria while staying within prescribed constraints (Crismond, 2006). In ETE settings, students may run more informal tests, ones that can yield useful information quickly to impact their evolving ideas and products faster. Technology educators regularly use design tasks to motivate and contextualize learning facts, concepts and skills found within their own discipline (e.g., Hacker & Burghardt, 2004). Some emphasize the interdisciplinary nature of design tasks when addressing multiple STEM topics (Layton, 1993; LaPorte & Sanders, 1993, 1996; Loepp, 1999; Barak & Raz, 2000).

Challenges for Teachers Using Design-Oriented PBL Tasks

Many challenges that teachers face in using PBL-based design activities are similar to those for other forms of PjBL instruction. Students doing inquiry or design projects need help in seeing the “big picture” of their work, in being systematic in collecting data, and in drawing meaningful conclusions from their work (Krajcik, Blumenfeld, Marx, Bass, Fredericks, & Soloway, 1998). The use of formative assessments in PBL is difficult for teachers, despite being critical for guiding instruction and mentoring teams effectively (CTGV, 1992). The problems of supporting collaborative and cooperative team work in inquiry- and design-oriented PBL are fairly similar. Such dysfunctions (Hsiung, 2010) can include team members being uninvolved or “taking charge” (Johnson & Johnson, 2002), doing “pseudo-learning” (Johnson & Johnson, 1999), exhibiting “status differential” among one another (Salomon & Globerman, 1989) or lacking skill in managing time, materials, or a team’s talent.

Some teaching challenges are more unique to doing design activities as projects. The presence of underlying links between “big STEM ideas” and a design task that experts easily see does not guarantee that students will perceive the need to know those concepts when the time comes. Such connections often get lost in the “doing” (Barrow et al., 1998, pp. 273–274) associated with building and testing working models and prototypes. The range of STEM content and process skills that instructors need to be familiar with to support unanticipated solutions that students want to create lies beyond any single teacher’s or expert’s grasp, except for the most constrained design challenges. Teachers attempting interdisciplinary STEM integration can encounter "intractable" problems that include students compartmentalizing their knowledge, teachers being unaware of the instructional timing of shared topics by other discipline teachers (Kimbell & Stables, 2008, pp. 175–177), and other "formidable" logistical challenges (Davidson, Evens, & McCormick, 1998). Teachers often lack the pedagogical content knowledge that would make reviewing or re-teaching topics from other STEM disciplines efficient and effective. It seems that teaching with design challenges is not for faint-hearted educators, and can be especially challenging for those with little or no design experience under their belts.

CONTROVERSIES IN USING DESIGN-BASED PBL ACTIVITIES

A Teacher's Dilemma: Constructivist Versus Direct Instruction with Design Tasks

A number of educational debates and controversies have been linked to the use of design challenges since their appearance on the educational scene. One has recently re-surfaced with the publishing of a draft of the replacement to the NRC's *National Science Education Standards* (1996). When *NSES* first appeared, science educators were asked by its authors to add supporting students in doing "technological design" to their list of core learning objectives. The last draft of the *Science Education Conceptual Framework* was much more direct: "Engineering and technology are featured alongside the natural sciences in recognition of the importance of understanding the designed world and of the need to better integrate the teaching and learning of science, technology, engineering, and mathematics" (NRC, July 12, 2010 draft, p. 1). A question that was raised when *NSES* first appeared is still applicable today: "Are science teachers, especially those without training in engineering design, able to support students in doing such work?"

An even more contentious debate relates to the pedagogical approaches often associated with the various flavors of PBL, specifically the preferred use of constructivist over direct instruction approaches by authors of these learning environments. Wiggins and McTighe (2005, p. 269) describe such a choice as one of the "unavoidable dilemmas in design" that teachers face when planning most lessons. Hands-on inquiry and design tasks can be highly motivating and involve authentic work, but typically require more time to implement and assess compared to non-constructivist teaching methods like lecturing and textbook-based instruction. When is direct instruction the more effective instructional strategy to use versus constructivist approaches when students do problem- or project-based work?

In this debate, authors like Kirschner, Sweller, and Clark (2006) challenge the use of constructivist approaches with PBL. They cite numerous research findings that show direct instruction approaches helping students change ideas held in their Long-Term Memory [LTM]. In the Klahr and Nigam study (2004), the effectiveness of direct instruction with feedback was compared to discovery learning with no feedback in grade 3–4 students' acquisition and transfer of the Control of Variable Strategy [CVS] that is part of planning unconfounded scientific experiments. They also reference studies supporting the use of "worked examples" that helps novice learners acquire the knowledge structures that experts use when solving more well-defined problems. Students who are not shown these more efficient knowledge structures and solution pathways, they argue, are left to "discover" them on their own (Kirshner et al., 2006), which may or may not happen, and places high demands on students' Short-Term Memory [STM] that can only hold from seven to as few as four items at any one time (Miller, 1956; Cowan, 2001).

These supporters of direct instruction do not specifically reference design challenges in their critiques of PBL, although they could. Design and scientific inquiry share a number of strategies (e.g., framing a problem or a hypothesis; conducting research; using feedback and iteration to improve the work). Inquiry strategies are typically done in a non-linear fashion [e.g., Krajcik et al.'s "investigation web" (1998)], which is also true for design (Cross, 2000). Instructivists might well claim that ill-defined problems like design challenges can swamp a child's short-term memory with all the novel design decisions that must be made and variables that must be considered. Significantly, one of these writers also suggests that students should wait until after they have achieved competence numerous disciplines before attempting more open-ended projects (Mayer, 2004).

By not including design activities in their analysis, authors like Mayer, Kirschner and others missed an opportunity to review the work and discussions of certain early engineering educators who formed a Committee on Engineering Design (1961) that addressed problems in undergraduate engineering education that were appearing in the late 1950s and early 1960s (Mann, 1962). During the decade following World War II, engineering science emerged and gained preeminence in the education of undergraduate engineers, and its courses were replacing design courses that had previously had a place in the college engineering curriculum. However, as the 1950s graduates began entering the workforce – including students who were computationally competent and skillful at solving "single-answer problems" (1961) – industry leaders started to complain that recent hires were not prepared to address real-world, ill-defined design challenges (Committee on Engineering Design, 1961; Mann, 1962, 1981; Smith et al., 2005, p. 89). In its 1961 report in the *Journal of Engineering Education*, the Committee described the "negative effects" that a focus on solving end-of-chapter textbook problems was having on students' attitudes towards engineering. These included poor skills in dealing with incomplete or contradictory data, little development of imagination and "engineering judgment," little inclination to question instructors as possessors of unassailable and correct answers, and a perception that engineering science provided an "infallibility of logic" that could supplant learning from doing experiments on actual prototypes.

The recommendations made by the Committee at a series of conferences included the re-introduction of undergraduate design courses with similarities in pedagogy to design-based PBL materials developed later by cognitive and learning scientists. Students were to be given "direct experience" with designing that required using science and engineering science ideas to formulate "analyzable models" of products or systems that they designed, and develop graphical literacy and drawing skills to explore and communicate ideas. Students would be responsible for the "physical realizability" of their design ideas, for developing not only knowledge and skills but an attitude that emphasizes curiosity, "flexibility of mind," and the capacity to make decisions, take responsibility for them, and defend them while "reserving the right to reverse decisions" when experiments show the need to do so. At MIT in the early 1960s, this instructional prescription where students learned disciplinary fundamentals, did hands-on design tasks, and designed their own experiments was supported by faculty who did engineering design themselves, and often led to the work that students used for their undergraduate theses.

Design-Based PBL Challenges that Bridge Engineering and Science

An important aspect of instructivists' criticism of how PjBL is implemented is that students are provided "minimal support." Learners are asked to discover the ideas and skills needed to solve problems and projects on their own. However, the *design-based* PBL literature describes various kinds of scaffolding that instructors and researchers in K-16 settings have devised and on occasion studied.

One approach to scaffolding students in doing design-oriented PBL involves students carrying out problem-based investigations before attempting more open-ended design challenges. An example of this approach comes from Barrons et al. (1998), where sixth-grade students were designing a business plan related to running a booth as part of a school's fundraising carnival. Prior to creating their plans, students used the interactive multimedia system, *Jasper – The Big Splash*, which depicted a simulated business planning session where students created a "fun fair" to help a school raise money. *The Big Splash* simulation acted as a kind of "worked problem" that preceded students devising their own business plan.

In Zubrowski's (2002) "standard model" for integrating science into design challenges, students first attempt a design challenge with defined constraints and materials provided for them. They leave their first iterations behind to study a design solution that the teacher gives them – one that contains a number of design flaws but provides basic structures that students investigate through experimentation that informs students' work when they return to their initial designs and complete the challenge.

The *Learning By Design™* materials used a series of single-page Design Diary sheets (Kolodner et al., 2003, pp. 520–525) to support a range of activities that helped students get the big picture of their project work (Problem Understanding), do preliminary hands-on investigations (Messing About Observations), design experiments (My Experiment and My Rules-of-Thumb), make design decisions (Decision Grid), and communicate to others interim and final design ideas (Pin-up Session and Gallery Walk Notes). When studied, students using these Design Diaries had some limited success in linking science concepts to design decisions (Puntambekar & Kolodner, 2005). When additional pages (Specifications) and prompts were added so that students and teachers could better link design decisions to hypotheses developed during the inquiry part of the design/inquiry cycle (see Figure 2), students provided improved justification for their design choices and made more explicit links to relevant science ideas.

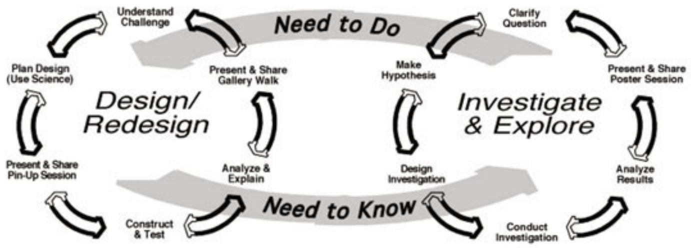


Figure 2. The Learning By Design™ design/inquiry process model emphasized a dialog between strategies associated with scientific investigations and with engineering design (Kolodner, Gray, & Fasse, 2003).

In the United Kingdom, the Nuffield *Design and Technology* materials (Barlex, 1995) scaffold students to do more open-ended "capability tasks" by having them first build requisite knowledge and skills by doing more structured "resource tasks." Black (2008, p. 7) describes one of Nuffield's capability tasks (Key Stage 3),where Key Stage 3 (middle school) students design a "weight machine that can be used in the school prep room to weigh small animals." The device needed to operate within a range of 0–500 grams, be accurate to within 10 grams of actual weight, be easy to read, and not cause injury or suffering to the animal. The unit employed 24 "resource tasks" to build necessary skills and knowledge related to: using general design process skills, understanding systems and feedback, communicating through orthographic-projection drawings, fabricating solutions and assessing the maintenance needs of design products (Black, 2008, p. 8).

Materials provided for project work can act as a kind of limited scaffold for students. MIT's early Introduction to Design courses (2.70, and later 2.007) used materials-constrained design activities where teams of students were given a box of materials to make a robotic device for a head-to-head competition to which the academic community at large was invited. Students received additional support in the form of lectures, recitation meetings, readings and access to an interactive multimedia learning system on relevant engineering and design topics (Crismond & Wilson, 1992). The early FIRST after-school robotics design competitions, which grew out of this MIT instructional model, initially used similar materials-constrained design tasks. With time, FIRST designers found this approach was proving difficult, especially for "rookie" teams new to the FIRST competitions. FIRST materials kits now contain complete subsystems (e.g., a transmission system did not need to be built from scratch) so that teams that want to can have a prototype robot up-and-running within four days of having opened the crate with the FIRST robotics building materials [Flowers, personal communication, 2007].

The above approaches are just a sampling from the literature which clearly show the use of scaffolded tasks and materials with projects that goes far beyond providing "minimally guided" instruction (Kirschner, Sweller, & Clark, 2006), and more resembles what Mayer (2004) calls "guided discovery." This can involve teacher modeling, collaborative work in teams, coaching with feedback, and as was seen in the undergraduate engineering programs described by Mann and others, an abundance of direct instruction to help students produce viable designs while developing in-depth disciplinary knowledge and skills.

The rest of this chapter will discuss two instructional approaches particularly suited to design-based PBL – creating design rules-of-thumb and doing diagnostic troubleshooting – both which help bridge the gap between engineering and science. To place these teaching strategies within the context of the pedagogical content knowledge that teachers need to know to use design tasks effectively, a table that synthesizes research in students' design thinking and learning will be introduced.

The Matrix of Informed Design

Although the research literature in engineering design expertise has grown steadily since Eastman (1970) carried out the first protocol analysis study of expert architects (Cross, 2000), research on learning progressions related to acquiring capability in engineering design is relatively undeveloped. In addition, teachers possess little "pedagogical content knowledge" (Shulman, 1986) needed to use design tasks effectively with students (Hynes, 2010), which includes, for example, awareness of design misconceptions and strategies for advancing the design capabilities of students of different ages and in various learning settings.

The Matrix of Informed Design (Crismond & Adams, 2010 (under revision); Crismond, 2005; Crismond, Lo, & Lohani, 2006) was developed as a representation of a teacher's pedagogical content knowledge in engineering design, and takes the form of a series of "contrasting set" statements (Bransford, Franks, Vye, & Sherwood, 1989) that highlight differences between how beginning versus informed designers think and behave (see Table 1). In the Matrix, "informed designers" are students who have some design experience, yet are far from being expert designers and can: learn while designing, make knowledge-informed design decisions, conduct sustained technological investigations, and use design strategies effectively. Each row of the Matrix represents a two-step learning progression expressing a different set of student behaviors that teachers can take note of and respond to during the course of instruction.

The two instructional strategies discussed in the remainder of this chapter can be situated within the Matrix of Informed Design. Formulating design rules-of-thumb falls under the purview of Matrix Pattern F, where students conduct confounded or valid experiments and interpret results while investigating the impact of changing design variables on a prototype's performance. Design-based troubleshooting is described in Matrix Pattern G, where designers focus attention on key problem areas when diagnosing and troubleshooting ideas or devices. Within the Matrix are design strategies that overlap with those used in scientific inquiry, as in Matrix Pattern B (research), part of Pattern D (modeling), Pattern H (working in teams) and Pattern J (thinking metacognitively). Other strategies more closely aligned with engineering design include Matrix Pattern C (brainstorming), the other part of Pattern D (sketching) and Pattern I (doing multiple iterations when designing).

MATRIX OF INFORMED DESIGN

Table 1. The Matrix of informed design displays 10 patterns of design behavior (Column 2) that contrast how beginning designers (Column 3) and informed designers (Column 4) do the same strategies or habits of mind

	Patterns	*Descriptions of patterns*	
	Beginning VS Informed designers	*What beginning designers do*	*What informed designers do*
Explore the Challenge	**A. Problem Solving VS Problem Framing**	Treat design tasks as well-defined problems and make decisions prematurely, often right after reading the design brief.	Delay making design decisions in order to explore, understand and frame the design problem.
	B. Skipping VS Doing Research	Skip doing research and instead pose or build solutions immediately.	Do research and hands-on investigations to learn more about the problem and possible solutions.
	C. Idea Fixation VS Idea Fluency	Get stuck on their first design ideas that they won't let go of.	Practice idea fluency via brainstorming, lateral thinking, idea incubation, etc.
	D. Surface VS Deep Drawing and Modeling	Sketch ideas or make models of devices that would not work if built.	Use words, drawings and models to investigate design ideas and explore how things work.
Choose, Test and Improve Ideas	**E. Ignore VS Balance Benefits and Tradeoffs**	Attend only to positive traits of favored ideas, and notice only drawbacks of lesser approaches.	Weigh both benefits and tradeoffs of all ideas before making design decisions.
	F. Confounded VS Valid Tests and Experiments	Do few or no prototype tests, or run confounded experiments when attempted.	Conduct and analyze valid experiments to learn about key design variables or to optimize product performance.
	G. Unfocused VS Diagnostic Troubleshooting	Use a generalized, unfocused way of observing when testing and troubleshooting prototypes.	Focus attention on key problem areas when diagnosing and troubleshooting ideas or devices.
Use Effective Design Habits	**H. Dysfunctional VS Collaborative Design Work**	Team members are uninvolved *OR* work in isolation *OR* individuals dominate group work and decision making.	Members of team collaborate and cooperate in performing different project roles and making key design decisions.
	I. Haphazard or Linear VS Managed and Iterative Designing	Designing is done haphazardly *OR* steps are done in a rigid sequence *OR* once in linear order.	Do design in a managed way, where ideas are improved iteratively via feedback, and strategies are used flexibly, in any order, as needed.
	J. Tacit VS Reflective Thinking	Do tacit designing with little self-reflection or monitoring of actions.	Practice reflective thinking by keeping tabs on design work and thinking.

Developing Design Rules-of-Thumb from "Fair-Test" Experiments

Most design process models make some mention of doing research and testing prototypes when possible. In the *Learning By Design*™ materials, later incorporated in the *Project-Based Inquiry Science* curriculum (Georgia Tech Research Corp, 2010), design teams planned and conducted experiments to learn about the impact that changing a single variable or subsystem had on a product's performance. Results from these "fair tests" were used to formulate design rules-of-thumb – recommendations or advice based on data from tests that are created to help designers make informed decisions – which then get shared with all teams so that groups do not have to conduct experiments on all key variables themselves.

Rules-of-thumb act as context-specific principles that guide good practice, but not all of them are derived from scientific experiments. Some are based on data collected about users' preferences or behaviors. When designing an independent power system for a house outside a public utility's electric grid (Paul, 1981), a rule-of-thumb for choosing to design an AC versus DC system relies on estimates of total expected wattage load and peak loads that are derived from observations of hourly usage. Others are more craft-based and get passed down from master to apprentice. The recommendation to design with pairs of bearings versus a single bearing or three or more bearings for the same rotating shaft (Crismond & Wilson, 1992), or select bucket elevators to move sticky or abrasive materials vertically and belt conveyors for high capacity or long-distance transports, can be explained by science, but were formulated before such explanations were available.

The *PBIS* curriculum scaffolds the development of design rules-of-thumb with a single-page worksheet that helps students structure their data collection and make statements that causally link variables tested with product outcomes. In the *LBD*™ model parachute design challenge, where students devise a chute from given materials that will take the most time to fall a given distance, students create design rules-of-thumb that relate chute performance with design variables like surface area of a canopy, canopy shape, number of canopy layers, weight of the chute system, string length, number of strings, and use of vent holes. Some features yield rules that are more straightforward to report than others, yet their investigation can still yield surprises. While students initially think that selecting the number of strings to use when making a parachute is quite critical, they come to realize that using 3–4 strings is fine, that adding more strings does little to improve performance, but that attaching only two strings to a canopy results in a collapsed chute when released. Other design variables are more complicated to describe, as when making the same change to a single variable produces opposing impacts on a product's performance. Adding a vent hole to a canopy, for example, dampens a chute's swaying behavior caused by the alternating vortices of turbulence that form behind the canopy as it passes through a column of air. This improves its performance, but also reduces the canopy's total surface area, which reduces air drag that leads to increased speed of descent. Dimensions, or better still, proportions, must be proposed by rule-of-thumb authors that optimize these two competing factors related to vent hole size.

Creating design rules-of-thumb that are both accurate and useful to other design teams making quite different designs can be challenging. Students must become skillful at filtering out "noise" in their experimental data in order to discern usable generalizations. During periodic reporting sessions that *PBIS* calls "Investigation Expos" and "Idea Briefings," teams share their rule-of-thumb statements and get feedback from other students and their teacher, and revise them until they communicate findings useful to the entire class.

Perhaps because of the excitement students feel when trying out new ways to improve their designs, they are prone to conducting confounded experiments, most typically by changing more than one element in their prototypes between design iterations. For instance, students can forget that by cutting a larger vent hole into a given canopy, they have also reduced the total mass of the system, and end up performing a confounded test. Attaching the paper remnants that came from cutting the larger hole into the canopy can keep the system's mass constant while varying only the vent hole size. Having students create rules-of-thumb can help them realize that controlling all but one variable during testing is an ongoing chore that requires creativity and a certain level of care and insight to tackle successfully.

Regarding the constructivist versus the direct instruction issue raised earlier, it is clear that both instructional approaches could be useful in helping students develop their own design rules-of-thumb. Research from Klahr and Nigam (2004) has shown that the Control of Variable Strategy can be taught to a greater number of children through direct instruction, and that the capacity of students who learned CVS via discovery and direct instruction to transfer this knowledge to new contexts months later was independent of these learning pathways. Direct instruction of CVS would need to be complemented, however, with scaffolds and supports that help students do the more ill-defined tasks of framing their approaches to the design challenge, and combining multiple and even conflicting rules-of-thumb when formulating and refining an optimal final product.

Troubleshooting in Engineering Design

Most authors agree that a fundamental distinguishing feature that separates science and engineering is that science uses methods to build and test knowledge about the natural world, while engineering seeks to develop insights helpful in creating systems and products to meet human needs (NRC, 1996). Ideas for products and systems only very rarely arrive in their final form when first conceived. Experienced designers know that first prototypes often fail when built and tested, and look or work in ways not originally envisioned. Design ideas and prototypes need constant troubleshooting, where flaws, glaring or subtle, get found and fixed. Diagnostic troubleshooting is an important yet understudied procedure in designing, one with strong links to inquiry in science, and when emphasized in instruction that accompanies design-based PBL can help bridge science and engineering learning in K-16 education.

Numerous studies have been carried out regarding the first of two basic categories of troubleshooting, involving diagnosing and fixing devices and systems that were once operational but no longer work (Rasmussen, 1984; Morris & Rouse, 1985). Such "classic" troubleshooting involves well-defined and studied systems, and the use of established troubleshooting heuristics to remedy known problems (Jonassen & Hung, 2006). Technicians can rely upon remembered cases of previous repairs, refer to troubleshooting flowcharts that they have been trained to use, and when unfamiliar problems present themselves, use their knowledge of a device's physical layout and the causal knowledge of how parts and subsystems interact to fix the device or system.

The troubleshooting that designers do is fundamentally different from classic troubleshooting, and has been little studied by ETE researchers despite it being a process central to engineering design. Design-Based Troubleshooting [DBT] involves diagnosing and fixing the problematic parts of envisioned but not-yet-developed systems, or prototypes that are undergoing continuous re-design and development. DBT is described in the Matrix of Informed Design's Pattern G (see Table 1), which states that beginning designers "use a generalized, unfocused way to troubleshoot ideas during testing" while informed designers "focus attention on key problem areas when diagnosing and troubleshooting ideas or devices."

The driving force for conducting the following study of students' DBT thinking was a disturbing pattern that I noticed across the grades while I videotaped students doing design tasks for an NSF-funded teacher professional development project, *Design In The Classroom* (99–86854). I regularly observed that when certain students tested their prototypes – the model parachute described earlier is a prime example – they would have their noses pointed at a stopwatch or some other tool for doing instrumented observations, and were not noticing how their chutes were actually *behaving* during descent. Through such practices, these students missed noticing the flawed performance of their imperfect prototypes. This might help explain why some designers made few or no changes even when given the opportunity to do multiple design iterations. This phenomenon, where final designs resemble first prototypes, has been called idea fixation by Sachs (1999) and "functional fixedness" by Cross (2000), and is considered a widespread problem with beginning and expert designers alike.

A study that focused on DBT was conducted in Spring 2007 with 41 eighth-grade students who did three month-long design tasks as part of their coursework for an engineering class that was co-taught by a physics and technology education teacher in Columbia, MO (five others were dropped because of absences). Although neither teacher was an engineer by training, both had years of experience using design activities and co-teaching together. At the end of the year-long course, students first designed model parachutes, then bottle rockets with passively deployed parachutes, and finally small- and then larger-scaled trebuchets (Crismond, 2008). Photos and videos were taken of the final tests of these products and were evaluated by blind external reviewers who had experience teaching with these design challenges. The main research question asked in this study was whether students' performance of individual or combined elements of DBT were correlated with quality ratings of their final products.

In the design-based troubleshooting sequence (see Table 2), the first two steps of DBT are clearly linked to inquiry (Elstein & Schwartz, 2002), while the third step requires science and engineering ideas and a mental model of how the device works. Adding the last step – where the designer suggests ways to improve the device – transforms what has thus far been an analytic act of diagnostic reasoning and an inquiry task of noticing and naming problems and proposing possible explanations for those problems (hypothesizing), into an act of designing, since students are asked to devise ways to change and hopefully improve the product.

Table 2. The 4-step diagnostic troubleshooting protocol combines inquiry-related diagnostic reasoning with a final step where ideas for improving the product are proposed

Design-Based Troubleshooting	Observing	How did the device behave during testing? What did you notice?
	Diagnosing	What names would you give to any problems with product performance that you noticed, if any?
	Explaining	Why do you think the problem occurred or the device behaved as it did?
	Fixing	How might you change the design to fix the problem and improve the product?

The instructional sequence below for the parachute design challenge that emphasized DBT was representative of the other two design tasks. Students were first introduced to the challenge – to create a parachute that took the longest time to fall a given distance – and were then divided up into teams of four (on average) and asked to build-and-test a basic parachute and discover some key variables that would impact the chute's performance. They then watched short video clips of pre-recorded parachute drops, first at regular speed and then in slow motion, where each clip displayed an obvious and different problem (e.g., canopy collapsing or never inflating, excessive oscillation, unbalanced load, uneven string tension, etc.). Students were asked to tell what they noticed during the drop, what name they might give the problem, and why the problem might be occurring. Students were then asked to propose ways of fixing these problems, which they would subsequently test and revise again for a number of design iterations.

The teams then began their work, shared design rules-of-thumb based on their experiments, and were periodically selected to give answers to the DBT protocol while watching parachute drops of other teams that had been recorded and the tests of their current prototypes. The quality of students' diagnostic reasoning and science content knowledge about how their devices work were rated by two scorers trained in using a rubric for assessing these comments. At the conclusion of the unit, videos of final product tests were also recorded. A different pair of evaluators, one a mechanical engineer and another a technology education teacher, did a blind review of trebuchet prototypes, based on photographs and videos that had been taken, and of the final trebuchet tests that were conducted in the school's parking lot. The quality of final trebuchets was scored using a 10-point scale based on the product's function (3 points), behavior (3 points), structure (2 points), economy (1 point) and aesthetics (1 point). Students' content knowledge was rated based on answers they gave to questions related to how things work (e.g., How do key design variables impact product performance?); systems thinking (How would you divide up the model trebuchet into a number of subsystems?); and design thinking (What changes did you make between the first and final prototype and why?).

When taped interviews of three randomly selected teams from the class were studied, four levels of DBT capability were noted. Top-level troubleshooters spontaneously focused their attention on problematic portions of the device, and predicted the impact the flaw they noted might have on the prototype's performance and why. Second-tier troubleshooters pointed out similar problematic behaviors and could identify their causes, but were less confident that what they had noticed were real problems. At the third level of DBT performance, subjects identified fewer specifics in their observations, and were less precise in zooming in on problem areas because of device misconceptions they held. The least capable troubleshooters noticed very few critical events during prototype tests, and had imprecise and vague explanations for how and why devices behaved as they did.

Scores for the four components of DBT capabilities of three teams were rated, and scores for the four components were tallied and correlated with the overall quality scores of the teams' final products. Teams varied in the number of prototypes they created before building their large-scale final trebuchets, the number of non-trivial feature changes they made between the prototypes and the final product, and the ability to make connections spontaneously to science topics when explaining their design decisions and how the devices work.

While the analysis of the small number of cases presented in Table 3 cannot yield valid generalizations about larger populations of designers, the following trends were noted in the three teams studied. All three groups made accurate observations during prototype tests, although Team B with its top-level troubleshooter had a higher score than the other teams. The score for providing an accurate diagnosis was also highest with Team B, but Team I outscored Team G in this aspect of DBT. Interestingly, the explanations teams gave for how the products worked and behaved seemed most predictive of higher-quality designs. The "fixes" that all three teams provided were of good quality, although Team I suggested fewer changes than the other two. Prior knowledge also played a role in the remedies teams proposed – the member of Team B who knew about bushings emphasized how reducing friction in the throw arm might improve the throw's accuracy, and addressed this issue in his team's final design.

Teams did DBT work throughout all phases of their designing. The four-step protocol helped structure interviews and support students in improving their products while revealing gaps in students' thinking. The prediction that poor DBT was connected to proposing fewer changes over multiple design iterations and producing lower quality products was not well supported by these data. Better supported was the role that understanding how the product works plays in students developing better designs.

Table 3. Data shows aggregated scores for three teams of 8th-grade designers doing the four elements of design-based troubleshooting and the quality scores for final designs

Team	*Observing (0–1)*	*Diagnosing (0–1)*	*Explaining (0–1)*	*Remedying (0–1)*	*Total DBT score (0–4)*	*Product quality (0–10)*
B	0.78	0.85	0.70	0.80	<u>3.13</u>	**6.0**
G	0.60	0.55	0.56	0.80	<u>2.51</u>	**5.9**
I	0.68	0.70	0.45	0.70	<u>2.53</u>	**4.4**

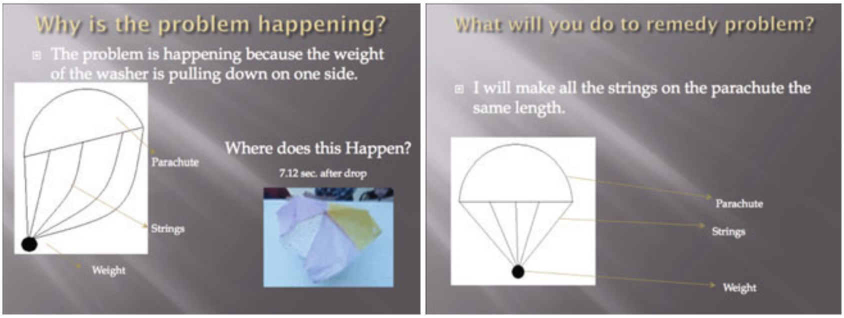


Figure 3. Students used Powerpoint to create presentation portfolios that displayed their design-based troubleshooting thinking via voice-over annotations of prototype tests, and communicate students' suggestions for improvements to their next design iterations

In a more recent study involving another group of eighth-graders from Columbia, MO, who took the same engineering course and faced the same three design tasks, students used small digital recorders to create video clips of their prototype tests, and then captured their own audio commentary as they replayed and watched their tests. They did a frame-by-frame analysis of their parachutes' behaviors during descent, with some indicating the precise moment when they thought their prototypes showed the first signs of trouble. Students then edited these materials and included them in a PowerPoint file (see Figure 3), which acted as an electronic portfolio system for their evolving design work and thinking. By knowing the behaviors that they wanted their chutes to exhibit, and practicing effective DBT thinking, students were able to ask the powerful design question, "What do I change so that my product will perform *this* way?"

SUMMARY

Advocates of PBL have explored ways to create meaningful understandings of STEM ideas and skills in students by having them solve problems and projects, including design tasks, that range from the well- to the ill-defined, are set within contexts that students consider authentic and sometimes cross disciplinary boundaries. Two learning outcomes are relevant to doing informed design and contain elements of both scientific inquiry and engineering design are described in this chapter. Design rules-of-thumb are contextualized generalizations that link the effects of varying product features with performance outcomes, and lie somewhere in the middle of a continuum that on one end holds abstractions of science and engineering science (e.g., Newton's Laws of Motion; Hook's Law), and on the other end craft-like recipes for effective practice. Their use can complement the case-based reasoning and deductive thinking that designers employ when making informed design decisions. Diagnositic troubleshooting is a critical design strategy that is essential for designers to use in order to improve ideas and prototypes over multiple iterations.

The dilemma of using constructivist or direct instruction approaches (Wiggins & McTighe, 2005) to achieve will likely inspire debate long into the future, and may only be resolved when researchers and teachers can place “thinking caps” on learners and get real-time imaging of actual neural activity to reveal differential impacts of different instructional interventions. Until that time comes, educators who want to use design projects to teach STEM subjects should weigh the benefits and tradeoffs of each approach (see Matrix Pattern E) before making their instruction choices, and as well should look to future research to inform this longstanding debate.

Such research should clearly articulate the operational definitions and “vector of instructional components” for all approaches being considered, as Klahr has recently suggested (2010), and assess their impacts on gains in students’ STEM learning and capacity to do “informed designing.” I would add that testing with “impoverished” forms of any instructional approach should be avoided. Asking students to design without scaffolding, where in essence students would need to invent the mechanical elements needed to construct a device, or discover laws of physics and engineering based on experiments they run, has little chance for success or value as research that can inform classroom practice. The smart use of scaffolding is a must when doing and testing design-based project work, as it has been with other flavors of PBL (Hmelo-Silver, Duncan, & Chinn, 2007).

The direct instruction treatment in this proposed study might include strategies like simply reading about the engineering design process (Atman and Bursic, 1996), cognitive tutoring, providing subjects finished models of designed products and worked examples showing the thinking of experts doing design tasks. The constructivist treatment in the proposed research might use materials developed in line with the three curriculum design principles that Kanter (2010) describes for building meaningful science understandings with design projects. These include: (a) motivating students with a need to learn key STEM concepts, (b) helping students construct these ideas via first-hand experiences, and (c) helping students structure their new knowledge for successful retrieval when designing.

The pedagogical recommendations associated with re-introducing design courses into undergraduate engineering programs that were made by a small group of engineering educators in the early 1960s in effect identified an Achilles heel of direct instruction of the day and attempted to redress it. The flaw may relate to a problem of a certain type of transfer – a review of the transfer literature as it relates to ETE can be found in chapter No. four in this volume, contributed by Johnson, Dixon, Daugherty and Oenardi. Students in the 1960s who developed proficiency in solving well-defined problems did mainly tasks involving *analysis* (e.g., solving end-of-chapter problems in a heat transfer course), but very little *synthesis,* which is a central component to design thinking (Jones, 1984, p. 63). What the Committee on Engineering Design (1961) described as lacking in engineering undergraduates whose training mainly involved solving well-defined engineering science problems was that they had not developing intellectually and attitudinally to deal with the risks, uncertainties and challenges of solving ill-defined design problems and projects. What they recommended was not to replace engineering science with design, nor to continue with the engineering science *status quo*, but to employ a hybrid approach that involved the scheduling and coordination of both kinds of courses and instruction.

The constructivist versus direct instruction dilemma and debate has ignored this third pedagogical option and potential treatment for the proposed study – the use of a hybrid approach that combines the two instructional methods.

The research being proposed here should therefore also test a "multi-attribute" hybrid instructional treatment, one that blends constructivist and direct instruction approaches. Subjects in the hybrid group at times might explore materials to build connections with prior knowledge and face the challenge of proposing and constructing new ideas. At other times, they would experience direct instruction to build relevant science and engineering science ideas in long-term memory so that they could produce meaningful explanations regarding how their devices do and do not work. Among the teaching strategies that might be included in this third treatment would be approaches that bridge inquiry and design and support students in developing and using design rules-of-thumb and doing effective diagnostic troubleshooting.

The proposed research study would report on the degree to which each of the three instructional approaches – constructivist, direct instruction and hybrid – helped students in schools learn STEM disciplinary knowledge and skills, and gain confidence and self-efficacy in addressing and completing design projects. Such research would be critical to ETE practitioners because it could help them better prepare students to engage in similar enterprises with competence in the workplaces of the future.

REFERENCES

Atman, C. J., & K. M. Bursic. (1996). Teaching engineering design: Can reading a textbook make a difference? *Research in Engineering Design*, *8*, 240–250.

Barak, M., & Raz, E. (2000). Hot-air balloons: Project-centered study as a bridge between science and technology education. *Science Education*, *84*(1), 27–42.

Barlex, D. (1995). *Nuffield design and technology student's book*. Harlow: Longman.

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., et al. & the Cognition and Technology Group at Vanderbilt. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. *The Journal of the Learning Sciences*, *7*(3&4), 271–311.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-Based Learning: An approach to medical education*. New York: Springer Publishing Company.

Black, P. (2008). Strategic decisions: Ambitions, feasibility and context. *Educational Designer*, *1*(1). Retrieved on January 18, 2010, from http://www.educationaldesigner.org/ed/volume1/issue1/article1/

Bereiter, C., & Scardamalia, M. (2000) Commentary on part I: Process and product in problem-based learning (PBL) research. In D. Evensen & C. Hmelo (Eds.), *Problem-based learning: A research perspective*. (pp. 185–195). Mahwah, NJ: Lawrence Erlbaum Associates.

Bransford, J. D., Franks, J. J., Vye, N. J., & Sherwood, R. D. (1989). New approaches to instruction: Because wisdom can't be told. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 470–497). New York: Cambridge University Press.

Cognition and Technology Group at Vanderbilt [CTGV]. (1992). The Jasper Series as an example of anchored instruction: Theory, program description, and assessment data. *Educational Psychologist*, *27*(3), 291–315.

Committee on Engineering Design. (1961). Report on engineering design. *Journal of Engineering Education*, *51*(8), 645–660.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, *24*, 87–114.

Crismond, D. (2005, April 4). *Design strategies table: Identifying and contrasting behaviors of beginner versus informed designers*. Invited Paper at NSF's Special Interest Session: Research on Design in Technology and Engineering, ITEA 67th annual conference, Kansas City, MO.

Crismond, D. (2006, October 9–12). *Design's different uses in science, technology education and math classrooms: Case studies from the US*. Invited Paper for the 5th Global Colloquium on Engineering Education, Rio de Janeiro, Brazil.

Crismond, D. (2008, June 22–25). *Case studies of diagnostic reasoning's role in engineering design*. Paper presented at the ASEE annual conference & Exposition, Pittsburgh, PA.

Crismond, D., & Adams, R. (article under revision, 2010). Beginning designers' perceptions of their performance and the impact of selected designer strategies on design work. *Journal of Engineering Education*.

Crismond, D., Lo, J., & Lohani, V. (2006, April 7–11). *Beginning designers' perceptions of their performance and the impact of selected designer strategies on design work*. Paper presented at the National AERA Conference, San Francisco.

Crismond, D., & Wilson, D. G. (1992, November 11–14). *Designing an evaluation of an interactive multimedia program: Assessing MIT's EDICS*. Proceedings of 22nd Annual IEEE Frontiers in Education conference, Nashville, Tennessee (pp. 656–661).

Cross, N. (2000). *Engineering design methods: Strategies for product design* (3rd ed.). New York: John Wiley & Sons.

Davidson, M., Evens, H., & McCormick, R. (1998). Bridging the gap: the use of concepts from science and mathematics in design and technology at KS 3. *IDATER'98*, 48–53.

Eastman, C. (1970). On the analysis of intuitive processes. In G. T. Moore (Ed.), *Emerging methods in environmental design and planning* (pp. 21–37). Cambridge MA: MIT Press.

Elstein, A. S., & Schwarz, A. (2002). Evidence base of clinical diagnosis: Clinical problem solving and diagnostic decision making: selective review of the cognitive literature. *British Medical Journal*, *324*, 729–732.

Fortus, D., Dershimer, R. C., Krajcik, J. S., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching*, *41*(10), 1081–1110.

Georgia Tech Research Corporation. (2010). *Project-based inquiry science: Teachers planning guide*. Armonk, NY: It's About Time, Herff Jones Company.

Hacker, M., & Burghardt, D. (2004). *Technology education: Learning by design*. Boston: Pearson.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Swell, and Clark. *Educational Psychologist*, *42*(2), 99–107.

Hsiung, C. M. (2010). Identification of dysfunctional cooperative learning teams based on students' academic achievement. *Journal of Engineering Education*, *99*(1), 45–54.

Hynes, M. M. (2010 (in press)). Middle-school teachers' understanding and teaching of the engineering design process: A look at subject matter and pedagogical content knowledge. *International Journal of Technology and Design Education*.

Johnson, D. W., & Johnson, R. T. (1999). Making cooperative learning work. *Theory into Practice*, *38*(2), 67–73.

Johnson, R. T., & Johnson, D. W. (2002). *Joining together: Group theory and group skills*. Boston: Allyn Bacon.

Jonassen, D. H. (2003). *Learning to solve problems: An instructional design guide*. San Francisco: Pfeiffer.

Jonassen, D. H., & Hung, W. (2006). Learning to troubleshoot: A new theory-based design architecture. *Educational Psychology Review*, *18*(1), 77–114.

Kanter, D. (2010). Doing the project and learning the content: Designing project-based science curricula for meaningful understanding. *Science Education*, *94*(3), 525–551.

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

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.
Knoll, M. (1997). The project method: Its vocational education origin and international development. *Journal of Industrial Teacher Education*, *34*(3), 59–80.
Klahr, D. (2010). Coming up for air: But is it oxygen or phlogiston? *Education Review*, *13*(13).
Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction: Effects of direct instruction and discovery learning. *Psychological Science*, *15*(10), 661–667.
Kolodner, J., Gray, J., & Fasse, B. (2003). Promoting transfer through case-based reasoning: Rituals and practices in learning by design classrooms. *Cognitive Science Quarterly*, *3*(2), 119–170.
Krajcik, J., Blumenfeld, P. C., Marx, R. W., Bass, K. M., Fredericks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *Journal of Learning Sciences*, *7*(3&4), 313–350.
LaPorte, J., & Sanders, M. (1993). Integrating technology, science, and mathematics in the middle school. *The Technology Teacher*, *52*(6), 17–21.
LaPorte, J., & Sanders, M. (1996). *Technology science mathematics*. New York: Glenco/McGraw-Hill.
Layton, D. (1993). *Technology's challenge to science education*. Buckingham, UK: Open Univ. Press.
Loepp, F. (1999). Models of curriculum integration. *Journal of Technology Studies*, *25*(2), 21–25.
Mann, R. (1962, September 5–7). *Design and experiment - scope and reality*. Paper given at the Education for Engineering Design conference, UCLA.
Mann, R.W. (1981). Engineering design education: U.S. – retrospective and contemporary. *Journal of Mechanical Design*, *103*, 696–701.
Mayer, R. E. (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.
Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*, 81–97.
Morris, N. M., & Rouse, W. B. (1985). Review and evaluation of empirical research in troubleshooting. *Human Factors*, *27*(5), 503–530.
National Research Council [NRC]. (1996). *National science education standards*. Washington, DC: National Academy Press.
National Research Council [NRC]. (2010). *New national science education standards*. Washington, DC: National Academy Press (draft in work).
Paul, T. D. (1981). *How to design an independent powers system*. Necedah, WI: Best Energy Systems for Tomorrow.
Putambekar, S., & Kolodner, J. (2005). Towards implementing distributed scaffolding: Helping students learn science from design. *Journal of Research in Science Teaching*, *42*(2), 185–217.
Rasmussen, J. (1984). Strategies for state identification and diagnosis in supervisory control tasks, and design of computer-based support systems. *Advances in Man-Machine Systems Research*, *1*, 139–193.
Reiser, B. J., Tabak, I., Sandoval, W. A., Smith, B. K., Steinmuller, F., & Leone, A. J. (2001). BGuILE: Strategic and conceptual scaffolds for scientific inquiry in biology classrooms. In S. M. Carver & D. Klahr (Eds.), *Cognition and instruction: Twenty-five years of progress*. Mahwah, NJ: Erlbaum.
Sachs, A. (1999). Stuckness in the design studio. *Design Studies*, *20*(2), 195–209.
Salomon, G., & Globerson, T. (1989). When teams do not function the way they ought to. *International Journal of Educational Research*, *13*(1), 89–99.
Scott D. J., Dixon, R., Daugherty, J., & Lawanto, O. (2011). General versus specific intellectual competencies: The question of learning transfer. In M. Barak & M. Hacker (Eds.), *Fostering Human Development Through Engineering and Technology Education* (pp. 55–71). Rotterdam: Sense Publishers.
Shulman, L. S. (1986). Those who can understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.
Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005). Pedagogies of engagement: Classroom-based practice. *Journal of Engineering Education*, *96*(1), 87–101.

Ullman, D. G. (1997). *The mechanical design process*. Boston: McGraw Hill.

Ullman, D. (1992). Research in design thinking. In N. Cross, K. Dorst, & N. Roozenburg (Eds.), *Research in design thinking*. Proceedings of a Workshop Meeting held at the Faculty of Industrial Design Engineering, Delft University of Technology, The Netherlands, May 29–31, 1991. Delft: Delft University Press.

Wiggins, G, & McTighe, J. (2005). *Understanding by design* (2nd ed.). Upper Saddle River, NJ: Pearson/ Merrill Prentice Hall.

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.

David P. Crismond
School of Education, City College
City University of New York
USA

MICHAEL HACKER AND JAMES KIGGENS

14. GAMING TO LEARN

A Promising Approach Using Educational Games to Stimulate STEM Learning

OVERVIEW

This chapter addresses how playing and developing educational games are instructional strategies that could add immeasurably to the contribution ETE programs make to contemporary STEM education.

The introduction to this chapter presents a rationale for game-based learning that addresses the changing perceptions and capabilities of youth in the present era and provides research-based support for the high-interest learning that gaming has the potential to promote.

The promise of playing and designing/developing thoughtfully conceived games is described in terms of increasing student engagement, promoting inquiry-based learning, the effect on self-efficacy, attitudes toward further ETE study and stimulating interest in related STEM careers.

Criteria for game design are proposed that would make games appealing to all learners, including students typically underrepresented in STEM courses and careers.

The chapter concludes with a discussion of the challenges posed by the widespread implementation of gaming to learn strategies. These challenges include: a) the gulf between the promise of gaming in theory and the availability of effective games to use; b) the considerable professional development needs (both pre-service and in-service) that must be addressed; and c) the influence of strategies required for widespread adoption (institutional challenges such as building stakeholder support and changing stakeholder perceptions, and technical challenges such as hardware and software availability, firewall issues, etc.).

INTRODUCTION

Even before the landmark study *A Nation at Risk* was published in 1983, policy-makers and educators were addressing the disparity between existing student and worker capabilities and those needed to maintain national pre-eminence (NCEE, 1983). Today, the educational imperative is made all the more daunting by the exponential rate of change in information and communication technology (ICT), the impact of globalization and the uncertainty in the global economy. A bright spot is the multibillion-dollar video and computer game industry, which has a vast global

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 257–279.

audience and is one of the fastest-growing industries in the United States. What is particularly salient for educators is how the facility of today's students with gaming, simulation and interactive communication is reframing their interests and educational expectations.

Our student body has changed more dramatically than in any similar time period in history; for them, interactive learning is the new learning paradigm. Of the total American teen student population (Junco & Mastrodicas, 2007):

- 93% use the Internet and 84% own a cell phone
- 66% use text messaging
- 75% have a Facebook profile and most check it daily
- 34% use websites as their primary source of news
- 44% read blogs and 28% author a blog

According to the Pew Internet and American Life Project, virtually all American teens play computer, console or cell phone games, and the gaming experience is rich and varied, with a significant amount of social interaction and potential for civic engagement. According to this Project (Lenhart et al., 2008):

- Gameplaying is universal, with almost all teens playing games and at least half playing games on a given day.
- Gameplaying experiences are diverse, with the most popular games falling into the racing, puzzle, sports, action and adventure categories.
- Gameplaying is also social, with most teens playing games with others at least some of the time, and it can incorporate many aspects of civic and political life.

DEVELOPING TRANSFERABLE COGNITIVE SKILLS

In response to the ongoing changes required in order to compete in the global economy, employers are demanding transferable skills that are typical outcomes promoted by learning games.

Of significant importance to STEM educators is that the meta-skills (skills that enable gaining more skills) enhanced by game development (knowledge integration, mathematical reasoning, logical and systems thinking, applying ICT skills and programming concepts, applying the design process) are exactly those transferable abilities that are in high demand and can offer students access to promising career and entrepreneurial opportunities (I Support Learning, 2010). An imperative for the use of digital game-based learning in the classroom is that skills such as how to interact with people and collaborate with team members can be embedded authentically in game design experiences.

WHY VIDEO GAMES ARE SO POPULAR

A video game is comprised of three main components: (1) a non-trivial objective; (2) rules; and (3) gameplay. The phenomenal success of entertainment video games is due to the deep engagement that players develop through games that are well matched to player motivation. Within the game development industry, players are identified by type and demographic (Bartle, 1996), and games are designed purposefully to appeal to a given player in a given genre on a given platform. The nature of this engagement can range from a player spending many hours a week joining the millions of players who participate in massively multiplayer online games, such as the community of more than16 million people playing World of Warcraft, or a player spending an equal amount of time playing simple but highly engaging casual games such as Trism (iPhone), Tetris (Web/DS) or Farmville (Web/Facebook).

THEORETICAL FRAMEWORK

Perceptual Control Theory and Flow Theory

Research on human learning helps explain why computer games are so appealing. Perceptual Control Theory (PCT) presumes that humans are essentially intricate control mechanisms and are goal-driven. PCT provides a framework that explains why young people are riveted by games with clear goals, where they recognize that intervention is possible and where their actions provide immediate and understandable feedback (Powers, 1973). Flow theory (Csikszentmihalyi, 1990) describes the state in which people are so involved in an activity that little else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it. The two principal characteristics of flow are: (1) total concentration in an activity; and (2) the enjoyment derived from the activity. Flow involves an optimal level of challenge. Tasks that are too difficult create anxiety and frustration. Tasks that are too easy create boredom. Additionally, flow is characterized by control over the environment.

Computer games are captivating because they satisfy PCT and flow theory criteria. They encourage total concentration. Participants can derive great enjoyment and fulfillment from the activities. The level of challenge can be adapted to the user's skills so that the user controls the computer-generated environment and gets immediate feedback. Youth in the Internet generation are demanding educational experiences that involve interactive, motivational online learning activities (Aldrich, 2004), and the learning environment must change to be relevant to students whose use and knowledge of technology is rapidly rendering the traditional classroom obsolete.

GAME GENRES AND PLATFORMS

A video game is widely understood to be a "game mediated by a computer" (Adams and Rollings, 2007). Video games for entertainment have a diverse range of genres, including role-playing (RPG), real-time strategy (RTS), first-person shooters (FPS), action (including a popular type called "platformers"), puzzle, sports, racing and massively multiplayer online games (MMOG), to name just a few. Table 1 depicts game genres by order of popularity ratings by teens who report playing games in that genre (Lenhart et al., 2008).

The games are played on a wide array of hardware platforms, including consoles (Microsoft Xbox 360, Sony Play Station 3, Nintendo Wii), personal computers and hand-held devices (Sony PSP, Nintendo DS). These entertainment games are delivered to the hardware platforms through a diversity of techniques, including retail

Table 1. Game genres in order of teen popularity

Genre examples	*Player popularity rating*
Racing (NASCAR, Mario Kart, Burnout)	74
Puzzle (Bejeweled, Tetris, Solitaire)	72
Sports (Madden, FIFA, Tony Hawk)	68
Action (Grand Theft Auto, Devil May Cry, Ratchet and Clank)	67
Adventure (Legend of Zelda, Tomb Raider)	66
Rhythm (Guitar Hero, Dance Dance Revolution, Lumines)	61
Strategy (Civilization IV, StarCraft, Command and Conquer)	59
Simulation (The Sims, Rollercoaster Tycoon, Ace Combat)	49
Fighting (Tekken, Super Smash Brothers, Mortal Kombat)	49
First-Person Shooters (Halo, Counter-Strike, Half-Life)	47
Role-Playing (Final Fantasy, Blue Dragon, Knights of the Old Republic)	36
Survival Horror (Resident Evil, Silent Hill, Condemned)	32
MMOGs (World of Warcraft)	21
Virtual Worlds (Second Life, Gaia, Habbo Hotel)	10

box sales (DVD, CD, BlueRay), Web downloadable games, Massively Multiplayer Online games (MMO), and mobile/hand-held games, such as those developed for Nintendo DS, Nintendo Game Boy, Sony PSP, Sega Game Gear, Nokia N-Gage, iPod and other PDAs, and mobile phones.

SERIOUS GAMES

Serious games are widely understood to be video games used for purposes other than entertainment. According to Sawyer and Smith (2008), Serious Games are organized by genre and include (among others) education, training, health, advertising and persuasion. The most current generation of Serious Games for education (also described as digital game-based learning) is now almost a decade old and there are a great number of successful "commercial off-the-shelf" (COTS) titles relating to various disciplines, including those shown in Table 2:

Table 2. Examples of serious games for education

Discipline	*Game title*
Biology	*Metablash! Virtual Cell*
Ecology	*Operation: Resilient Planet*
General Science	*Science Pirates: The Curse of Brownbeard*
	Conspiracy Code
History	*Discover Babylon (fas.org/Babylon)*
	River City
	Making History
	Peacemaker
	Global Conflict: Palestine
Health	*Re-Mission*

Table 2. (Continued)

Math	*DimenxianM* for algebra *NIU-Torcs* for numerical methods *Lure of the Labyrinth*
Management	*Virtual U*
Mechanical Engineering	*Time Engineers*
Network Engineering	*Mind Share*
Physics	*Crayon Physics* *Physicus* *Coaster Creator* *Phun*

Over the last decade, Serious Games have advanced as proprietary trainers, and educational researchers have demonstrated that it was possible to leverage the hugely successful design conventions of entertainment games to develop learning games with objectives, rules and gameplay that present complex, situated decision structures where players learn by doing through an ideal use of constructivist pedagogy. Serious games for education are most effective when the game goals and the learning goals are innately meshed. The same is true for the gameplay and learning activities, which are indivisible in effective games. Under these conditions, achievement in the game is directly measurable as the achievement of intended learning outcomes.

Digital game-based learning goals require many important skills, including systems thinking, problem solving, information tracking and resourcing, collaborative information sharing, leadership, teamwork and communication. Effective educational games anchor learning through authentic tasks and environments, and encourage learners to explore and experiment with alternatives, thus deepening their understanding of the concepts to be learned.

Serious games have achieved visibility and traction in education, elevated by significant, though limited, recent research that supports their effectiveness. This includes research that concludes that digital game-based learning can dramatically reduce the learning divide between high- and low-achievers in the classroom (Kebritchi, Hirumi, & Bai, 2010).

THE PROMISE OF SERIOUS GAMES IN EDUCATION

The use of serious gaming is a logical approach in the maturation of curriculum. It can add a riveting, contemporary dimension to engineering and technology education programs, making them attractive to a wider pool of students, including females, and can keep education relevant to students in an age where information and communication technology has become the dominant technological paradigm. Infusing gaming into the school curriculum will promote a contemporary and systemically transformative educational model that would fast-forward the ETE movement.

DimensionM™ from Tabula Digita

The West Virginia Department of Education provided *DimensionM*™ from Tabula Digita to 1,000 students from seven middle and high schools across four counties in West Virginia. Research from the University of Central Florida (UCF) relating to the use of one of the *DimensionM*™ games (Dimenxian) reported that "immersive educational video games can improve students' mathematics understanding and skills, and significantly raise scores on district-wide math benchmark exams." These research findings investigated the effects of modern math computer games on learners' math achievement and math course motivation in public high school settings. In eight studies pertaining to math-related computer games, six were found to positively affect students' mathematics learning and two were found to have "mixed" results (Kebritchi et al., 2010).

In the games, key objectives are covered through a series of highly immersive action-adventure missions. Educational video games contain 3D graphics, sound, animation and storylines comparable to the quality of those in popular entertainment video games.

The UCF study, conducted by a team of faculty and graduate students at the university, consisted of algebra and pre-algebra students and 10 teachers, all from Orange County, Florida. Experimental and control groups were used to test the researchers' hypotheses and were evaluated using pre- and post-study district benchmark exams, game preparation tests, surveys, classroom observations and personal interviews. Students in the experimental group of 193 high school students who played the Tabula Digita video games over an 18-week period scored significantly higher on district math benchmark tests than students in the control group who did not play the video games. In fact, the increase in scores for the test group was more than double the increase in scores for the control group. The higher achievement scores and greater gain scores on the district benchmark tests by students who played the games are particularly significant since a high correlation exists between the district's math benchmark tests and the statewide math component of Florida's Comprehensive Assessment Test (FCAT).

According to the teachers involved in the study, the games were effective teaching and learning tools because they were experiential in nature, offered an alternative way of teaching and learning, and gave the students reasons to learn mathematics to solve the game problems and make progress in the games. The teachers also commented that the games helped address students' math phobias and increased time on task. As one teacher states, "it (the games) makes them want to learn (math)."

Immune Attack from the Federation of American Scientists

With funding from the US National Science Foundation (NSF), the Federation of American Scientists (FAS) developed the video game *Immune Attack* to immerse 7^{th}–12^{th} graders into the microscopic world of immune system proteins and cells. *Immune Attack* is digital game-based learning targeted at improving the understanding of cellular biology and molecular science. Research conducted on the use of this game with 180 students, 7^{th} graders, has shown that students who play it show significant gains in confidence with molecular science-related material and in their knowledge of cellular biology and molecular science (Yarbrough & Fleischman, 2009).

In May 2008, *Immune Attack* was made available for free download on the FAS website (See FAS Website in reference list). *Immune Attack* has been downloaded by over 9,000 people. Five hundred teachers have registered to evaluate *Immune Attack* in their classrooms (FAS, 2010).

Whyville from Numedeon

Whyville is a digital game-based online learning community for children aged 8 to 15. Of these users, 67% are female, a demographic that is difficult to interest in science and math. Numedeon Inc. launched *Whyville* in 1999 and continues to add educational activities based on an inquiry approach to learning, with learner-centered, hands-on learning activities for art history, science, journalism, civics, economics, and more. *Whyville* works directly with the Getty, NASA, the School Nutrition Association and the Woods Hole Oceanographic Institution.

Game Development as an Equitable Instructional Strategy

Gaming is an innovative teaching strategy that can particularly support under-represented student populations in expanding their awareness of and educational preparation for viable, contemporary STEM careers. Properly selected curriculum design criteria (see Table 3) can maximize the appeal of educational games to females, who tend to be drawn to topics and contexts relating to people's needs and concerns, environmental issues, interpersonal relationships and real-life settings (NSF, 2003). Game environments naturally transcend barriers of language, geography, race, gender and physical abilities, and online games will ensure access to all students.

The gender and racial gap in STEM programs appreciably limits the pool of potential workers and is a serious concern threatening the nation's intellectual and economic competitiveness (Mendoza and Johnson, 2000). Because of their interdisciplinary nature, game development programs appeal to a broader array of students, including women (Microsoft, 2008).

Table 3. Curriculum development criteria

Ensuring personal relevance
Including a focus on communication and language skills
Placing emphasis on personal mastery and building self-esteem
Using inquiry- and design-based activities to experience the world
Using real-life contexts
Working in cooperative teams
Promoting interpersonal relationships that build leadership skills

GAME DESIGN/DEVELOPMENT AS A STRATEGY TO DEEPEN UNDERSTANDING

Every truth has four corners: as a teacher I give you one corner;
it is for you to find the other three. — Confucius

In designing and developing games, students delve deeply into the content that underpins the gameplay. For example, in designing the *Year of the Plague* game to support instruction related to Defoe's *A Journal of the Plague Year*, California high school students became totally engrossed in study about the Great Plague. The developers (as learners) had to apply knowledge related to the Plague (symptoms, history, geography of London in 1665, sociology, etc.) to successfully meet game objectives. They immersed themselves in the literature to ensure that the game design and mechanics reflected historically accurate events, characters and backgrounds (Kiggens, 2009).

In their case study of 20 high school students in a game design class in Pennsylvania, El-Nasr and Smith (2006) discussed the learning that took place when students created characters and the 3D setting for a football game. According to the authors, "students developed an understanding of Boolean logic and programming constructs including threading, and event- and rule-based programming. They learned the benefits of iterative design and how to divide work among team members. They gained a better understanding of 3D geometry and vector mathematics. They applied the Pythagorean Theorem and used tangents, vector geometry and 3D transformations. These were difficult concepts to assimilate but by applying them in visual 3D space, students were able to use and understand them" (El-Nasr and Smith, 2006).

Gamestar Mechanic (E-Line Media, 2010) is a digital game-based learning product centered upon the tenet that game design is an activity that allows learners to build technical, technological, artistic, cognitive, social and linguistic skills, and understandings that are ideal for today's world. As a process, game design is an excellent point of entry for learners toward an authentic application of system-based thinking, creative problem solving, art and aesthetics, writing and storytelling, interactive design, game criticism and programming skills. *Gamestar Mechanic* differs from other products that enable game creation by focusing on the act of game development and the art of game design.

Gaming and Computer Science

Game design helps students delve deeper into computer science, and game development has become a favored new major at more than 500 post-secondary schools across North America. According to Moskal et al. (2004), game design programs have rekindled and sustained interest in computer science (CS), and 88% of game design students continued in CS compared to 47% in the control group.

Bayliss (2008) cites several compelling examples of computer science programs benefitting from game design underpinnings. The University of South Carolina implemented a game design curriculum that has increased enrollment in the school's CS department from 52 students in 2005 to 379 students in 2008. At the Rochester

Institute of Technology, the Reality and Programming Together program has been instituted "expressly to reverse the ongoing decline in CS enrollment by taking advantage of ubiquitous interest in computer games." This approach to CS seeks to recruit and retain students, as well as improve instruction, by integrating the basics of CS into designing and building computer games.

IMPLEMENTATION OF GAMING IN ENGINEERING AND TECHNOLOGY EDUCATION

Technology education has been a subject in transition for over 20 years. Its precursors were manual training and industrial arts. Many teachers, trained as industrial arts teachers, are still teaching as they were taught; despite the overarching need for a technologically literate student body and workforce, many school programs are still rooted in crafts teaching. At the same time, there has been an ongoing call from state and national professional leaders in the field to accelerate technology education's transition to a contemporary STEM-based discipline by making it more engineering-based.

According to ITEEA Executive Director Kendall Starkweather, "the idea to develop educational gaming will resonate well with the technology and engineering education community" (Starkweather, 2007). Results of a 2008 survey of technology education state supervisors indicate that 95% would supplement the existing curriculum with SMTE materials, teachers will find Web-based modalities accessible (74%) and necessary computers will be available (79%) (Hacker & Crismond, 2008).

It is increasingly evident that digital game-based learning literacy should be included as a core skill set for ICT readiness for educators in today's technology education classroom. Research data and trend analysis strongly indicate that today's learner is prepared to engage successfully in digital game-based learning. Achieving this new literacy will require institutional change, with a focus on enabling teachers in the classroom with this paradigm. This institutional change will require a shift in allocation of financial resources, but this is just the first step.

Serious Games for education are commercially available and the palette of choices across the curriculum is steadily increasing. Yet, even when there is a commercial game that is closely matched to the needs of a given curriculum, there is more to successful adoption than merely finding the financial resources to purchase the game and improve the technology infrastructure. First and foremost, teachers must be experienced players themselves and be fully inculcated in digital game-based learning pedagogy. This will require an institutional appreciation for the value and effectiveness of digital game-based learning – as demonstrated through strong and continuing professional development support. Additionally, the ecosystem of the classroom must be adapted to suit the emergence of the game-based constructivist learning community. IT policies will need to adapt, acceptable use policies, as well as programs and tools for assessment of learning outcomes will need to be revised, and play as learning must become a value statement for all stake-holders across the institution – administrators, teachers, students, support staff and parents.

As new teachers enter the profession, they comprise a growing demographic that will readily adopt digital game-based education. The average age of a video game player in the United States is 35 years, and 68% of all adults report having played a video game within the last year. Typically, today's teacher does play video games (Entertainment Software Association, 2009). The teacher's role in the digital game-based learning system is paramount. Research clearly indicates that to be an effective instructional strategy, gaming requires the teachers' careful scaffolding and incorporation of the game content into the class curriculum.

The authors believe that if provided with effective Serious Games, teachers would readily adopt them. However, in the face of the many challenges and competition for time in the class day, games must be as or more efficient than traditional instruction in terms of the time required for both teacher preparation and classroom delivery. This parameter is a primary consideration for adoption. Digital game-based learning must justify the cost in terms of classroom time with a return on investment of significantly improved learning performance.

THE VISION – 3D GAMING IN ETE PROGRAMS

Our vision for implementing 3D gaming in ETE programs involves using research on human learning and contemporary educational pedagogy to develop digital game-based learning underpinned by STEM concepts. We are struck by how engaged children are when playing video games; we are also struck by the opportunity that exists to develop digital game-based learning about STEM concepts, where game-based decisions made by students reflects and deepens STEM knowledge. Our vision is to leverage the motivation that is intrinsic to digital game-based learning so that students correctly and joyfully apply STEM concepts to achieve game/learning goals. This is just-in-time learning at its best where students embrace learning in the service of improved game performance.

While there are certainly challenges to realizing the potential of digital game-based learning in engineering and technology education, the early successes clearly demonstrate a roadmap for wide-spread adoption. Implementation can and should occur within the context of a reform-based school environment – rather than be seen as a fleeting, non-academic fad. It is both feasible and appropriate to infuse digital game-based learning in a school setting in such a way as to retain the authenticity and power of video games.

Survival Master: A Case Study of a 3D Game for Middle School ETE Students.

In the *Survival Master* game (see game website) for STEM learning in development with National Science Foundation funding (DRL 0821965) at the Center for Technological Literacy at Hofstra University in New York, 8th grade learners are situated in a survival scenario and are challenged to learned standards-based concepts and demonstrate higher-order thinking skills, including engineering design, problem solving, mathematical analysis, plan formulation and execution, and response to rapid change. This learning game leverages an informed design approach that embeds a design pedagogy developed and validated through several NSF projects conducted by the Hofstra CTL (Hacker, 2010). In informed design, learners are engaged in a progression of knowledge and skill builders (KSBs) – short, focused activities designed to teach salient concepts and skills. KSBs prepare students to approach the design challenge from a knowledgeable base, as opposed to engaging in trial-and-error problem solving where conceptual closure is often not attained. The approach gives the learner first-hand experience with how experts approach problems, as well as valuable experience in team-building.

The game invites students to undertake the design of an emergency survival shelter. It is targeted to 8th grade students who have had some previous exposure to introductory algebra.

Problem Situation: Here's a problem situation that students are asked to consider.

To be understood by students: You are part of a four-person team of engineers and scientists who are studying the effects of global warming in a remote area of Alaska. You have just begun your study of the region when an earthquake strikes and destroys buildings, wrecks power lines, cracks the airport runway, damages roads and triggers a landslide. Even the tent you were using has been ripped to shreds by falling debris. You are cut off from civilization except for the battery-operated radio equipment you have brought with you.

Design Challenge: Here is the design challenge students are asked to undertake. It will require them to apply their science, technology, engineering and math (STEM) skills.

To be understood by students: Your team is 200 miles away from the nearest city and the earthquake has made travel impossible. Your team must build a shelter to keep you warm during the time it will take for a rescue team to reach you.

With temperatures below freezing, your challenge, as one of a team of earthquake victims, is to design and build a rapidly erectable structure that will provide insulation from the cold, withstand the weight of snow (snow load) and the force of wind (wind load), and be built of materials that are readily available locally. Specifications and constraints are provided that detail the temperatures, available heat source, shelter size, and wind and snow loads. Available materials are specified.

Survival Master game goals are driven by desired learning outcomes. The gameplay (as learning activities) is authentic and situated in real-world contexts, yet engages the learner in common entertainment genres and game mechanics that are second nature to the digital native. For example, *Survival Master* has four KSB game levels and each of the levels has a gameplay that leverages a different genre of entertainment gameplay. KSB 1 is a 'puzzle/matching' level designed to teach concepts about surface area and volume of geometric shapes (see Figure 1); KSB 2 is a 'platformer' level that teaches about heat flow; KSB 3 is an 'action' level that focuses on k and R values; and KSB 4 is a 'construction' level focused on structural design concepts.

SMTE Key Ideas

KSB 1: Surface Area and Volume Calculations

Students will know that volume is a measure of filling an object and surface area is a measure of wrapping an object.

To demonstrate their understanding, students will:

1. Given the outside dimensions and the mathematical formulas for the volume of each shape, correctly calculate the volume of four geometric shapes: a cube, a sphere, a square-based pyramid and a cylindrical prism.
2. Given the outside dimensions and the mathematical formulas for the surface area of each shape, correctly calculate the surface area of four geometric shapes: a cube, a hemisphere, a square-based pyramid and a cylindrical prism.

KSB 2: Conductive Heat Flow

KSB2A: Students will know that heat (Q) flows from hot (T_h) to cold (T_c) through a material by conduction.

To demonstrate their understanding, students will:

Given an object with a temperature difference from one side to the other, explain that as the temperature difference (ΔT) increases, the conductive heat flow (Q) increases.

KSB 2B: Students will know that since heat is transferred from a hot temperature (T_h) to a cold temperature (T_c) through a flat surface, reducing surface area reduces heat transfer.

To demonstrate their understanding, students will:

Given objects with different surface areas (everything else being equal), describe how surface area affects conductive heat flow.

KSB 2C: Students will know that different materials conduct heat at different rates depending upon their thermal conductivity. Thermal conductivity is symbolized by the letter (*k*).

To demonstrate their understanding, students will:

1. Given a list of materials with different k values, identify those that are good insulation materials.
2. Given a heat source and two objects of the same dimensions made from different materials, be able to describe how different materials affect conductive heat flow.

KSB 2D: Students will know that heat flow decreases with increasing thickness.

To demonstrate their understanding, students will:

Given different thicknesses of the same material (everything else being equal), explain how thickness affects conductive heat flow.

KSB 2E: Students will know that the formula that relates heat flow (Q) to its determining factors is $Q = kA\,(T_h - T_c)/L$.

To demonstrate their understanding, students will:

Given the heat flow formula and a standard calculator, correctly calculate an outcome based upon manipulation of the variables in the formula.

KSB 3: Relationship between k Value and R Value

Students will know that:

1. k and R values are both measures of a material's resistance to heat flow. k value relates only to the type of material whereas R value also takes into account the material's thickness (L).

2. Since R value takes thickness (L) into account yet is related to k value, R, L and k can be expressed in a relationship. The R value of a material equals its thickness / its k value (R=L/k**).**
3. The total R value (R_t) of a system of materials is the sum of each of the individual R values ($R_t = R_1 + R_2 + R_3 + R....$).

To demonstrate their understanding, students will:

1. Given k values and thicknesses for several different materials, calculate the R value of each material using the formula R = L/k.
2. Solve for heat loss using the formula $Q = A (\Delta T) / R$ given surface area A, R value and ΔT.
3. Given individual R values of several materials, determine the total R value of a system made from layers of those materials by summing the individual R values.

KSB 4: Structural Design

KSB 4A: Students will know that: dead loads, live loads and wind loads are among those that must be taken into consideration when designing a structure.

To demonstrate their understanding, students will:

1. Given information about dead and live loads, define dead load and live load and give some examples of each.
2. Given a representation of wind blowing against a tower on a foundation that supports a platform with a filled water tank upon it, and correctly label the dead load, live load and wind load.
3. After seeing a video of "Galloping Gertie" (the Tacoma Narrows Bridge Collapse), explain why wind loads must be considered when designing a structure in addition to dead loads, which have a constant magnitude (such as the weights of the construction materials), and live loads that change in magnitude and/or location (such as people in a building or cars on a bridge).

KSB 4B: Students will know that structural integrity refers to the ability of individual structural members that comprise the structure (and their connections) to perform their functions under loads.

To demonstrate their understanding, students will:

Given a representation of a tower and its foundation that supports a water tank, correctly identify the components where the lack of structural integrity might affect the item's function or safety.

KSB 4C: Students will know that selecting materials involves making tradeoffs between qualities.

To demonstrate their understanding, students will:

After explaining that structural integrity depends upon the ability of individual structural members that comprise the structure to perform their functions under loads, explain how selecting materials for a structural project involves making tradeoffs between competing qualities such as strength, cost, availability and the ease of working with the material.

KSB 4D: Students will know that: the overall stability of a structure and its foundation refers to its ability to resist overturning and lateral movement under loads.

To demonstrate their understanding, students will:

1. Given the challenge to analyze a representation of a braced tower and its foundation that supports a load, explain that the stability of the structure depends upon its ability to resist overturning and lateral movement under loads.
2. After investigating the design of a water tower, explain why a water tank is sometimes made in a spherical or cylindrical shape rather than a different geometric shape such as a rectangular prism or a square-based pyramid.

KSB 4E: Students will know that structural design is influenced by climate and location, function, appearance and cost.

To demonstrate their understanding, students will:

After reviewing images or models of a variety of structures built for different purposes in different geographic areas (deserts, mountains, icy climates), describe how structural design is influenced by function, appearance, cost and climate/location.

Drawing upon their life experience as gamers, these games are immediately accessible and intuitive for the learner. *Survival Master* culminates in a group multi-player shelter design challenge, where students work together in teams of four and apply the informed design model to the design of an emergency survival shelter.

Figures 1, 2, 3 that follow are screen shots from the Survival Master game. Three images are displayed that illustrate elements of the game intended to teach skills through the KSBs and the culminating multiplayer design challenge.

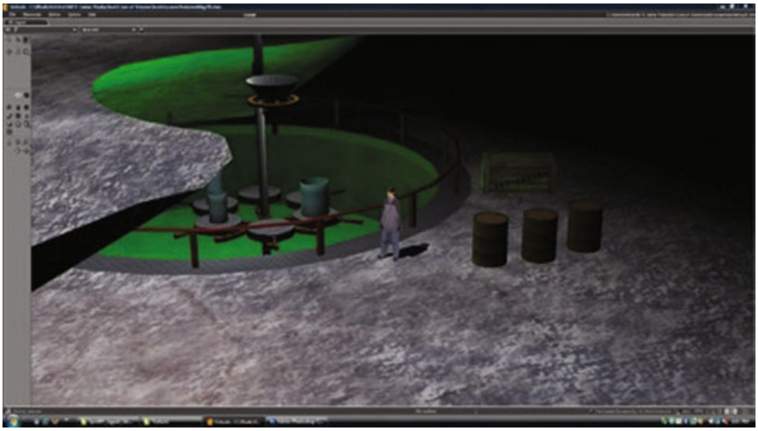


Figure 1. A scene from KSB 1 of the survival master game for middle school ETE. In this figure, a player (represented by an avatar) is walking in the game environment finding geometric shapes (cubes, square-based pyramids, spheres) filled with liquid that will be poured through a funnel into cylinders. The player must choose the cylinder that holds the same volume as the geometric shape.

Figure 2. *A scene from KSB 2 of the survival master game for middle school ETE. In this figure, a player moves a platform that models heat flowing from hot to cold.*

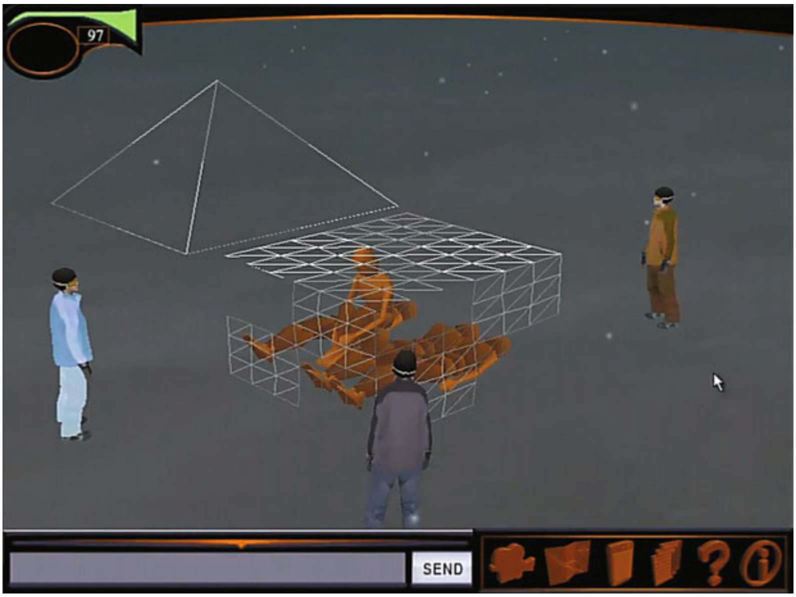


Figure 3. *A scene from the multiplayer part of the survival master game for middle school ETE. In this figure, players are designing a shelter to protect them from the Alaskan cold.*

Hybrid Modeling

Proponents of situated cognition have suggested that learning is far more meaningful when students can draw on real-world situations, especially situations in which they are personally invested (Lave and Wenger, 1991). Practices of authentic inquiry are best fostered through engagement in activities that are both model-based and situated in real-world activities (Barab, Hay, &Hickey, 2006). A uniqueness of the pedagogical approach taken in the design of the *Survival Master* game is the use of hybrid modeling. The term hybrid modeling characterizes the linking of real-world and computer-based models (Blikstein & Wilenski, 2006). Gameplay alone is an innovative pedagogy, however, hybrid modeling enables students to engage in a virtual design simulation, optimize their designs on-screen and then build functional models to compare physical and virtual implementations. In the *Survival Master* game, the functional physical model can be either full-size or a scale model (teacher's choice). It must meet all the design criteria. Students must consider the tradeoffs in choosing a cube-shaped structure (ease of construction, but high surface area, greater heat loss and increased snow-load on the roof), or a pyramidal or spherical/hemispherical structure (more complicated construction and bracing, but lower snow load and lower wind load in the case of a hemisphere).

The significance of hybrid modeling stems from the value added when students engage in both a virtual modeling and a physical modeling experience. A contemporary engineering and technology education program can propel this innovative pedagogical melding and provide students with the multiplicity of benefits that a synergistic blending of cyber learning and hands-on design and construct modeling can offer. A comparison of the merits of virtual and physical modeling is presented in Appendix 1. For example, using virtual modeling, students can easily vary *geometric* attributes of a shape (e.g., length, width, height) and define the resulting areas, perimeters and volumes. Additionally, they have the ability to make many iterations quickly, which provides a *shameless way* for students to build needed knowledge in a timely fashion and allows them to learn from trying out "what if" scenarios easily.

In developing physical models, tactile and kinesthetic experience of the design complements and improves comprehension of the problem. Physical modeling can convey ideas in unique ways that complement on-screen designs, especially for people with limited visualization skills. Additionally, a physical model better captures the irregularities and vagaries of a complex, real-world environment.

IMPEDIMENTS TO IMPLEMENTATION

In ETE, there are impediments to the adoption of gaming that relate to: (1) the image of video games as entertainment alone; and (2) the present state of teacher education that relies, to a large measure, on the comfort level of the present, traditionally trained professoriate. In ETE, pre-service training is still largely focused on materials-based technology, even in an age where ICT has become the dominant technological paradigm (Hacker, 2009). For example, using the experience gleaned through the development of *Survival Master*, it has become clear that teachers who are traditionally trained as industrial arts or crafts teachers have difficulty with the mathematics demanded by players in the game, even though the mathematics is at an elementary algebra level. Gaming, we have found, requires teachers to reorient their instructional practice. In gaming, students are the active partners in the educational transaction. The role of the teacher changes dramatically from presenter to guide, and many teachers are more comfortable in a role where they actively instruct. It has also become apparent that teachers are not always able to address firewall issues that must be solved in order to enable students to download gameplay elements.

We see three primary challenges to the implementation of educational gaming on the institutional level relating to the plethora of curriculum mandates: a general tendency of policy-makers to fear or mistrust video games as pedagogy and a prevailing lack of digital game-based learning literacy on the part of senior level teachers.

Regional and state curriculum mandates create the same difficulty in leveraging commercial off-the-shelf (COTS) learning games as they do with regard to every other genre of instructional media and courseware. One approach to this challenge is to enable teachers to repurpose COTS learning games through 'modding,' which is a common feature of current video games whereby the developer has included in the game purchase the toolset required to develop the game so that the end-users can use that toolset themselves to "modify" the game. This capacity has a new dynamic with the rise of open source or free development tools in use in the video game production industry that allow the teacher and/or learners to use the same tools to modify the game's content.

To redress the issue of teachers' fear and mistrust of video games, one promising model is to nurture their ability to become involved in game-based learning development. Across the US, a diverse range of digital game-based learning projects are actively seeking interested teachers to assist with educational game development. In this model, teachers then bring new skills and experience to their institution and serve as professional developers. The power is in the game. Avoiding or hiding the word game is a mistake and a disservice. Embracing the video game as integral part of the student's life presents an opportunity for the institution to link its capacities with one of the learner's most important self-identifications – his existence as a gamer. The institution has the infrastructure and resources to do so; all that is missing is the bridge – much in the manner that institutions welcome external communities of learning such as museums, scouting, sports, etc.

New teachers and new millennium learners at every level come to an institution with literacy in gaming that is largely misunderstood and most often underappreciated by senior faculty and administrators. This gaming literacy remains an untapped resource, one that can be effectively and efficiently enabled to become digital game-based learning power. This can best be accomplished with a "bottom-up" approach with a professional development investment aimed at the digital natives in the institution. These digital natives are poised to become a first wave of adopters, forming a cadre of peer mentors for teachers and learners alike. This is an especially inviting aspect for institutions that are in the process of evaluating new possibilities for pedagogy, the role of the teacher and learning communities.

A PROPOSED MODEL FOR INSTITUTIONALIZING GAME-BASED LEARNING

Teachers learn about educational gaming most effectively when it is presented as just another curriculum innovation. In earlier evolutions where computers were first brought to the classroom, followed by Web applications, a successful model for local implementation emerged that is still a good fit today. A model for implementing and institutionalizing game-based learning should include a focus on the following elements:

- **Professional Development**. Provide pedagogical and technical enhancement to pre- and in-service teachers to increase their capability and disposition to develop and implement game-based instruction in the ETE classroom.
- **Learning Communities**. Establish and support learning communities of natural alignments of intra-discipline, early adopters within the institution that work together to resolve local challenges.
- **Leadership**. Encourage leadership from the bottom-up. While it is important for support and leadership from the administration, the long-term success is dependent upon a widespread grass-roots initiative.
- **Support and Resources**. Hardware and software are needed. But, there must also be a deep institutional commitment to ongoing professional development training and support.
- **Celebrate Success**. Promote the early projects. Measure and report on the effectiveness. Involve the learners and their parents.
- **Renew**. Bring in experts and researchers. They provide new directions and help provide new energy to propel the projects beyond the early adopters to institution at large.

SUMMARY

Digital game-based learning is evolving from a promising prospect to a gender equitable, vitally engaging, core instructional strategy to be integrated into ETE instruction. The promise of playing and designing/developing thoughtfully conceived games can increase student engagement, promote inquiry-based learning, positively affect self-efficacy and attitudes toward further ETE study, and stimulate interest in related STEM careers.

Recent commercial successes of Serious Games products have demonstrated that digital game-based learning has a maturity and suitability for STEM learning that warrants serious consideration at all levels of education.

Institutions need to consider how they could transform their organizational systems and instructional practices to take advantage of educational games. This may require fundamental changes in attitude, management and models of organization. This may best be accomplished through bottom-up, grass-roots communities that privilege learning initiatives.

Teacher education should include both the technical and pedagogical means for teachers to implement game-based learning. Educational policy-makers should be helped to envision and support the potential of game-based learning. This will require an institutional commitment to provide new methods of professional development training that will support digital game-based learning as essential teacher training.

Institutions should engage digital game-based learning researchers and development communities to take advantage of the ongoing opportunities to participate in the development of new digital game-based learning products and research initiatives.

To effectively sustain efforts in reform and transformation, institutions should celebrate each small success achieved by early adopters as they lead their peers in embracing this new educational paradigm. These efforts should be measured and broadly reported to the educational community-at-large.

REFERENCES

Adams, E., & Rollings, A. (2007). *Fundamentals of game design.* Upper Saddle River, NJ: Pearson Prentice Hall.

Aldrich, J. (2004, March 7–18). Open modules: A proposal for modular reasoning in aspect-oriented programming. In C. Clifton, R. L¨ammel, & G. T. Leavens (Eds.), *Proceedings of the Foundations of Aspect-Oriented Languages Workshop at AOSD*. Available at http://www.eecs.ucf.edu/FOAL/papers-2004/aldrich.pdf

Barab, S., Hay, K., & Hickey, D. (Eds.). (2006). *Proceedings of the seventh International Conference of the Learning Sciences (ICLS)*. Bloomington, IN.

Bartle, R. (1996). Hearts, clubs, diamonds, spades: Players who suit MUDs. *Journal of Virtual Environments*, *11*(1). Available at http://www.brandeis.edu/pubs/jove/HTML/v1/bartle.html

Bayliss, J., & In Microsoft PressPass – Information for Journalists. (2008). *More than fun and games: New computer science courses attract students with educational games*. Available at http://www.microsoft.com/presspass/features/2005/sep05/09-12CSGames.mspx

Blikstein, P., & Wilenski, U. (2006). 'Hybrid modeling': Advanced scientific investigations linking real-world sensing and multi-agent computer-based models. In S. Barab, K. Hay, & D. Hickey (Eds.), *Proceedings of the seventh International Conference of the Learning Sciences (ICLS)* (pp. 890–891). Bloomington, IN.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York: HarperCollins.

E-Line Media, & Institute of Play. (2010). *Gamestar Mechanic Software*. Available at http://www.gamestarmechanic.com

El-Nasr, M. S., & Smith, B. K. (2006). Learning through game modding. *Computers in Entertainment*, *4*(1), 1–20.

Entertainment Software Association. (2009). *Essential facts about the computer and video game industry*. Available at http://www.theesa.com/facts/pdfs/ESA_EF_2009.pdf

Federation of American Scientists (FAS). (2010). *Immune Attack Software*. Available at http://www.immuneattack.org

Hacker, M., & Crismond, D. (2008). *Virtual vs. physical modeling*. Hempstead, NY: Hofstra University Center for Technological Literacy.

Hacker, M. (2009, March 26–28). *A transformative model for technology education*. Paper presented at the International Technology Education Association (ITEA) conference, Louisville, KY.

Hacker, M. (2008). *Survey of technology education state supervisors*. Hempstead, NY: Hofstra University Center for Technological Literacy.

Hacker, M. (2010). *Informed design*. Hempstead, NY: Hofstra University Center for Technological Literacy. Retrieved June 11, 2010, from http://www.hofstra.edu/pdf/Academics/Colleges/SOEAHS/ctl/ctl_informeddesign_003.pdf

I Support Learning, Inc. *Curriculum at-a-glance: Web game design*. Retrieved June 1, 2010, from http://www.isupportlearning.com/PDF/Web.pdf

Junco, R., & Mastrodicasa, J. (2007). *Connecting to the Net.Generation: What higher education-professionals need to know about today's students*. Washington, DC: NASPA.

Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers & Education*, *55*(2), 427–443.

Kiggens, J. (2009). *Report on Defoe's. A journal of the plague year*. Unpublished report.

Lave, J., & Wenger, E. (1991). S*ituated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Mendoza, E., & Johnson, K. (2000). *Land of plenty: Diversity as America's competitive edge in science, engineering and technology (NSF 02-107)*. Washington, DC: Congressional Commission on the Advancement of Women and Minorities in Science, Engineering and Technology Development.

Microsoft PressPass – Information for Journalists. (2008). *More than fun and games: New computer science courses attract students with educational games*. Available at http://www.microsoft.com/presspass/features/2005/sep05/09-12CSGames.mspx

Lenhart, A., Kahne, J., Middaugh, E., Macgill, A., Evans, C., & Vitak, J. (2008). *Teens, video games and civics*. Pew Internet and American Life Project. Available at www.pewinternet.org/~/media/Files/Reports/2008/PIP_Teens_Games_and_Civics_Report_FINAL.pdf

Moskal, B., Lurie, D., & Cooper, S. (2004). Evaluating the effectiveness of a new instructional approach. *ACM SIGCSE Bulletin*, *36*(1), 75–79.

National Commission on Excellence in Education. (1983). *A nation at risk*. Washington, DC: U.S. Government Printing Office.

National Science Foundation (NSF). (2003). *New formulas for America's workforce: Girls in science and engineering*. Arlington, VA. Available at http://www.nsf.gov/pubs/2003/nsf03207/nsf03207_1.pdf

Powers, W. T. (1973). *Behavior: The control of perception*. Chicago: Aldine.

The Survival Master game. Available at http://www.gaming2learn.org

Sawyer, B., & Smith, P. (2008). Serious games taxonomy. San Francisco: Game Developer's Conference, Serious Games Summit.

Starkweather, K. (2007). *Letter of support. Simulations and modeling for technology education.* A proposal to the US National Science Foundation (NSF).

Yarbrough, C., & Fleischman, J. (2009). *'Shoot-em up' video game increases teenagers' science knowledge*. EurekAlert. Available at http://www.eurekalert.org/pub_releases/2009-12/asfc-v112609.php

Michael Hacker
Co-director, Center for Technological Literacy
Hofstra University on Long Island, New York
USA

James Kiggens
CEO, Course Games, Santa Barbara, California and
Founding Director, Serious Games Design Institute
Santa Barbara City College, California
USA

APPENDIX 1: MERITS OF VIRTUAL VS. PHYSICAL MODELING

Virtual Modeling – Unique Advantages

Pedagogy

- Matches the preferred learning style of many of today's students
- Enables students with limited drawing skills to render successfully
- Helps students capture interim versions of their designs
- Helps teachers assess the evolution of students' ideas and their progression of learning
- Allows students to communicate by generating rendered design ideas for projected or printed PowerPoint presentations
- Eliminates waste of material resources
- The ability to make many iterations quickly provides a *shameless way* for students to build needed knowledge in a timely fashion

STEM Content Knowledge and Skill

- Permits students to easily vary *geometric* attributes of a shape (e.g., length, width, height) and define resulting areas, perimeters and volumes
- Scaffolds students' ability to visualize 2- and 3D shapes
- Allows for easy repetition to support development of skill in using the software
- Enables the use and integration of other software (e.g., Excel, PowerPoint)
- Enhances the ability to use (and understand the use of) software as a powerful modeling tool

Design

- Fosters creativity and higher quality through iteration
- Allows for trying out alternatives without additional costs (in terms of time, capital, materials, equipment)
- Allows students to learn by trying out "What if" scenarios with little risk
- Easy editing and duplicating of complex virtual objects, angles and shapes
- Provides instantaneous visual feedback to help make more informed design choices
- Permits precise scaling and dimensioning of geometric shapes and elements
- Rapidly calculates geometric areas to help students check calculations

Social Networking

- Students can share virtual models over networked computers
- Work can continue in other places such as at home

Other Advantages (not necessarily unique to virtual modeling)

- The software offers specific features, including ease of editing and replicating shapes and angles, providing students access to an almost unlimited supply of clip art and other online resources, and representational reality.

- Reinforces key concepts and skills learned in class (e.g., modeling, design, ratio and proportion, scale, making and interpreting “nets”)
- Develops higher-order thinking skills (e.g., synthesis, analysis, evaluation) in the context of solving engaging problems
- Consistent with contemporary design methods
- Supports creativity through a vast library of already-rendered objects, capacity to save versions and return to them later

Physical Modeling – Unique Advantages and Added Value

Pedagogy

- Students feel significant ownership of their constructed model
- Tactile and kinesthetic experience of the design complements and improves comprehension of the problem
- Physical model conveys ideas in unique ways that complement on-screen designs, especially for people with limited visualization skills
- Doing physical measuring reinforces measuring skills
- Geometry is experienced in a more meaningful, real-world way

STEM Content Knowledge and Skill

- Skills in using hand tools and machines and in processing materials are developed
- Promotes skills in effective management and use of limited materials to achieve a specific purpose
- Errors in math and design thinking are made visible by making the physical model
- Physical model provides a reality check to screen-based modeling (e.g., gravity can be absent in screen-based modeling)

Design

- Building a prototypical physical model is an essential component of the design process
- A physical model provides additional feedback to designers, i.e., it informs designers where the virtual model may not be accurate and keeps the virtual design honest
- A physical model better captures the irregularities and vagaries of a complex, real-world environment
- Working with a 3D physical model is a necessary complement to working with virtual models (e.g., it is sometimes easier to view the impact of changes in object placement in the physical model)
- A physical full-scale prototype permits testing designs under real-world conditions
- Allows testing of prototype qualities not easily modeled on the computer. An example is *ergonomics* (the “fit” between the design and human users)

- Contributes added realism for purposes of visualization, presentation and marketing
- Promotes creative thinking in that students may find it easier to create and develop their ideas when handling physical materials

Social Networking (not unique to physical modeling)

- Enhances communication skills through group discussion and planning
- Students recognize that teamwork is a necessity to get the job done effectively and on time

EVANGELINE S. PIANFETTI AND GEORGE C. REESE

15. TRANSFORMING EDUCATION

The Promise of Engineering and Technology Education in a Digital Age

INTRODUCTION

The Changing Landscape in Society

American writer and futurist Alvin Toffler stated, "The illiterate of the twenty-first century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn." The 21st century is a time in which we are discovering that we need to relearn how we think about what is learned, how it occurs, and who is learning. In classrooms today, teachers are facilitating the learning of students considered "digital natives" (Prensky, 2001). The pervasiveness of technologies and digital media in society and their reach into P-12 classrooms are forcing us to reconsider how we might best educate students of the 21st century. Our children are growing up in a world shaped by technological resources and yet in many classrooms, there still is a struggle on how to meaningfully integrate technologies that students are finding commonplace in their daily lives. Consequently, we are at a crossroads in which the expectations of 21st century learners are not being met by our schools. While it has become cliché to say that we are preparing students for careers that do not yet exist, it is all too obvious that our schools are still structured for the careers of 1980, if not 1880.

The basic tenets of education in general, however, have not changed. Education is about preparing all our children to be productive citizens. Our challenge today, therefore, is to find ways of fostering critical thinking, collaboration, problem solving and creativity that characterize the main attributes of success in our global society.

The Changing Landscape for Students

Both students and teachers are being redefined as digital media and technologies are shaping informal and formal learning environments. Traditional school subject boundaries are breaking down. Biology, chemistry and physics are still school subjects, but now bio-informatics, genomics and nanotechnology are just a few of the newly identified fields in which today's students might find their careers. But if we reflect on what we are truly considering, we are looking at how digital media and technologies are reframing what the digital natives (Prensky, 2001), are coming to expect

M. Barak and M. Hacker (eds.), Fostering Human Development Through Engineering and Technology Education, 281–293.

from their schooling. These students need fewer skills with any particular technology, but are seeking out those technologies that make them do more, faster and better. They are, as Prensky (2009) suggests, seeking digital wisdom that is “a twofold concept, referring both to wisdom arising from the use of digital technology to access cognitive power beyond our innate capacity and to wisdom in the prudent use of technology to enhance our capabilities” (p. 1). Prensky (2009) further identifies how digital technologies are enhancing what we do. For example, handheld devices increase our ability to remember with the help of electronic storage and calendaring. Data-gathering tools allow us to make determinations more readily as to how some variable may impact a learning environment. What this all means is that students today are looking at digital technologies as a way of fostering their thinking – for them to think critically, collaboratively and to solve programs; all of these are key characteristics that are expectations of a 21st century workforce. But if we consider this to be the expectations of the millennial student, we have encountered a contradiction in how schools are currently structured in which the standards-based curriculum, “teaching for the test,” is in direct conflict with any form of inquiry-based learning where the emphasis is on students and the process and contextualization of learning. Linn (2000) and Linn, Clark and Slogtta (2003) provide evidence as to successful models of practice and what can occur when students are challenged by the learning and not by a prescribed curriculum.

Similarly, efforts in inquiry learning all seem to look at knowledge through a spiral pattern in which the learner is best engaged when they ask a question and ultimately reflect on the answer to see how it relates to the knowledge they may already have or have gained, as illustrated in Figure 1. This exploratory process accounts for students actively participating in the learning process and, as Linn (2000) and Linn, Clark and Slogtta (2003) would agree, take ownership of contextualizing what is learned.

These ideas for what is reshaping our vision of schools as going beyond mere places to receive credentials but places where learning is the emphasis gives us a chance to take pause and consider Engineering and Technology Education as a vehicle by which the millennial expectations are potentially met.

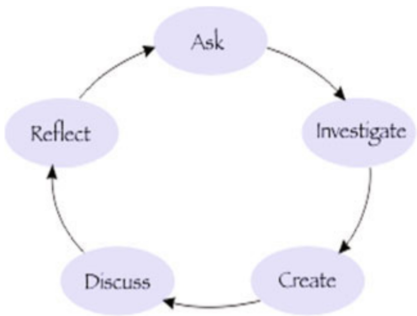


Figure 1. Inquiry spiral. Bruce (1998) discusses the philosophy of innovation that goes with this online approach.

ETE and the Changing Demands on Curriculum

In this chapter, we will argue that Engineering and Technology Education (ETE) provides an opportunity to re-examine curricula in light of new technologies. ETE curricula can bridge outdated notions that define tracks of college-bound and non-college-bound preparations. We also assert that ETE brings us closer to the venerable ambition of education as life that was espoused by thinkers like John Dewey and Alfred North Whitehead. Finally, we acknowledge the challenges ahead as well as the possibilities.

LOOKING BACK

Life as the Subject-Matter for School

Looking back almost a hundred years, Alfred North Whitehead decried the fact that the curriculum of students was remote from life.

> The solution which I am urging is to eradicate the fatal disconnection of subjects which kills the vitality of our modern curriculum. There is only one subject-matter for education, and that is Life in all its manifestations. Instead of this single unity, we offer children – Algebra, from which nothing follows; Geometry, from which nothing follows; Science, from which nothing follows; History, from which nothing follows; a Couple of Languages, never mastered; and lastly, most dreary of all, Literature, represented by plays of Shakespeare, with philological notes and short analyses of plot and character to be in substance committed to memory. Can such a list be said to represent Life, as it is known in the midst of the living of it? The best that can be said of it is, that it is a rapid table of contents which a deity might run over in his mind while he was thinking of creating a world, and has not yet determined how to put it together. (Whitehead, 1929, p. 18).

John Dewey also noted the many problems with the prepared curriculum and pointed to the direction of relevance as a solution.

> The legitimate way out is to transform the material; to psychologize it—that is, once more, to take it and to develop it within the range and scope of the child's life. (Dewey, 1902/1956, p. 30)

Both Dewey and Whitehead call for a curriculum that is life itself. In the many decades since they wrote, there have been great changes in education and movements in curricula, but the aspiration of making the curriculum closer to life has remained a distant ambition.

Today, we have new tools and advancements in the cognitive psychology of learning. However, as traditional pedagogies prevail due to teacher attitudes, school structures and curricular demands, we in the field of education are challenged to embrace learner-centered, authentic, inquiry-based problem-solving activities in the context of old structures of schooling. It is well known that these structures will usually overwhelm innovation (Cuban, 1993; Tyack & Cuban, 1995). So how can we adapt to the new tools within our old structures? We believe that ETE is a promising path.

The Evolving ETE Picture

Engineering and Technology Education (ETE) is an evolving field that has emerged from the historical roots of industrial arts education and is acquiring a new academic grounding with connections to engineering design (Daugherty, Rees & Merill, in press). Vocational preparation promoted direct practical applications of learning – those that students would need upon graduating high school and entering a skill-based field such as mechanic or carpenter. These courses were based on the industrial arts (Dugger Jr., 2002; Lauda, 2002; Zargari & MacDonald, 1994) and tended to focus on rote thinking and those skills necessary to get specific tasks accomplished. Implied in this type of class was the understanding that the students taking them would not be going to post-secondary education. They were in the non-college track. Over 10 years ago, Volk (1997) projected a decline in industrial education classes and a direct impact on technology education classes. The trend continues today as we see less vocational and "tech prep" courses in schools that are re-envisioning their curriculum and attempting to mainstream technology education into core subject matter, in particular mathematics and science (Volk, 1997). But as these courses are being eliminated, they are not being replaced by a modern, integrated technology education, but rather by an effort to compel students to take more traditional mathematics and science.

The new mechanism, advocated by reports like *Rising Above the Gathering Storm* (Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology, 2005), is Science, Technology, Engineering and Mathematics (STEM) education. A program like *Project Lead the Way* (Bottoms & Anthony, 2005; Bottoms & Uhn, 2007) is one example of a program that has moved away from the industrial arts curriculum toward the direction of the pre-engineering high school curriculum. This brings forward the problem of increasing the mathematics and science background of students in order to focus on the higher-order thinking skills necessary for engineering design. Is high school pre-engineering one more content area to be studied? Or can it be connected with mathematics and science content? Added to these questions is the fact that mathematics and science pedagogy and curricula are changing. In the late 1980s and early 1990s, there were reports that called for a mathematics and science for all students, especially those who have traditionally been left out of mathematics and science careers (See, for example, American Association for the Advancement of Science, 1990; Brooks, 1991; Mathematical Sciences Education Board & National Research Council, 1989). So how do the agendas come together and where does ETE fit in?

THE CHANGING PICTURE

21st Century Skills: Changing Expectations of Students

Emphasis on STEM education is now of critical importance in our K12 schools, which are trying to develop students who are globally competitive and ready for the expectations of a 21st century workforce. Wallis and Steptoe (2006) identify characteristics that will define our future workforce as individuals who can think across disciplines, be creative, process information rapidly and accurately and whose quest for learning allows them to construct their own knowledge path while teachers facilitate their experiences. And yet, we find most schools still employing traditional teaching methods instead of those better suited for 21^{st} century learning. The consequence of this is that students may gain only core knowledge instead of portable skills that would allow them to be successful in the workforce. As a result, students are ill-prepared for the 21^{st} century because their classroom experiences have for the most part been framed within 20^{th} century pedagogy, as illustrated in Table 1. According to the US Department of Education, "when students are using technology as a tool or a support for communicating with others, they are in an active role rather than the passive role of recipient of information transmitted by a teacher, textbook, or broadcast. The student is actively making choices about how to generate, obtain, manipulate, or display information."

Table 1. Comparing 20^{th} century classrooms vs. 21^{st} century classrooms. Adapted from the National Educational Technology Standards for Students (ISTE, 2007, p. 6)

20^{th} Century classroom	*21^{st} Century classroom*
Time-based	Outcome-based
Focus on memorization of facts	Focus on what students know, can do, and like after all the details are forgotten
Lesson focus on the lower level of Bloom's Taxonomy	Learning is designed on the upper level of Bloom's Taxonomy
Textbook-driven	Research-driven
Passive learning	Active learning
Learners work in isolation; classroom within four walls	Learners work in collaboration with classmates and others around the world; global classroom
Teacher-centered: teacher is the center of attention and provider of information	Student-centered: teacher is the facilitator/coach
Little or no student freedom	Great deal of student freedom
'Discipline problems' – teachers do not trust students and vice versa; no student motivation	No 'discipline problems'– students and teachers have mutually respectful relationship as co-learners; students are motivated
Grades are averaged	Grades are based on what is learned
Low expectations	High expectations
Teacher is the judge – no one else sees students' work	Self, peer and other assessments; public audience, authentic assessments
Curriculum/school is irrelevant and meaningless to the students	Curriculum is connected to students' interests, experiences, talents and the real world

Table 1. (Continued)

Print is the primary vehicle of learning and assessment	Performances, projects and multiple forms of media are used for learning and assessment
Diversity in students is ignored	Curriculum and instruction address student diversity
Literacy is the 3 'Rs – reading, writing and mathematics	Multiple literacies of the 21st century – aligned to living and working in a globalized new millennium

What we see prevalent in classrooms exhibiting 21st century characteristics is an understanding that what we expect from our students and for our students emphasizes those learning theories that enable students to construct their own meaning by taking responsibility for their learning. The cognitive science discoveries of the previous century have laid the groundwork for this change in pedagogy. We know that students bring pre-conceptions (right, wrong or merely naïve) to the classroom, that they are constantly learning in communities of practice both in and outside school, and that collaboration with capable peers can greatly enhance learning (Bransford, Brown, & Cocking, 2000; Brown & Campione, 1994; Peterson, 1994; Vygotsky, 1978). Project-based learning (see Chapter 13 in this volume) enables the process of the learning to be as important as the product. The measurement of student understanding is based on their use of technology to construct meaning and question the basis of their own knowledge. Other key learning theories such as activity theory (see Chapter 2) and distributed cognition (see Chapter 1) see authentic tasks and an awareness of how information and knowledge blend through the creation of artifacts as a measure of awareness of knowledge and its relation to the world around us. ETE offers the opportunity of transition from standard pedagogy to more modern approaches for teaching and learning as influenced by technological literacy. In the absence of restructuring our pedagogy to better integrate technology education, we will, as former Secretary of Education, Rod Paige, once stated, "...still educat[ing] our students based on an agricultural timetable, in an industrial setting, and yet tell[ing] students they live in the digital age." Much of this shift is embroiled in an understanding of teachers' attitudes towards technology education and its historic roots.

The Changing Role for Teachers

Technology is changing expectations for everyone, including teachers. Twelve years ago, Tapscott (1998) suggested that the computer and digital resources that students and teachers utilized in the classroom far surpassed what each group utilized in their homes. This is clearly not the case today. Prensky (2001) asserts that students today are "digital natives" and, as a result, are making unique demands of teachers and of the types of learning encountered in formal school environments. ETE mirrors a similar path in which its historic roots are grounded in the manual and industrial arts movements of the 1800s. However, its inception was a focus on providing students with skills necessary for a workforce whose emphasis was on skilled labor in which individuals entered task-specific jobs such as those found on the assembly line (Kirkwood, Foster, & Bartow, 1994). In response to this need within society, vocational education curricula were developed and by the 1950s found a mainstay in many high school classrooms. The distinction here was that the hands were more critical to society than the mind. But as the demands of society changed, in part as a result of the pervasiveness of technologies in all aspects of our lives and the vision of how technologies could impact the future, a decline in vocational education programs was seen and emphasis was placed on other aspects of the school's curriculum (Hansen & Reynolds, 2003).

Today, emphasis is placed on STEM education. But education technology, let alone technology education, is still a challenge for teachers. Ninety-seven percent have access to email. Yet, two-thirds of teachers have less than eight hours a year of professional development with technology (Gray, Thomas, & Lewis, 2010). As a consequence, students typically use technology for low-level tasks such as word processing and practicing basic skills. Gray et al. (2010) found that 83% of teachers in high poverty schools reported that students use technology to practice basic skills (p. 3). If we consider that technology education supports 21^{st} century views of ubiquitous learning in which knowledge is constructed through the situated events and authentic learning opportunities crafted in learning environment, it is particularly challenging because, as Wersch (2008) writes:

> Classrooms built to re-enforce the top-down authoritative knowledge of the teacher are now enveloped by a cloud of ubiquitous digital information where knowledge is made, not found, and authority is continuously negotiated through discussion and participation. In short, they tell us that our walls no longer mark the boundaries of our classrooms.

What we need to see are teachers who are willing to take risks in rethinking their instructional practices. As stated by ISTE CEO, Don Knezek:

> Teachers must become comfortable as co-learners with their students and with colleagues around the world. Today it is less about staying ahead and more about moving ahead as members of dynamic learning communities. The digital-age teaching professional must demonstrate a vision of technology infusion and develop the technology skills of others. These are the hallmarks of the new education leader (Nagel, 2008).

These leaders within education are the ones who will ensure that our students are life-long learners. In terms of the rhetoric of the emerging standards, this means that they are college and career ready.

LOOKING FORWARD

College and Career Readiness

As mentioned above, tracking for college and non-college students has been the historical norm in schools. However, "while not every high school graduate plans to attend college, the majority of the fast-growing jobs that require a high school diploma, pay a salary above the poverty line for a family of four, and provide opportunities for career advancement require knowledge and skills comparably to those expected of the first year college student" (ACT, 2008, p. 1). As a result, we are seeing a blending of college readiness to also encompass career readiness. "Improving the college and career readiness of all our students will provide a better foundation of knowledge and skills to allow future workers to adapt the changing requirements of a more technologically sophisticated and internally competitive working world" (ACT, 2008, p. 1). College and career readiness (CCR) standards are being established in core disciplines, in particular those with emphasis in STEM areas. For example, if we look at the Common Core Standards for mathematics (Common Core State Standards Initiative, 2010), the guiding principles of learning and understanding fundamental concepts are critical, but how they relate to ways of problem solving, critical thinking and making connections is of deeper emphasis.

Teaching, Learning and Making Connections through ETE

The current testing and accountability regime under America's No Child Left Behind Act forces an emphasis on traditional teaching, and it measures success by standardized tests. Ironically, the higher-order skills that we want from our students demand more emphasis on student learning, and success will be measured by products. It could well be the case that we are discarding the lessons of cognitive revolution when they can serve us best.

As the cognitive science frameworks of the early chapters indicate, learning is a social process. An example is the Xerox copy machine repairmen, who learn from each other by telling "war stories" (Brown & Duguid, 2000, pp. 99–106). This is not the ersatz activity of students solving problems in a textbook, but real learning to solve pressing day-to-day problems with the tools of our culture. This should hold true for students in schools as well. "To learn to use tools as practitioners use them, a student, like an apprentice, must enter that community and its culture (Brown et al., 1989)." This is what ETE, even in the days of industrial education, has always done, and therein we see the opportunity for making connections.

One of the authors collaborated for six years with a career and technical high school. In the early days of this collaboration, as the principal was conducting a tour, he said, "We don't need you to tell us about hands-on, we've always done it. Also, you won't see much lecturing here. Students come in and start working."

This is very different from what happens in, say, the typical mathematics classroom in the United States, as described in a summary of the TIMSS Video Study in the National Research Council report, *Adding It Up*.

> In the videotaped lessons from the United States, a typical lesson begins by checking homework or engaging in a warm-up activity. The teacher then presents a few sample problems and demonstrates how to solve them. This part of the lesson is often conducted in recitation fashion, with the teacher asking fill-in-the-blank questions as the procedures are shown. Seatwork is assigned, and students complete exercises like those they have been shown. The teacher often ends the lesson by checking some of the seatwork problems

and assigning similar problems for homework (Kilpatrick, Swafford, Findell, 2001, pp. 49–50).

Mathematics in the United States has had new standards and revised textbooks and numerous calls for a change in pedagogy. Meanwhile, hands-on learning has been taking place nearby in career and technical education schools. But those were not the college-bound students. Today, they, like most students in the United States, consider themselves college-bound. The pedagogy of ETE may be a model that United States mathematics classes can look to. And they need not cross a border to see it in action.

Revisiting Whitehead's Example

Whitehead's example of the poverty of the current curriculum was quadratic equations. He bemoaned their lack of coherent connection to the living minds of children. Today, while not fully addressing the problems Whitehead presented, we are closer to a pedagogy that can empower the active minds of students. We can think of quadratic equations in multiple representations as seen in Figure 2, and, more important, through a well-grounded ETE curriculum, can present a more lively set of explanations.

A quadratic function can be represented as a parabola. Teachers can explore unique properties of a parabolic reflector that impacts rays of a satellite dish to the focal point or the case of maximizing power delivered to electronic circuits. The teacher can provide more practical mechanisms to mediate the joint exploration and provide a new opportunity for agency to the student. The student can make his/her own investigation and exploration within the parameters of the topic. This could involve design and mathematical inquiry with dynamic geometry tools, for example, the Geometer's Sketchpad or GeoGebra, as illustrated in Figure 3 (see links to these tools in the reference list).

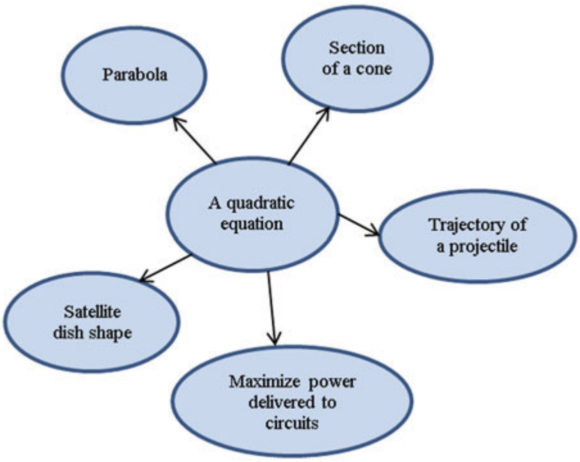


Figure 2. Ways of exploring quadratic equations.

Another example is data gathering from a video of projectile motion. The educational technology program Logger Pro (see reference list) does this, as seen in Figure 4. Another example would be an animated exploration of slicing a cone. The particular technologies mentioned are merely examples.

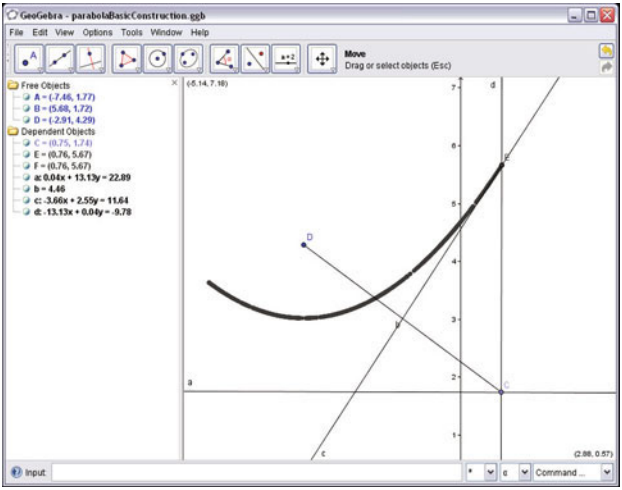


Figure 3. Dynamic analysis of quadratics equation using GeoGebra.

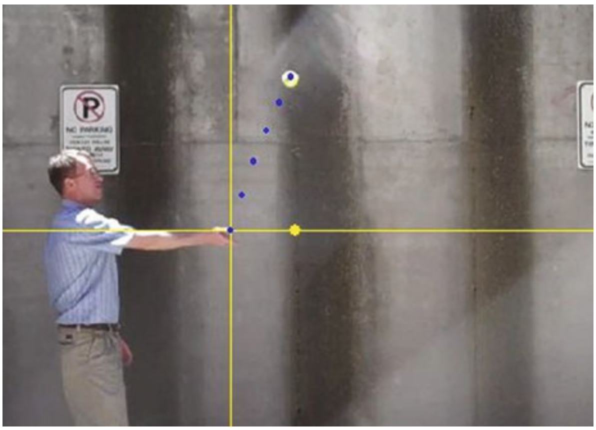


Figure 4. A physics teacher can analyze the motion of a projectile frame by frame.

Many classroom-oriented and professionally-oriented technologies exist and they are changing constantly. The tools are important, but regardless of the tools used, the goal will be to understand the properties of the satellite dish, or why a hanging cable is a catenary and not a parabola, or to get a robot to launch a projectile accurately, or some other practical problem. Through this process, we move closer to the components of problem solving that Schunn and Silk noted in the conclusion of Chapter 1 and in the *Adding It Up* report (Kilpatrick et al., 2001). If this can happen, we can get closer to teaching algebra in the way that Whitehead would have it. That is, an algebra from which something "follows"; as sense of purpose for the learning the mathematics in context.

As Daker reminds us in Chapter 2, we are not merely depositing information into the minds of students. Activity theory tells us that tools matter and the social circumstances in which they are used are also essential. The activity of students and teachers is always mediated by tools, be they chalkboards or calculators or robots.

CONCLUSION

Transformative practices in education are producing a change in the expectations for schooling in which there is an understanding that the needs of the workforce are a driving factor in what, how and when students should be learning. Learning theories are coming together to reveal the key components of the learning process as defined by knowledge acquisition through authentic, inquiry-based learning activities. When we consider the familiar instructional practices of schools, we are seeing the transition to classrooms that embrace engineering and technology education as the means by which learning is designed and knowledge is crafted.

"Tools drive science" (Brown, 2007). They drive education as well, and new tools mean new curricula and new challenges for putting them into action. In this chapter, we have made two points. The first is that ETE has the potential for democratizing education by giving empowering tools to all members of an education community and allowing them to use those tools for their ends. This can militate against the historic tendency to sort students into the college-bound and non-college-bound and rather prepare all students to be lifelong learners. Our second point is that ETE can be a unifying pedagogical approach that embraces multiple tools and multiple curricula to bring us closer to a vision that has been hoped for since the days of Dewey and Whitehead. That is, to make the curriculum closer to the active life of the mind.

REFERENCES

ACT. (2008). *The forgotten middle: Ensuring that all students are on target for college and career readiness before high school*. Iowa City, IA: ACT. Available at http://www.act.org/research/policymakers/reports/ForgottenMiddle.html

American Association for the Advancement of Science (AAAS). (1990). *Science for all Americans: Project 2061*. New York: Oxford University Press.

Bottoms, G., & Anthony, K. (2005). *Project lead the way: A pre-engineering curriculum that works, a new design for high school career/technical studies*. Atlanta, GA: Southern Regional Education Board. Available at http://www.pltw.org/bulletins/SREB_Research_Brief.pdf

Bottoms, G., & Uhn, J. (2007). *Project lead the way works: A new type of career and technical program (Research Brief)*. Atlanta, GA: Southern Regional Education Board. Available at http://www.pltw.illinois.edu/07V29_Research_Brief_PLTW.pdf

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academies Press.

Brooks, H. (1991). Scientific literacy and the future labour force. In T. Husen & J. P. Keeves (Eds.), *Issues in science education: Science competence in a social and ecological context* (pp. 19–29). Oxford, England: Pergamon Press.

Brown, A. L., & Campione, J. C. (1994). Guided discovery in a community of learners. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 229–272). Cambridge, MA: MIT Press. Available at http://www.russellsage.org/special_interest/literacy/Campione.pdf

Brown, J. S. (2007). *Innovation and technology: Interview from Wired Magazine. JohnSeelyBrown.com*. Available at http://www.johnseelybrown.com/wired_int.html

Brown, J. S., & Duguid, P. (2000). *The social life of information*. Boston: Harvard Business School Press.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Bruce, B. C. (1998). *The inquiry page: Learning begins with questions*. Urbana, IL: Inquiry Page. Available at http://inquiry.illinois.edu/index.php

Committee on prospering in the global economy of the 21st century: An agenda for American science and technology. (2005). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: National Academies Press.

Common Core State Standards Initiative. (2010). *Common core standards for mathematics*. Available at http://corestandards.org/assets/CCSSI_Math%20Standards.pdf

Cuban, L. (1993). Computers meet classroom: Classroom wins. *Teachers College Record*, *95*(2), 185–210.

Daugherty, J., Reese, G. C., & Merrill, C. (in press). Trajectories of mathematics and technology education pointing to engineering design. *Journal of Technology Studies*.

Dewey, J. (1902/1956). *The child and the curriculum. The school and society* (Combined ed.). Chicago: University of Chicago Press.

Dugger W. E., Jr. (2002). Roots of technology education: Standards projects. *Journal of Technology Studies*, *28*(2), 96.

GeoGebra. *Free mathematics software for learning and teaching*. Available at http://www.geogebra.org/cms/

Geometer's Sketchpad®. *Dynamic Geometry® mathematics visualization software*. Available at http://www.dynamicgeometry.com/

Gray, L., Thomas, N., & Lewis, L. (2010). *Teachers' use of educational technology in U.S. public schools: 2009 (NCES 2010-040)*. Washington, DC: National Center for Education Statistics, Institute for Education Sciences, U.S. Department of Education. Available at http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2010040

Hansen, L. S., & Reynolds, C. (2003). The future of industrial technology education at the K-12 level. *Journal of Industrial Teacher Education*, *40*(4).

International Society for Technology in Education (ISTE). (2007). *National educational technology standards for students* (2nd ed.). Eugene, OR: ISTE. Available at http://www.iste.org/welcome.aspx

Kilpatrick, J., Swafford, J. O., & Findell, B. (2001). *Adding it up: Helping children learn mathematics (ESI-9816818)*. Washington, DC: Mathematics Learning Study Committee, National Research Council. Available at http://books.nap.edu/html/adding_it_up/summary.pdf

Kirkwood, J., Foster, P., & Bartow, S. (1994). Historical leaders in technology education philosophy. *Journal of Industrial Teacher Education*, *32*(1), 6–25.

Lauda, D. P. (2002). Conceptualizations of Jackson's Mills. *Journal of Technology Studies*, *28*(2), 93–95.

Linn, M. C. (2000). Designing the knowledge integration environment. *International Journal of Science Education*, *22*(8), 781–796.

Linn, M. C., Clark, D., & Slogtta, J. (2003). WISE Design for Knowledge Integration. *Science Education*, *87*(4), 517–538.

Logger Pro 3. Beaverton, OR: Vernier Software & Technology. Available at http://www.vernier.com/soft/lp.html

Mathematical Sciences Education Board, & National Research Council. (1989). *Everybody counts: A report to the nation on the future of mathematics education*. Washington, DC: National Academy Press.

Nagel, D. (2008). The future of instruction: The teacher as co-learner. *THE Journal*. Available at http://thejournal.com/articles/2008/06/30/the-future-of-instruction-teacher-as-colearner.aspx

Peterson, P. L. (1994). Learning and teaching mathematical sciences: Implications for in-service programs. In S. J. Fitzsimmons & L. C. Kerpelman (Eds.), *Teacher enhancement for elementary and secondary science and mathematics: Status, issues, and problems* (pp. 6–1 to 6–36). Washington, DC: National Science Foundation.

Prensky, M. (2001). Digital natives, digital immigrants. *On the Horizon*, *9*(5), 1–10.

Prensky, M. (2009). H. Sapiens digital: From digital immigrants and digital natives to digital wisdom. *Innovate: Journal of Online Education*, *5*(3).

Tapscott, D. (1998). *Growing up digital: The rise of the net generation*. New York: McGraw-Hill.

Tyack, D., & Cuban, L. (1995). *Tinkering toward utopia: A century of public school reform*. Cambridge, MA: Harvard University Press.

Volk, K. E. (1997). Enrollment trends in industrial arts/technology teacher education from 1970–1990. *Journal of Technology Education*, *8*(2), 66–70.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wallis, C., & Steptoe, S. (2006). How to bring our schools out of the 20th century. *Time*. Available online: http://www.time.com/time/nation/article/0,8599,1568429,00.html

Wersch, M. (2008). *A vision of students today (& what teachers must do)*. Encyclopedia Britannica blog. Retrieved from http://www.britannica.com/blogs/2008/10/a-vision-of-students-today-what-teachers-must-do/

Whitehead, A. N. (1929). *The aims of education and other essays* (Mentor Books ed.). New York: The New American Library.

Zargari, A., & MacDonald, K. (1994). A history and philosophy of technology education. *Technology Teacher*, *53*(8), 7–11.

Evangeline S. Pianfetti and George C. Reese
University of Illinois at Urbana-Champaign
USA

BIOGRAPHIS

Moshe Barak

Prof. Moshe Barak is currently the Head of the Department of Science and Technology Education at Ben-Gurion University of the Negev. He received his PhD degree in Education in Science and Technology from the Technion – Israel Institute of Technology (1986), where he served as lecturer and senior research associate. His research interests focus on fostering higher-order cognitive skills such as problem solving and creativity in science and technology education. Prof. Barak has over 30 years of experience in curriculum development and evaluation in areas such as control systems, robotics, image processing and electronics, including teachers' pre-service and in-service training. He has been engaged in a range of studies on the cognitive and affective effects of project-based learning and using information and communication technologies (ICT) in science and technology education.

David Barlex

Dr. David Barlex is an acknowledged leader in design & technology education, curriculum design and curriculum materials development. He directed the Nuffield Design and Technology Project, which produced an extensive range of curriculum materials widely used in primary and secondary schools in the UK and was Educational Manager of Young Foresight, an initiative that has developed approaches to teaching and learning that enhance students' ability to respond creatively to design & technology activities. David's research interests include pedagogy that develops design ability and creativity and the professional development of teachers. He currently collaborates with researchers in the UK, Canada, New Zealand and the USA

David Crismond

David Crismond is an Associate Professor of Science Education at the City College of New York. He received his masters degree in 1992 from MIT's mechanical engineering department, and earned his doctorate in Human Development and Psychology from the Harvard Graduate School of Education in 1997. His has taught for 11 years in NJ public schools, has developed science- and engineering design-related materials at MIT, TERC and Georgia Tech, all with the support of NSF funding. Dr. Crismond's main research interests revolve around K-16 science and engineering cognition and pedagogy, and teacher professional development in these areas. Dr. Crismond recently completed a collaborative NSF-funded project with Tufts University that developed software called the Design Compass that supports students' reflective thinking while designing. He is developing and currently teaching three K-8 graduate courses for in-service teachers that emphasize doing literacy- and math-enhanced hands-on science and engineering activities with students.

John Dakers

John R Dakers was formerly a lecturer at the University of Glasgow in Scotland. He has since joined the University of Technology at Delft in the Netherlands and now works alongside Marc de Vries and his team. He is interested in promoting the need for students to develop a scientific and technological literacy in order to better understand the impact that science and technology have upon society. He writes extensively on issues relating to technology and science education. His first book "Defining Technological Literacy" deals with this very subject and was published by Palgrave MacMillan in 2006. He and his fellow Editors recently won the prestigious "Silvius-Wolansky Award for the Outstanding Scholarly Publication in Technology Education" published by Sense-publishers.

Jenny Daugherty

Dr. Jenny Daugherty is an Assistant Professor in the Technology Leadership & Innovation Department in the College of Technology at Purdue University. Dr. Daugherty received her Ph.D. from the University of Illinois, Urbana-Champaign and was a doctoral fellow with the National Center for Engineering and Technology Education. Her research focuses on the design of technology and engineering professional development, particularly spanning high school teacher education to workforce education.

Raymond A Dixon

Dr. Raymond A Dixon is presently a research associate with the Center for Mathematics, Science and Technology (CeMaST) at the Illinois State University. He received his PhD from the University of Illinois at Urbana-Champaign. His research focuses on expert cognition and performance. He is a fellow of the National Center for Engineering and Technology Education (NCETE) and has worked at different levels in education as a teacher, instructor, trainer and administrator.

Jacques Ginestié

Jacques Ginestié is Professor at the Université de Provence. He is the director of the School of Education of Aix-Marseille (IUFM) and in charge of the research unit Gestepro. His investigations are about the teaching-learning process in sciences and technology education. Through the activity analysis, he studies interactions between pupil, teacher and knowledge in the school organisation with a specific interest for the role played by the technical languages in the transmission of technological knowledge. He is member of many scientific committees and academic societies.

Michael Hacker

Michael Hacker is Co-director of the Center for Technological Literacy at Hofstra University in New York. For almost five decades, Engineering and Technology Education has been at the core of his professional life. Over the past 18 years, he served as PI or Co-PI on ten large-scale NSF projects focused on improving teaching and learning in K-16 STEM education. As the former New York State Education Department (NYSED) Supervisor for Technology Education, he co-managed the development of the New York State Standards for Mathematics, Science, and Technology and led several statewide engineering and technology education curriculum projects. Prior to his NYSED position, he served as a secondary school teacher, department supervisor, and university teacher educator, and was a member of the team that developed the national Standards for Technological Literacy.

Scott D Johnson

Scott D Johnson is Professor and Associate Dean for Online Learning in the College of Education at the University of Illinois at Urbana-Champaign. He has been involved in technology education for over 30 years as high school teacher, training consultant, and teacher educator. His research and consulting activities address ways to improve the quality of technical instruction by exploring the cognitive process differences that enable experts to solve technical problems more efficiently than novices. He received his Ph.D. from the University of Minnesota in the US.

Karl M Kapp

Karl M Kapp, Ed.D. is a scholar, writer and expert on the convergence of learning, technology and education. He is a professor of instructional technology at Bloomsburg University in Bloomsburg, PA and serves as the Assistant Director of the University's Institute for Interactive Technologies. In that capacity he assists government, corporate and non-profit organizations to leverage learning technologies to reach their goals. Karl has served as a National Science Foundation (NSF) external evaluator for over ten years and is currently serving as Co-PI on a NSF grant titled "Simulation and Modeling in Technology Education (SMTE)" to develop a 3D interactive game to teach middle school students math, science and engineering concepts. His team is responsible for game design. He is author of several books discussing the convergence of learning and technology. His most recent collaborative work is "Learning in 3D: Adding a New Dimension to Enterprise Learning and Collaboration" published by Pfeiffer (2010).

Jim Kiggens

Jim Kiggens is the CEO of Course Games, where he is currently producing the "Survival Master" game for STEM education in development by the Center for Technological Literacy, Hofstra University, through their DR K-12 Simulations and Modeling for Technology Education project funded by the NSF. He has been a studio business owner since 1988, producing educational videogames, advergames, simulations, motion graphics, digital effects for broadcast, commercial interactive titles and web designs in parallel with 16 years of teaching media arts on the collegiate level. Since 1995, Jim designed, implemented and delivered the game development and digital animation curricula and programs at Santa Barbara City College, Bellevue University, Cerro Coso College, Mt. San Jacinto College, Mesa College, and Victor Valley College. He the founding Director of the Serious Game Design Institute at Santa Barbara City College, the founding Department Chair in Media Arts at Cerro Coso College, and the founding Department Chair in Multimedia at Mt. San Jacinto College.

Oenardi Lawanto

Technology Education at Utah State University (Email: olawanto@usu.edu). Before coming to Utah State University, he taught several electrical engineering courses for 15 years and held several administrative positions at one large private university in Indonesia. His research interests include the areas of cognition, learning, instruction, and e-learning. He has developed enhanced guided notes (EGN) on electric-circuit courses that invite students to exercise metacognitive knowledge during lectures. He received his Bachelor's, Master's, and PhD degrees from Iowa State University, the University of Dayton, and the University of Illinois at Urbana-Champaign, respectively.

Thomas T Liao

Dr. Thomas T Liao is a Distinguished Teaching Professor Emeritus of the Department of Technology and Society at StonyBrook University. He chaired the department from 1986 to 2002. He is co-editor of the Journal of Educational Technology Systems. In the 1990s, he co-chaired, with Dr. James Rutherford, the New York State Education Department's committee which developed the Learning Standards that integrated the study of Mathematics Science and Technology at the K-12 level. In the past 45 years, he has been involved in many NSF sponsored science, engineering and technology curriculum development and teacher enhancement projects. From the ECCP [Engineering Concepts Curriculum Project] program in the 1960s to the TPE [Technology, People and Environment] project in the 1970s to the STIM [Socio Technological Instructional Modules] project in the 1980s to the MSTe [Math, Science, Technology in Elementary grades] project in the 1990s to the MSTP [Math, Science, Technology Partnership] program in the 2000s. As a science and engineering educator, his expertise is the use technological contexts to help students to learn and apply STEM concepts. He was an early advocate and one of the leaders of the STS [Science, Technology and Society] movement.

Linda Rae Markert

Following more than thirteen years of service, Markert recently stepped down as the Dean of the School of Education at the State University of New York at Oswego. Under her leadership since November 1997, the unit received accreditation of its educator certification programs by NCATE. She is also responsible for bringing over $2 million in external grant funds to SUNY Oswego. Prior to becoming dean, she chaired Oswego’s Department of Technology. She held a professorship for fifteen years at San Jose State University. Dr. Markert returns to her full professor position in Oswego’s Department of Educational Administration. Markert holds her doctorate from the University of the Pacific. She received a Visiting Scholar appointment at the Massachusetts Institute of Technology, and completed a leadership symposium at the Harvard Graduate School of Education. The fifth edition of her textbook titled Contemporary Technology: Innovations, Issues & Perspectives was released in 2010.

Johnny J Moye

Johnny J Moye, Ph.D., is a Career and Technical Education Supervisor at Chesapeake Public Schools, Chesapeake, VA, USA. He supervises curriculum and professional development for 126 Engineering and Technology Education, Family and Consumer Sciences, and Trade and Industry teachers. He has published articles on classroom practice and incorporating Core Academic content into Career and Technical Education courses.

Evangeline S. Pianfetti

Dr. Evangeline S Pianfetti (Vanna) is the Assistant Dean for Learning Technologies at the University of Illinois, College of Education in Urbana-Champaign. She is also a Visiting Assistant Professor in the Department of Educational Psychology and Special Education. Currently, she is the principle investigator for the I-LLINI Partnerships grant which aims to improve middle school student performances in core content area through the meaningful integration of technology. Vanna is a Smithsonian Laureate for classroom innovation in technology and a Gold Award winner in the ThinkQuest for Tomorrow's Teachers competition.

George Reese

Dr. George Reese is Director of the Office for Mathematics, Science, and Technology Education in the College of Education at the University of Illinois in

Urbana-Champaign. His work is focused on teacher professional development and university-school partnerships to improve K-12 STEM education.

John M Ritz

John M Ritz, Ed.D., is professor and graduate program director of STEM Education at Old Dominion University, Norfolk, VA, USA. He has worked extensively with technological literacy curriculum development and STEM integrative approaches to instruction throughout his career. He has published on educating classroom teachers about new developments in technology and how these can be taught through a technological and engineering literacy programs. John may be reached at jritz@odu.edu

Christian D Schunn

Christian D Schunn is a Research Scientist at the Learning Research and Development Center and an Associate Professor of Professor of Psychology, Intelligent Systems, and Learning Sciences and Policy at the University of Pittsburgh. He received his PhD in Psychology from Carnegie Mellon in 1995. His research ranges from cognitive / social psychology studies of science/engineering and connections to classroom technology, math, and science instruction.

Eli M Silk

Eli M Silk is a PhD candidate in the Cognitive Studies in Education program and a Graduate Student Researcher at the Learning Research and Development Center at the University of Pittsburgh. He received his BA in Computer Science at Swarthmore College in 2001. His current research focuses on the role of mathematics in helping K-12 students better understand and design physical systems.

Marc J de Vries

Marc J de Vries is professor of Science Education at Delft University of Technology, affiliate professor of Reformational Philosophy of Technology at the same institute, and assistant professor at Eindhoven University of Technology. He is the editor-in-chief of the International Journal of Technology and Design Education. He published, among others, the book Teaching About Technology, an introduction to philosophy of technology for technology educators.

P John Williams

Associate Prof. P John Williams is the Director of the Centre for Science and Technology Education Research at the University of Waikato. He teaches and supervises research students in technology education. Apart from New Zealand, he has worked and studied in a number of African and Indian Ocean countries and in Australia and the United States. He directed the nationally funded Investigation into the Status of Technology Education in Australian Schools. His current research interests include mentoring beginning teachers and electronic assessment of performance. He has published over 40 articles and has authored and co-authored 11 books, regularly presents at international and national conferences, consults on Technology Education in a number of countries, is a longstanding member of 8 professional associations and is on the editorial board of 4 professional journals. He is the External Examiner for the Mauritius and Hong Kong Institutes of Education. He holds an adjunct professorial position at Edith Cowan University in Perth, Western Australia.

INDEX

S