Chapter 3

THE "T" AND "E" IN STEM

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For more than a decade, experts from across the United States have warned of a looming national crisis in the fields of science, technology, engineering, and mathematics. The crisis, as most suggest, is a looming shortage of professionals entering the fields of science, technology, engineering, and mathematics (STEM). Researchers and prognosticators alike predict anything from a loss of productivity and gross national product to a very real lowering of the standard of living in the United States if increased attention is not given to the STEM disciplines.

Supporting the STEM quandary in the United States, the National Research Council (2007) noted that just as the nation's economic engines and national security measures have come to rest squarely on the shoulders of the STEM fields, secondary and post-secondary students are turning away from science, technology, engineering, and mathematics in record numbers. Meanwhile, the National Science Board reported that the United States is currently experiencing a chronic decline in homegrown STEM talent and is increasingly dependent upon foreign scholars to fill workforce and leadership voids (National Science Foundation, 2008). Similarly, the Council of Graduate Schools (2007) noted that university graduate student admissions to some post-secondary STEM programs are down more than 30 percent over previous levels, and in some areas only 16 percent of the students in science and engineering disciplines were citizens of the United States. At the same time as students and professionals seem to be turning away, career opportunities in STEM fields seem to be exploding. A recent report from the U.S. Bureau of Labor Statistics predicts that the number of jobs in STEM occupations will grow by 47 percent—three times the rate of all other occupations by the year 2010 (AASCU, 2005).

All of this leads one to consider the urgency and timeliness of this publication and the necessity that the conversation not be confined to individual disciplines and their respective desires and issues, but rather to the entirety of STEM. Clearly, the fields of mathematics, science, engineering, and technology each have internal concerns and initiatives that exclude the others, but STEM education is more than, as they say, the sum of its parts. STEM education has the potential to prepare the next generation of students with enhanced skills to solve complex problems, consider consequences, think critically, collaborate across disciplinary boundaries, invent and innovate, and compete with the best the world has to offer.

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For more than a decade experts from across the United States have warned of a looming national crisis in the fields of science, technology, engineering, and mathematics.

STEM education in K-12 education has never been more important, nor as much discussed. To address the persistent issues raised by state and national reports, as well as reports from business and industry, substantial efforts must be undertaken to improve elementary and secondary science and mathematics education as well as increased efforts to provide technology and engineering education for all precollege students. Identifying a field of study as a STEM discipline is a way of clarifying what is and what is not included in the STEM club. Unfortunately, while there is generally some degree of clarity about the "S" and the "M," there is also widespread uncertainty by many about the other half of the acronym.

Numerous publications have emphasized the position that STEM plays in our national security as well as the present and future economic competitiveness and viability of the United States (AASCU, 2005; ITEA, 2000/2002/2007; NSF, 2003; NRC, 2007; Potter, et al). But while such an emphasis has been encouraging to those who have advocated on its behalf, two letters seem to have gotten lost in the middle of the acronym: the "T" and the "E"—or the technology and engineering—seem to be overlooked by many (Dieffenderfer, 2006). To support this assertion, consider the number of school districts and states that have increased mathematics and science requirements in recent years by adding courses, inserting mandatory high-stakes tests, and by championing rigor, and then consider the minority of school districts and states that have initiated comprehensive STEM education programs that address the "T" and the "E" in the STEM acronym as well as science and mathematics.

> *So, squeezed for time and resources, relatively few local school districts and states or provinces have opted for what they see as the luxury of including the study of technology as part of the core curriculum (ITEA, 2000/2002/2007, p. 3).*

It therefore seems reasonable to conclude that many educational and political leaders have yet to comprehend or accept the collective nature of STEM education and have rather attempted to address perceived problems by heaping on increased expectations and requirements for mathematics and science education. What these leaders fail to recognize or acknowledge is the potential that technology and engineering educa-

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tion have for exponentially increasing the synergy and yield of STEM learning activities in the K-12 educational systems in America.

Dieffenderfer (2006) suggests that many policymakers and educators simply assume that if students learn increased levels of science and mathematics, they will have accomplished STEM education, and all will be well. While most would agree that a strong foundation and deep skills in mathematics and science are certainly important, preparing the next generation in these two disciplines alone will not address the dearth of STEM talent identified in most state and national reports. Students with little or no exposure to or experience with technology or engineering have a very low probability of engaging in those fields after schooling is complete (Dieffenderfer). The International Technology Education Association (2000/2002/2007) noted that, when taught effectively, technology was not simply one more field of study seeking admission to an already crowded school curriculum, but rather it serves to reinforce and complement the material that students learn in other STEM classes. Bybee (2000) noted that, for a society so deeply dependent on technology, we are largely ignorant about technology concepts and processes, and we have largely ignored this incongruity in our educational system.

"T" is for Technology

When considering the "T" in STEM, many mistakenly fall for one of two familiar misconceptions. First, many assume that the technology in STEM is referring to the implementation of computers and/or instructional technology devices and software. While computers are certainly a part of the equation in technology education, this definition is far too narrow an understanding and represents only one technological tool among many. Conversely, technology education should be viewed in the sense of a discipline dedicated to the study of all the modifications humans have made in the natural environment for their own purposes (Dugger & Naik, 2001).

> *"To be clear, the use of computers, as one of many educational technologies, is essential in this age. However, it should not be confused with the study of technology, which provides students with opportunities to learn about the processes of design, fundamental concepts of technology and engineering, and the limits and possibilities of technology in society" (Bybee, 2000, p. 23).*

This discipline, commonly referred to as technology education, includes the study and application of learning experiences related to inventions, innovations, and changes intended to meet human wants and needs. In short, if humans thought of it and made it, it's technology (Wonacott, 2001). The International Technology Education Association (2000/2002/2007) defines technology as the modification of the natural environment in order to satisfy perceived human needs and wants (p. 9).

The common assumption that the word technology in STEM is referring to computers is compounded by a second familiar misconception. When asked to define the word technology, many individuals suggest that it is the application of science or applied mathematics. Although this definition of technology has a long standing in this country (Stokes, 1997), it is well past time to establish a new understanding about technology (Bybee, 2000). Sanders (1999) indicated that while science and technology are closely related, there are fundamental differences. Science generates knowledge for its own sake by proposing and testing explanations, while technology, on the other hand, develops human-made solutions to real problems. Of course, science uses technology to generate knowledge, and technology uses scientific knowledge to generate solutions, so the two are integrally connected; but they are different fields driven by different concepts and processes (Bybee, 2000).

Technology education is a discipline devoted to the delivery of technological literacy for all. As a result of studying technology in Grades K-12, students gain a level of technological literacy that may be described as one's ability "…to use, manage, assess, and understand technology" (ITEA, 2000/2002/2007, p. 9). In the report, *Technically Speaking: Why All Americans Need to Know More about Technology* (2002), the National Research Council declared the overriding benefit of being technologically literate:

> *In a world permeated by technology, an individual can function more effectively if he or she*

> *is familiar with and has a basic understanding of technology.*

Further, the report suggests that to take full advantage of the benefits of technology, or even avoid some of the pitfalls of technology, we must become better stewards of technological change. The variety of technology available today is extensive, as are the human problems that technology might solve. As a result, individuals need more than just knowledge of the technology that surrounds them; they also need the skills and knowledge to use the new and changed technologies of tomorrow—they need to be technologically literate (Potter, et al. 2000).

Technology education programs in the K-12 schools are advancing, not with the goal of preparing students for the workplace or increasing the relevance of core subjects, but to provide all students with a measure of technological literacy. The goal is to prepare citizens who understand the nature of technology and its interaction with the other STEM disciplines and society (Cajas, 2001). It's the objective of literacy—core ideas, concepts, skills, and values that are important for all citizens—that connects science, technology, engineering, and mathematics. Cajas (2001) noted that:

> *Traditionally, the interaction between science and technology education has been seen in terms of dichotomies: technology is "doing," while science is "understanding," and so on. However, when we move to the arena of literacy in science and technology, these dichotomies no longer hold: there is a common body of scientific and technological ideas and skills that is relevant for the education of all students (p. 725).*

One of the great benefits of learning about technology in a K-12 classroom or laboratory is to conduct activities and experiments that reflect the development of technology in the real world. Recent research on learning finds that many students learn best in experiential concrete ways rather than only through visual or auditory methods—and the study of technology emphasizes and capitalizes on such active learning (ITEA, 2000/2002/2007). For these reasons and others, a growing number of leaders have called for the study of technology to be included as a core field of study in elementary, middle, and secondary schools (ITEA).

Although there is a common tendency to emphasize the positive impacts of technology, *Standards for Technological Literacy: Content for the Study of Technology (STL)* (ITEA, 2000/2002/2007) calls on all educators to examine the intended as well as the unintended consequences of technological development and proliferation. Moreover, the standards outline the core concepts of technology and the relationship between technology and society as well as the complex relationship between technology and the environment, among numerous other standards. One of the fundamental lessons of technology education is that while technology can be used to solve problems, it may also create new ones (ITEA, 2000/2002/2007). Bybee (2003) noted that one unfulfilled promise in American education stands out above the rest, and that is the technological literacy of all citizens. Technology education provides a pathway to that needed technological literacy for all (Deal, 2002).

"E" is for Engineering

Unlike the disciplines of mathematics, science, and technology, engineering does not have an historic home in K-12 education. Subsequently, efforts to include engineering content at the secondary level have historically resulted from university outreach programs, units included in science classes, demonstration projects funded by external agencies (i.e., National Science Foundation, etc.), and most prominently through insertion into the technology education curriculum. The relationship between technology education and engineering has always been strong, but the recent public emphasis on K-12 engineering has served to strengthen the bond and provide incentives for the two fields to complement one another at the secondary level.

The ties between engineering and technology education have also recently been strengthened through the development and publication of *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000/2002/2007). Both fields have a strong interest and a mutually beneficial need for a technologically literate citizenry. While leaders in technology education often view engineering as a core concept with applications for all students and citizens, engineers tend to view technological literacy as an avenue that can be used to gain entrance to the field of engineering. Reid and Feld-

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haus (2008) supported this assertion when they noted that there is a movement by the engineering community to gain a better understanding of the K-12 issues that impact enrollment at postsecondary institutions, and to advance the state of engineering.

Given the broad interest in technological literacy, engineering and technology education can work in unison to promote K-12 educational programs that further core engineering concepts for all, as well as creating pathways to careers in engineering. Both fields have contributions to make. While technology education is recognized as the study of the human-made world, its artifacts and processes, engineering uses knowledge of science, mathematics, and technology to understand, design, and implement solutions to human problems.

Engineering uniquely connects the disciplines of mathematics, science, and technology education. Engineering is a way of understanding the human-made world, how it was created, how it functions, and how it might be changed (Burghardt & Hacker, 2009). Unlike scientific inquiry and mathematical analysis, engineering design does not seek a unique or correct solution, but rather seeks the best or optimum solution after a variety of factors are weighed, such as cost, materials, aesthetics, and marketability (Burghardt & Hacker). Likewise, Petroski (1996) suggested that the role of design is what most distinguishes engineering from science, which concerns itself principally with understanding the world as it is. Moreover, Petroski affirmed that:

> *Engineers throughout history have wrestled with problems of water not being where it was needed, of minerals not being close at hand, of building materials having to be moved" (p. 2).*

In this way, technology and engineering education use very similar approaches to the design process. However, technologists (or inventors and innovators) often use a design problem-solving process (or design loop) that includes less predictive modeling and analysis and more trial and error. Petroski (1996) noted that while engineering is a more highly mathematical and scientific endeavor, its practice still requires a good deal of commonsense reasoning about materials, structures, energy, and the like. Whereas mathematics and science help humans analyze existing ideas and their embodiment in "things," these analytical tools do not, in themselves,

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give us those ideas. Engineers have to determine how to alter nature and existing artifacts to better achieve objectives considered beneficial to humankind. In this way, the fields of technology and engineering education are inextricably linked by their common focus on the (engineering) design process. Technology educator and former Director of the Technology for All Americans Project, William Dugger once noted that:

> *[Design] is as fundamental to technology as inquiry is to science and reading is to language arts (ITEA, 2000/2002/2007, p. 90).*

Similarly, from the engineering community, William Wulf, former Director of the National Academy of Engineering, once noted that:

> *My favorite operational definition of what engineers do is, "design under constraint." We design solutions to problems. However, there are a set of constraints that we have to satisfy—size, weight, reliability, safety, economic factors, environmental impact, manufacturability, and whole list of "-bilities" (Wulf, 2002, p. 4).*

Design has been recognized as an essential part of technological understanding, and for many individuals the essence of engineering is design (Goldman, 1984).

Design: The Common Link between Technology and Engineering Education

Design is regarded by many as the core problem-solving process of technological development and engineering (ITEA, 2000/2002/2007). Koen (2003) noted that "design is the essence of engineering" (p. 28) and further suggested that design is the unique, essential core of the human activity called engineering. But for it, the engineer would not exist. Although alternatively called *engineering design*, the *engineering method*, the *design method*, *iterative design*, the *design loop*, and other names, for the purposes of clarity the concept/procedure will here be referred to as engineering design. Engineering design is the process of devising a system, component, or process to meet desired human needs and wants. It is an iterative decision-making process through which basic science, mathematics, and technological knowledge are applied to optimally meet a stated objective. In *Standards for Technological Literacy*, engineering design is described as:

> *A distinctive process with a number of defining characteristics: it is purposeful; it is based on requirements; it is systemic; it is iterative; it is creative; and there are many possible solutions (ITEA, 2000/2002/2007, p. 91).*

This description of engineering design seems equally well suited to either the field of technology or engineering education.

McNeill and Bellamy (1998) noted that, while each technological or engineering problem may have a unique solution, the underlying approach used to develop the solution is not unique. Effective problem solvers typically utilize a generic methodology that increases their probability of success. Although the literature presents a myriad of engineering design models or procedures for solving design problems, a methodology that is useful in both technology and engineering education consists of defining the problem clearly at the outset, gathering applicable research and related information, generating alternative solutions, evaluating or testing the alternatives through the use of models and prototypes, and finally communicating the results (Dieter, 2000). Beyond the engineering design process often used as a tool in technology education circumstances, engineering design processes used in the field of engineering frequently call for the formulation of a mathematical model or proof of the best system concept. The engineering design process can be applied to solve simple engineering or technological problems, design new products (whether they be consumer goods or highly complex products such as missile systems or jet planes), or to design complex systems such as an electric power generating station or a chemical plant, while yet another area is the design of a building or bridge (Dieter, 2000).

Regardless of the specific process used, the engineering design process may be best characterized by its iterative nature. The design of a new product or system is rarely as clear or linear as it seems when reading about it in history textbooks. The engineering design process is an iterative, creative, and nonlinear process that often requires backtracking and rethinking (Koen, 2003).

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Engineers refer to the use of heuristics to describe the implementation of known facts or quantities that can be plugged in toward the potential solution of a problem. A heuristic is a plausible aid or direction in solving an engineering or technological problem that is in the final analysis unjustified, incapable of justification, and potentially fallible (Koen, 2003). Koen noted that:

> *Engineering design, or the engineering method, is the use of heuristics to cause the best change in a poorly understood situation within the available resources (2003, p. 28).*

Technologists do not use heuristics in the sense that engineers do, relying instead on the pragmatic implementation and/or adaptation of known solutions to similar problems. These solutions are tempered by experiences, societal values, and available resources. Hence, the optimal solution to a given problem implemented by a technologist and the one implemented by an engineer may differ greatly, just as the route to that solution may differ greatly—but both will have arrived at that solution using a version of the engineering design process. Because we can bring our values to our design solutions, engineering design can be a very engaging instructional activity (Burghardt & Hacker, 2009).

Summary

Technological wherewithal is essential in this age, and the STEM disciplines of technology and engineering education have a substantial role to play in preparing those individuals who will pursue careers in STEM, but perhaps more importantly, these two disciplines will play an increasingly vital role in preparing those citizens who will interact with STEM in a less apparent manner. Collectively, STEM programs should prepare all citizens to interact with existing technologies and plan for a future that they can’t even imagine. Technology and engineering education will provide all K-12 students with the conceptual knowledge, design experience, and confidence to interpret what exists and improve upon it. The interaction between the natural inquiries of science, the analyses offered in mathematics, and engineering design offered in technology and engineering education will prepare future citizens who understand the limits, strengths, and possibilities of the natural and the technological world.

Clearly, the value of STEM education is greater than the sum of its parts. At the heart of STEM education is the interface between the disciplines, and for the desired synergy to occur advantageously, science, technology, engineering, and mathematics must all be at the table. In the science community, the result of such synergy is referred to as emergence—where the product of collaborative systems or organisms results in qualities not directly traceable to the individual components. Such emergence is also achievable and desirable in STEM education programs, but all members of STEM must be equally represented. Let us challenge educational leaders to invest in programs that include the optimum from all STEM disciplines and prepare citizens to thrive in a world where continual change and adaptation are the norm. A wealth of natural resources, ingenuity, and hard work provided the mechanisms that transformed our nation during the 20th Century. National and international transformations during the 21st Century will be driven by those who invest in and advance comprehensive STEM education programs.

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