

**ENGINEERING  
AND  
TECHNOLOGY  
EDUCATION**

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**Editors**

**Rodney L. Custer  
Thomas L. Erekson**

**57th Yearbook**

***Council on Technology  
Teacher Education***

**2008**

# Engineering and Technology Education

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## **Editors**

Rodney L. Custer  
Thomas L. Erekson

**57th Yearbook, 2008**

*Council on Technology Teacher Education*



**Glencoe**



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# FOREWORD

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For many of us, the term "engineering" brings to mind the mathematical precision required of designing products, structures, and technical systems. Concepts related to innovation and scientific reasoning can also come to mind. The knowledge associated with ergonomics, or human-factors engineering, may be an important part of the discussion.

In reality, much of the modern world has been carefully engineered for efficiency, performance, and safety. For instance, transportation planners have developed corridors that handle increasing volumes of traffic. Structural engineers have designed bridges, towers, and skyscrapers based on utility and function. Even the preparation area behind the counter at your favorite fast food establishment has been time studied to insure prompt service. That's right, your drink and sandwich were designed for efficient preparation, and dispensed to you from a service area approved through industrial engineering. Both the service and productive sectors are based on engineering principles.

Thus the 2008 CTTE Yearbook combines two most relevant topics: engineering and technology education. Due to the impact of these professions, this book is timely as well as informative. As the field of Technology Education continues to evolve, design and engineering thought has become essential content for all. I believe this work can provide a blueprint for attention and action well into the future.

On behalf of the Council on Technology Teacher Education, I commend the efforts of Drs. Rodney L. Custer and Thomas L. Erikson, co-editors of the 57th CTTE yearbook. Their time and dedication in directing this project is certainly appreciated. In addition, these two gentlemen have assembled an impressive team of chapter authors. We are delighted that these authors took time to share their wisdom and experiences with the Council membership.

I would sincerely hope that this publication gathers little dust on your shelf. Rather, I hope you will find numerous ways that this yearbook can direct your perceptions and shape your educational practices. Enjoy your Council yearbook, and thanks to all involved in its production.

Richard D. Seymour  
President, CTTE  
February 2008

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# YEARBOOK PROPOSALS

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Each year at the ITEA International Conference, the CTTE Yearbook Committee reviews the progress of yearbooks in preparation and evaluates proposals for additional yearbooks. Any member is welcome to submit a yearbook proposal, which should be written in sufficient detail for the committee to be able to understand the proposed substance and format. Fifteen copies of the proposal should be sent to the committee chairperson by February 1 of the year in which the conference is held. Below are the criteria employed by the committee in making yearbook selections.

CTTE Yearbook Committee

## CTTE Yearbook Guidelines

### A. Purpose

The CTTE Yearbook Series is intended as a vehicle for communicating major topics or issues related to technology teacher education in a structured, formal series that does not duplicate commercial textbook publishing activities.

### B. Yearbook topic selection criteria

An appropriate yearbook topic should:

1. Make a direct contribution to the understanding and improvement of technology teacher education;
2. Add to the accumulated body of knowledge of technology teacher education and to the field of technology education;
3. Not duplicate publishing activities of other professional groups;
4. Provide a balanced view of the theme and not promote a single individual's or institution's philosophy or practices;
5. Actively seek to upgrade and modernize professional practice in technology teacher education; and,
6. Lend itself to team authorship as opposed to sole authorship.

Proper yearbook themes related to technology teacher education may also be structured to:

1. Discuss and critique points of view that have gained a degree of acceptance by the profession;
2. Raise controversial questions in an effort to obtain a national hearing; and,
3. Consider and evaluate a variety of seemingly conflicting trends and statements emanating from several sources.

### C. The Yearbook Proposal

1. The yearbook proposal should provide adequate detail for the Yearbook Committee to evaluate its merits.
2. The yearbook proposal includes the following components:
  - a) Defines and describes the topic of the yearbook;
  - b) Identifies the theme and describes the rationale for the theme;
  - c) Identifies the need for the yearbook and the potential audience or audiences;
  - d) Explains how the yearbook will advance the technology teacher education profession and technology education in general;
  - e) Diagrams symbolically the intent of the yearbook;
  - f) Provides an outline of the yearbook which includes:
    - i) A table of contents;
    - ii) A brief description of the content or purpose of each chapter;
    - iii) At least a three level outline for each chapter;
    - iv) Identification of chapter authors and backup authors;
    - v) An estimated number of pages for each yearbook chapter; and,
    - vi) An estimated number of pages for the yearbook (not to exceed 250 pages).
  - g) Provides a timeline for completing the yearbook.

It is understood that each author of a yearbook chapter will sign a CTTE Editor/Author Agreement and comply with the Agreement. Additional information on yearbook proposals is found on the CTTE Web site at <http://teched.vt.edu/ctte/>.

# PREVIOUSLY PUBLISHED YEARBOOKS

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- \*1. *Inventory Analysis of Industrial Arts Teacher Education Facilities, Personnel and Programs*, 1952.
- \*2. *Who's Who in Industrial Arts Teacher Education*, 1953.
- \*3. *Some Components of Current Leadership: Techniques of Selection and Guidance of Graduate Students; An Analysis of Textbook Emphases*; 1954, three studies.
- \*4. *Superior Practices in Industrial Arts Teacher Education*, 1955.
- \*5. *Problems and Issues in Industrial Arts Teacher Education*, 1956.
- \*6. *A Sourcebook of Reading in Education for Use in Industrial Arts and Industrial Arts Teacher Education*, 1957.
- \*7. *The Accreditation of Industrial Arts Teacher Education*, 1958.
- \*8. *Planning Industrial Arts Facilities*, 1959. Ralph K. Nair, ed.
- \*9. *Research in Industrial Arts Education*, 1960. Raymond Van Tassel, ed.
- \*10. *Graduate Study in Industrial Arts*, 1961. R.P. Norman and R.C. Bohn, eds.
- \*11. *Essentials of Preservice Preparation*, 1962. Donald G. Lux, ed.
- \*12. *Action and Thought in Industrial Arts Education*, 1963. E.A.T. Svendsen, ed.
- \*13. *Classroom Research in Industrial Arts*, 1964. Charles B. Porter, ed.
- \*14. *Approaches and Procedures in Industrial Arts*, 1965. G.S. Wall, ed.
- \*15. *Status of Research in Industrial Arts*, 1966. John D. Rowlett, ed.
- \*16. *Evaluation Guidelines for Contemporary Industrial Arts Programs*, 1967. Lloyd P. Nelson and William T. Sargent, eds.
- \*17. *A Historical Perspective of Industry*, 1968, Joseph F. Luetkemeyer Jr., ed.
- \*18. *Industrial Technology Education*, 1969. C. Thomas Dean and N.A. Hauer, eds.; *Who's Who in Industrial Arts Teacher Education*, 1969. John M. Pollock and Charles A. Bunten, eds.
- \*19. *Industrial Arts for Disadvantaged Youth*, 1970. Ralph O. Gallington, ed.
- \*20. *Components of Teacher Education*, 1971. W.E. Ray and J. Streichler, eds.
- \*21. *Industrial Arts for the Early Adolescent*, 1972. Daniel J. Householder, ed.
- \*22. *Industrial Arts in Senior High Schools*, 1973. Rutherford E. Lockette, ed.
- \*23. *Industrial Arts for the Elementary School*, 1974. Robert G. Thrower and Robert D. Weber, eds.
- \*24. *A Guide to the Planning of Industrial Arts Facilities*, 1975. D.E. Moon, ed.
- \*25. *Future Alternatives for Industrial Arts*, 1976. Lee H. Smalley, ed.
- \*26. *Competency-Based Industrial Arts Teacher Education*, 1977. Jack C. Brueckman and Stanley E. Brooks, eds.
- \*27. *Industrial Arts in the Open Access Curriculum*, 1978. L.D. Anderson, ed.
- \*28. *Industrial Arts Education: Retrospect, Prospect*, 1979. G. Eugene Martin, ed.
- \*29. *Technology and Society: Interfaces with Industrial Arts*, 1980. Herbert A. Anderson and M. James Benson, eds.
- \*30. *An Interpretive History of Industrial Arts*, 1981. Richard Barella and Thomas Wright, eds.

- \*31. *The Contributions of Industrial Arts to Selected Areas of Education*, 1982. Donald Maley and Kendall N. Starkweather, eds.
- \*32. *The Dynamics of Creative Leadership for Industrial Arts Education*, 1983. Robert E. Wenig and John I. Mathews, eds.
- \*33. *Affective Learning in Industrial Arts*, 1984. Gerald L. Jennings, ed.
- \*34. *Perceptual and Psychomotor Learning in Industrial Arts Education*, 1985. John M. Shemick, ed.
- \*35. *Implementing Technology Education*, 1986. Ronald E. Jones and John R. Wright, eds.
- \*36. *Conducting Technical Research*, 1987. Everett N. Israel and R. Thomas Wright, eds.
- \*37. *Instructional Strategies for Technology Education*, 1988. William H. Kemp and Anthony E. Schwaller, eds.
- \*38. *Technology Student Organizations*, 1989. M. Roger Betts and Arvid W. Van Dyke, eds.
- \*39. *Communication in Technology Education*, 1990. Jane A. Liedtke, ed.
- \*40. *Technological Literacy*, 1991. Michael J. Dyrenfurth and Michael R. Kozak, eds.
- \*41. *Transportation in Technology Education*, 1992. John R. Wright and Stanley Komacek, eds.
- \*42. *Manufacturing in Technology Education*, 1993. Richard D. Seymour and Ray L. Shackelford, eds.
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- \*44. *Foundations of Technology Education*, 1995. G. Eugene Martin, ed.
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- 46. *Elementary School Technology Education*, 1997. James J. Kirkwood and Patrick N. Foster, eds.
- 47. *Diversity in Technology Education*, 1998. Betty L. Rider, ed.
- 48. *Advancing Professionalism in Technology Education*, 1999. Anthony F. Gilberti and David L. Rouch, eds.
- \*49. *Technology Education for the 21st Century: A Collection of Essays*, 2000. G. Eugene Martin, ed.
- \*50. *Appropriate Technology for Sustainable Living*, 2001, Robert C. Wicklein, ed.
- 51. *Standards for Technological Literacy: The Role of Teacher Education*, 2002. John M. Ritz, William E. Dugger, and Everett N. Israel, eds.
- 52. *Selecting Instructional Strategies for Technology Education*, 2003. Kurt R. Helgeson and Anthony E. Schwaller, eds.
- 53. *Ethics for Citizenship in a Technological World*, 2004. Roger B. Hill, ed.
- 54. *Distance and Distributed Learning Environments: Perspectives and Strategies*, 2005. William L. Havice and Pamela A. Havice, eds.
- 55. *International Technology Teacher Education*, 2006. P. John Williams, ed.
- 56. *Assessment of Technology Education*, 2007. Marie Hoepfl and Michael R. Lindstrom, eds.

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# *PREFACE*

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One of the purposes of the CTTE Yearbook series since its inception has been to address issues and trends that are important to the technology education field in a thoughtful and scholarly manner. This can represent a substantial challenge given the complexity of the issues and the substantial lead times required to conceptualize and produce an edited book of this type. The relationship of engineering and technology education has emerged over the past decade as an issue that warrants scholarly discourse. As with most trends, it is important to subject motives, thinking, and directions to thoughtful analysis, critique, and debate. Such is the case with the emerging relationship between engineering and technology education. Our hope is that this book will contribute to the discussion by framing key issues, providing historical context, and conceptualizing a base of theory.

Finally, we wish to thank our technology education and engineering colleagues who have provided encouragement and guidance for this work. We hope that the perspectives presented by the chapter authors will spur a scholarly dialog among the constituent groups and that this book will provide a foundation for a mutually valuable collaboration between engineering and technology education. We also wish to thank Glencoe/McGraw-Hill for the invaluable support that they have provided over the years.

57th Yearbook Editors  
Rodney L. Custer  
Thomas L. Erikson

# ACKNOWLEDGMENTS

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We would like to thank our friends at Glencoe/McGraw-Hill for their ongoing commitment to Technology Education through the CTTE Yearbook series. The yearbooks serve to document the key issues in our profession today and provide a valuable resource in establishing and communicating a future direction.

We also want to express appreciation to the Yearbook Committee for their guidance and support in the planning and writing process. The expertise and commitment of these individuals sustains a long tradition of professionalism that dates back to the inception of the series.

Finally, we particularly want to thank the author team for their work. They were responsive to deadlines and, more important, our requests for everything from major changes to minor edits. We genuinely respect and thank them for their insights and professionalism.

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Rodney L. Custer  
Illinois State University  
Thomas L. Erekson  
Western Illinois University

# INTRODUCTION

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The theme of this book seems *just right to me*—there needs to be a dialog between engineering educators and technology educators! They share two profound responsibilities and have much to learn from each other.

One of these responsibilities is to educate the best engineers in the world. The other is to create a public with enough understanding of engineering and technology to be responsible citizens in a technologically sophisticated democracy. Engineering is about creating technologies that satisfy human wants and needs, and many, if not most, of the most pressing problems facing us require just such engineered solutions: climate change, energy independence, economic prosperity in a “flat” world, and on and on. Solving these problems will require good engineering, but also a public that understands enough about engineering and technology to thoughtfully choose between competing claims on our public purse.

Thoughtful educators of both engineering and technology have recognized these dual responsibilities and have begun the task of reforming their respective curricula and introducing new pedagogy. The International Technology Education Association’s *Standards for Technological Literacy* and the National Academy of Engineering’s *Educating the Engineer of 2020* are but two examples of this. But think about how much more effective these efforts would be if they were seamless across the university/K–12 interface! Indeed, they would be better yet if it were seamless across the university/community college/K–12 interface! The dialog contained in this book won’t single-handedly achieve that seamless interface, but it’s a start.

The scholarly approach and tone of the book seem especially important to me. Too often in the past, work on both engineering and technology education has lacked good scholarship, and both the specific work and the fields have been dismissed as “light-weight” as a result. For our part at the NAE, several years ago we created the Center for the Advancement of Scholarship in Engineering Education (CASEE), with stress on the word “scholarship”, to address this issue because we felt it so important. One center at the NAE, and one scholarly book on engineering and technology education won’t wipe out impressions from decades of poor scholarship, but it’s a start.

And so, I say again, the theme of this book seems *just right to me*.

Wm. A. Wulf  
University Professor, University of Virginia  
President Emeritus, National Academy of Engineering

# Conceptual Foundations: Engineering and Technology Education

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## Chapter

Thomas L. Erikson  
Western Illinois University

Rodney L. Custer  
Illinois State University

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## INTRODUCTION

As we enter the 21st century it is clear that engineering education and technology education have the potential for a symbiotic alliance that will benefit both fields. Engineering educators have become very interested in strengthening the pathways to engineering by linking with K–12 education. At the same time, technology educators have developed national standards for K–12 education that include engineering content. Frankly, it is time to heighten and expand the discussion between the two fields. Collaboration between engineering educators and technology educators is an idea that needs to be further developed and put into practice. Hence, the rationale for this edition of the yearbook series, *Engineering and Technology Education*, is to provide a scholarly discussion of the rationale, benefits, and strategies to strengthen the engineering/technology education connection.

Engineering content is in the beginning stages of inclusion in K–12 schools throughout the nation. Some states have established K–12 education standards that include engineering (e.g., Massachusetts). Pre-engineering curriculum efforts like *Project Lead the Way* (PLTW) are expanding rapidly throughout the nation. Likewise federal policymakers have heightened interest in K–12 engineering as a component of STEM (science, technology, engineering, and mathematics) education, and have passed legislation authorizing funds intended to strengthen American competitiveness by strengthening STEM education.

Technology education has historical ties with engineering education through its predecessors' manual training and industrial arts. The ties between engineering and technology education have been strengthened through the development of the *Standards for Technological Literacy*

(STL) (International Technology Education Association, 2000). The STL include standards specific to engineering (e.g., Standard 9, Engineering Design). It should also be noted that the STL were reviewed and endorsed by the National Academy of Engineering (NAE) and National Research Council (NRC).

## **COMMON INTERESTS IN TECHNOLOGICAL LITERACY**

Engineering and technology education both have great interest in developing a technologically literate population. Technological literacy for all students is the overall goal for technology education. This goal has achieved consensus in technology education with the development and adoption of the STL. One could say that technological literacy is technology education's business.

The engineering profession, including engineering educators, also has great interest in technological literacy as a focus in K–12 education. Engineering leaders, for example, have identified the need for a technologically literate citizenry as key to our nation's future economic strength (Pearson & Young, 2002). Engineering's interest in technological literacy is also driven by a concern that the general public has little understanding of the human-made world, a sophisticated technological world with products and systems that have been developed by engineers. Petroski (1984) noted that “the essence of what engineering is and what engineers do is not common knowledge” among the public (p. x). Pearson (2004) noted that engineering, as a profession, feels undervalued by the general public and has been involved in a campaign to improve the public image of engineering.

Given the common interest in technological literacy, it appears that the time has come to solidify the alliance between engineering and technology education. However, several key questions face educators in both fields as such an alliance is proposed, including:

- Are the goals of technological literacy and the goals of K–12 engineering congruent and/or aligned?
- Will engineering educators, who tend to have a narrow view of K–12 education that generally focuses on math and science, embrace an alliance with technology education?

- Can technology education overcome engineering's perceptions of its image as "blue collar" shop classes with little to offer to prospective engineering students?
- What role(s) will technology education play in K–12 engineering curriculum?

There are no easy answers to these questions. The intent of this chapter, and, in fact, this edition of the yearbook series, is to initiate a scholarly dialog regarding the alliance between engineering and technology education.

## THE TRANSITION TO TECHNOLOGY EDUCATION

The transition from industrial arts to technology education has produced extensive changes in goals, philosophy, curriculum, methods, and facilities. This transition has been driven by the significant changes that technology and its innovations have brought to society, and the need to prepare the rising generation to function and lead in our technological society. As a result, technology educators have stepped forward with national standards and dynamic programs to educate students to become technologically literate.

There have been debates in the field about the overall goal for technology education. The former industrial arts curriculum was grounded in the study of industry, as an outgrowth of the industrial revolution, to prepare students to live in an industrialized world. Revolutionary technological changes have moved the world to a post-industrial age. Given revolutionary technological changes, education to prepare students for life in the technological world required more than just "tinkering" with the former industrial arts education. It required revolutionary change. Hence, from our perspective, technology education presents a significant, revolutionary change from its predecessors. This is best noted in the consensus achieved on its overall goal of technological literacy for all students, a significant change from the past goals. The development of the *Standards for Technological Literacy* (ITEA, 2000) has, in effect, solidified the goal of technological literacy in the field.

In addition to the overall goal of technological literacy, the transition to technology education has also produced significant changes in facilities, curriculum, and instruction. Technology education laboratories have gone far beyond the "shop" classes of the past. In many cases modern technology labs

actually look like engineering labs. Likewise, the curriculum has changed, now with a focus on the acquisition of knowledge, and developing critical thinking and problem solving skills rather than the development of psychomotor skills and the take home projects of industrial arts.

Technology educators are constantly looking for new and effective ways to improve learning in our quest to prepare the rising generation to be technologically literate. Our content, technology, offers robust opportunities for connections with all areas of study in education, especially engineering. Hence, the call for an alliance between engineering and technology education permeates this edition of the yearbook.

## **ENGINEERING AND TECHNOLOGY EDUCATION ALIGNMENT**

Linking technology education with engineering provides unique opportunities for the profession to improve student learning, strengthen education, and improve its position in K–12 education. Engineering content in technology education has multiple purposes. We suggest three major reasons for technology educators to embrace engineering:

1. To facilitate technological literacy;
2. To add intelligibility to math and science education by providing context for learning; and
3. To enhance pathways to engineering.

The *primary* purpose of technology education is to prepare students to become technologically literate in order to become participating members of our technological society. Engineering content in technology education must first and foremost facilitate the achievement of the goal of technological literacy for all. Engineering content, along with methods for designing solutions to problems, is compatible with the *Standards for Technological Literacy* (STL). In fact, experience with “engineering design” is specifically identified in the STL as a component of what students should know and be able to do to become technologically literate. Additional STL pertain to the designed world, and are likewise aligned with engineering. Hence, engineering content and engineering design can be integral to achieving technological literacy as defined by the *Standards for Technological Literacy* (ITEA, 2000).

Another goal that is closely aligned with the primary purpose for including engineering content in technology education is to enhance

learning in mathematics and science education by providing context. Context adds intelligibility to math and science, in effect bridging the gap between abstract concepts and authentic applications in real-world experiences. Such efforts should be encouraged and supported.

Wright (2006) noted that using engineering concepts, methods, and approaches in technology education adds intelligibility to math and science, and provides context for learning. He stated:

Using engineering [in technology education]...is to add rigor and relevance to otherwise incomprehensible theoretical subjects in the public schools. Math and science are very important, but the way these subjects have been taught adds little value to learning for most kids. In contrast, putting math and science into the context of the real world, which engineering does very well for us in technology education, promotes better learning of the concepts.

To add intelligibility to math and science, technology education must go beyond traditional activities and must include specific engineering concepts that are grounded in math and science, such as constraints, optimization, and predictive analysis.

A third goal for including engineering content in technology education is strengthening the pathways for students to pursue engineering as a viable career option. It is clear that technology education can play a role in providing educational experiences that provide students with a foundation for considering engineering as a career. This is a very important role for technology education given the shortage of engineers and scientists in the U.S. (National Science Board, 2003). K–12 students, like the general public, know very little about engineering and the work of engineers (Pearson, 2004; Petroski, 1984). Including engineering content and engineering design in technology education has the potential to provide career information about engineering to students through immersing them in authentic engineering design activities—what engineers do, if you will. Authentic engineering design experiences provide a base for student decision making about whether engineering is a good career choice. Such educational experiences also help students understand the need for mathematics and science knowledge that are used to solve engineering design problems. This assists students in selecting the appropriate array of classes to prepare for studying engineering at the college level.

There are some in the field who suggest that technology education should become engineering education in the K–12 schools, and that the profession should include the word “engineering” in its name. This singular approach, particularly if it increased the number of women and underrepresented minorities in the engineering pipeline, would likely be embraced by the engineering community. This is a viable goal, and pre-engineering curriculum projects like *Project Lead the Way* (PLTW) are so aligned. It should be noted that the former Technology Education Division (TED) of the Association for Career and Technical Education (ACTE) has changed its name to the Engineering and Technology Education Division (eTED) of ACTE (ACTE, 2007).

Strengthening the pipeline into engineering programs is a benefit, and part of the multiple purposes noted above. Wright (2006) also noted:

If students choose to go into engineering as a profession as a result of engineering experiences in technology education, great, but our purpose is to provide an authentic, meaningful context for learning for all students.

Frankly, it is time to stop “tinkering” with technology education and to embrace engineering as the content base. Linking technology education with engineering shows great potential for a symbiotic alliance that will benefit both fields. Such a link provides unique opportunities for technology education to improve student learning, strengthen education, and improve its position in K–12 education.

## **ENGINEERING’S PERCEPTIONS OF TECHNOLOGY EDUCATION**

Historical perceptions of technology education perpetuate a view that it is “shop” for lower ability students. Pearson (2004) noted this and stated that “most outside the profession, including many engineers, still see technology education through the lens of ‘shop class,’ a term almost always used pejoratively” (p. 68). These realities are disturbing to dedicated technology educators who see the transition to technology education as intellectually grounded with robust opportunities for authentic learning experiences.

It is often said that people see things through the lens of their past experiences. Hence, when “viewing” technology education, most people remember taking a “shop” class or two when they were in junior high

school or high school. More likely than not, those who went to college after high school probably took only a junior high industrial arts course, if they took any at all. In addition, the college-bound likely remember most shop classes as being populated by the lower ability students.

Is it surprising to technology educators that engineers perceive technology education as the shop classes of their past, if they are even aware of technology education? It should not be surprising. Engineers, after all, were in the college-bound track in high school, taking high doses of mathematics and science. They likely did not have the time in their school day to take technology education classes. While engineers' perceptions of technology education are beginning to change, in general, engineers stereotype technology education as "blacksmithing and tinkering," with little application to engineering.

How do we change the stereotypes of technology education held by engineers? We do not have a magic wand, so we have to heighten the dialog between the professions. We need to invite engineers, and engineering educators, to see first hand our dynamic technology education programs. We need to show them how technology education develops technological literacy, how it provides context for learning, and how it could strengthen the pathways to engineering.

## **TECHNOLOGY EDUCATION IN THE ENGINEERING SEQUENCE**

Engineering programs at universities continue to have very high attrition rates (National Academy of Engineering, 2005; Pearson, 2004). While attrition is a complex issue, one concern of leading engineering educators is that engineering students study the components of engineering in the first three years of college, and finally in their senior year they actually get to do engineering through their capstone design projects. While a technical base is essential, do first- and second- year engineering students actually have the requisite conceptual base to understand the big picture of what engineering is? That is, are we confident that the students clearly understand the context of engineering that enhances learning the technical components (e.g., statics, dynamics, calculus, physics)?

To assist us in understanding the importance of the context, or the landscape of what engineering is and what engineers do, we provide an analogy, comparing program planning in engineering education to learn-

ing to play a team sport. While virtually any team sport (e.g., softball, basketball, baseball, hockey) could be used as the focus for an analogy to program planning, we are using football because the following story is a true story, provided by Farren Johnson, a middle school technology teacher, from Mountain View, Wyoming.

As a boy, Farren was raised in rural northwestern Nebraska where he attended a one-room school through the eighth grade. Farren's family did not have television as he was growing up. Because the high school was too far from home to be bussed to and from high school each day, Farren was boarded in the town with the high school during the week. When he and his father were working with the high school principal on his schedule of courses, his father told the principal to "put him on the football team." So, after school each day for the first two weeks he went to football practice where he learned the skills of blocking, tackling, punting, running, passing and receiving, kick offs and kick off returns, special teams, and so forth. Farren said that the two weeks of football practice finally made sense after he saw his first football game—a game in which he played! You see, he had never seen a football game before playing in his first game.

Put yourself in Farren's situation. Can you imagine learning to play football, or any other team sport for that matter, without a conceptual understanding of how the game is played or never even having seen a game played? In such a situation, would learning and practicing the individual components and skills of football make sense to you? Probably not.

Compare Farren's football experience to the curriculum sequence in engineering education. Engineering students take several semesters of mathematics, calculus-based physics, and engineering foundation courses (e.g., statics, dynamics, thermodynamics) before they get to see how the "game" of engineering is played. Frankly, this is why the NAE and other leading engineering educators are calling for freshman-level engineering design experiences. Engineering students need a pedagogy that provides them with a context for learning the technical components of engineering. This is noted as follows in *Educating the Engineer of 2020* (NAE, 2005):

...it is becoming increasingly recognized that it is important to introduce engineering activities, including team-based design projects and community service projects, early in the undergraduate experience alongside basic science and math courses, so that students begin to develop an understanding of the essence of engineering as early as possible (p. 40).

First-year engineering students should have a lab-based engineering design course in which the students actually use the design process to solve problems. Some universities are experimenting with such approaches in engineering education. Utah State University, for example, offers a freshman-level, lab-based engineering design course for engineering majors. The challenge is that only one engineering program in the college has adopted the course as a requirement. Other engineering programs allow it as an elective (K. Becker, personal communication, August 22, 2007).

Another approach to helping engineering students gain context (see how the game is played) is to collaborate with the K–12 schools. Well-designed engineering curriculum initiatives in high schools have the potential to provide the big picture of engineering to students who are planning to major in engineering when they attend college. This approach would not impinge on the already full engineering sequence in colleges and universities, but it still provides prospective engineers with “an understanding of the essence of engineering” as they begin their college studies (NAE, 2005, p. 40).

Technology education can provide an authentic context to prospective engineering students as it makes engineering and engineering design integral to its curriculum. This role is congruent with the STL which include specific standards about engineering design. While such an approach would benefit first-year engineering students, it should be noted that technology education classes are not generally included in the college preparatory track in high schools. Perhaps if engineering educators and their universities highlighted the role technology education plays in preparing students for college, the status of technology education could be improved.

## **A PROMISING ALLIANCE**

For an alliance to actually happen, both engineering and technology education must derive benefits. As noted throughout this chapter, the benefits to engineering include access to K–12 education through technology education, greater awareness of engineering by K–12 students, and strengthening the pipeline of students to engineering programs at universities, with the potential to increase the participation of women and underrepresented minorities. Additional benefits may accrue to engineering education as technology educators, who have expertise in learning theory and the cognitive sciences, conduct research on learning and teaching that includes how students best learn engineering concepts.

Wicklein (2006) identified five good reasons for technology education to adopt engineering as its focus. He notes that engineering is better understood and valued by the public than is technology education. He also notes that an engineering focus will elevate the academic status of technology education. These reasons may be suspect given the concerns that engineering has about its public image, or lack thereof (Pearson, 2004).

Will adopting engineering as the focus elevate technology education in the eyes of the public, the students, and so forth? Foster (1994) published an essay about technology education's linkages with mathematics and science in an MST (math/science/technology) education alliance. In this essay, Foster cited several authors who suggested that an MST alliance would elevate the status of technology education (e.g., LaPorte & Sanders, 1993; Wescott, 1993). He also cited works by other authors who felt the profession was trying to achieve status by association with respected disciplines instead of being true to itself (e.g., Lewis, 1994; Petrina, 1993). Foster concludes by noting that he hoped that attempting to gain credibility by association in an MST alliance "isn't a last-ditch grasping at respectability" by technology educators (p. 82).

Frankly, Foster's (1994) questions about an MST alliance are relevant as we discuss STEM education and an alliance with engineering, including adopting engineering as the focus of technology education. While we are convinced that the time has come for technology to embrace engineering as its focus, the adoption must go well beyond status by association. Trying to achieve status by association with engineering as the primary reason for focusing the curriculum on engineering is shallow, and will likely be perceived as a "last-ditch" effort.

There are multiple benefits for technology education, and its students, with an engineering alliance. As noted earlier in this chapter, such an alliance can provide context for authentic learning, facilitate the acquisition of technological literacy, lend intelligibility to mathematics and science, strengthen the pathways to engineering (and other technical careers), and so forth. The time has come to formalize the promising alliance between engineering and technology education.

Pearson (2004) concludes that "[i]f engineers and technology educators are to work together in a meaningful way, they surely will need to spend more time getting to know one another" (p. 70). Several chapters in this edition of the yearbook series are co-authored by technology educators

and engineering educators. This was purposefully arranged by the editors. Engineers and technology educators need to spend time working together, learning from each other, and strengthening education in meaningful ways.

## **ENGINEERING AND TECHNOLOGY EDUCATION**

As noted in the first paragraph of this chapter, the rationale for this edition of the CTTE yearbook series is to provide a scholarly discussion of the rationale, benefits, and strategies to strengthen the engineering/technology education connection. As such, this book has been organized in four major sections:

- I. Theoretical Background and Foundations;
- II. Technology Education, Engineering and the Curriculum;
- III. Key Connections, Alliances, and Resources; and
- IV. Engineering and Technology Education—Perspectives on the Future.

These sections broadly define areas of the discussion of engineering/technology education alliances and the benefits of an alliance to each field. The four sections, and the chapters therein, are in reality only a starting point for an intellectual dialog. The dialog, including perspectives of the past, the present, and the future, is intended to spur ideas for collaboration between engineering and technology education. As such, this edition of the yearbook series does not provide cookie-cutter strategies for fostering the alliance. Rather it is hoped that leaders from both fields will gain new perspectives and ideas from the pages of this book and will generate and implement action plans to make the alliance a reality.

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## BACKGROUND

Leaders in the field of technology education have been contemplating another stage in its metamorphosis by adopting the methods of the engineering profession as content (see Lewis, 2005). The adoption of *Project Lead The Way* is evidence that many school districts see merit in this. The fact of a National Center for Engineering and Technology Education (NCETE) is further evidence that curriculum change in the direction of engineering beckons. Adopting engineering as content poses many challenges for technology education. How should teachers be prepared? What will students learn? How will learning and teaching be evaluated? Questions of this order reflect the fact that in seeking to adopt engineering, technology education needs to become more familiar with the engineering profession. In this chapter, we take a small but important step towards this end by examining the historical roots of modern engineering, roots that reveal shared lineage with technology education. A contention of the chapter is that if this shared lineage is understood broadly, both within the engineering profession and the field of technology education, current attempts to adopt engineering as content will stand a better chance of succeeding.

The chapter evolves in keeping with the following framework (a) European precursors, (b) the “Useful Knowledge” movement in the United States, (c) the decline of apprenticeship, and the rise of industrial training, (d) engineering education before the Morrill Act of 1862, (e) professionalization, (f) modern engineering (1940–present), (g) structure of the modern engineering profession, (h) engineering program accreditation and professional registration, and (i) summary and conclusions.

## EUROPEAN PRECURSORS

An industrial revolution had been ongoing in Europe even as the new American colonies strove to consolidate as a country in the 17th and 18th centuries. Hence, at the dawn of American industrialization there were many lessons to be learned from European experience. One of these lessons had to do with the role that engineers play in nation building as well as the ways in which they could be educated and trained. Pfammatter (2000) explains that the modern engineering tradition responded to an 18th century movement in Europe and the United States, fueled by revolutionary yearnings and centered on the view that the development of scientific and technological arts was an important key to progress. Reynolds (1991) notes that American engineering emerged out of French and British traditions. Engineers had been a part of technical corps in the French army since the 16th century, designing fortresses and constructing roads and bridges to move armies. Due to a shortage of trained personnel and the need to standardize and improve civic construction practice, the French government established the *École Nationale des Ponts et Chaussées* (ENPC) (“National School of Bridges and Roads”), the world’s oldest engineering school, in 1747 to train engineers in bridge and road construction. The school reflected a shift from apprenticeship to formal education as the model for training engineers. The ENPC endures today as one of the elite French graduate engineering schools, with a focus on formal mathematical and theoretical engineering.

The *École Polytechnique*, today one of France’s elite higher education institutions, was founded in 1794 during the French revolution, conceived as a training ground for engineers, architects, and officers who would help in creating the new French state. Founders included physicists, mathematicians, and chemists, among other technical professionals and academics. The school was an affiliate of the government, serving the French public service but especially the military. It was the first training center for engineers and architects with an institutionalized teaching program and training goals. The curriculum had a research focus. An innovative polytechnic model of teaching was developed that was a blend of scientific theory and engineering practice. This unique pedagogical approach became a model of engineering training that was imitated elsewhere in Europe and the United States in the early 19th century.

The British had in the mid-18th century become a world commercial and industrial power and, in the process, had produced a large number of engineers. As Reynolds (1991) points out, British engineers were trained on the job. Their expertise in superintending large technical projects was in demand internationally. The British apprenticeship approach to the training of engineers was adopted in the United States, with workshops and engineering projects being the setting for training. For most of the 19th century, a high proportion of engineers in the United States was trained via the on-the-job method. The construction of the Erie Canal 1817–1820 produced a widely developed on the job training (OJT) system for civil engineers and was the setting for the training of a large number of them. Finch (1960) writes that the Erie Canal had graduated frontier surveyors and assistants into engineers by the time of its completion and indeed, that the canal project was arguably the first American engineering school (p. 264).

## **THE USEFUL KNOWLEDGE MOVEMENT IN THE UNITED STATES**

In the United States, as in Europe, nascent industrialization had been the impetus for the growth of knowledge and expansion of literacy. These impulses were also fueled by revolutionary notions, literacy being seen by reformers, notably Benjamin Franklin and Thomas Jefferson, as a concomitant of freedom. More particularly, the content of such literacy had to be of use—useful knowledge being viewed as a democratizing agent, a way for ordinary workers to raise their status. Between 1776 and 1840 there was in the northeastern part of the country an expansion of societies that promoted and emphasized the spread of “useful knowledge” through various journals and magazines (Watkinson, 1990). The concept of useful knowledge differed throughout the various states and among the different classes of people. Benjamin Franklin and Thomas Jefferson saw useful knowledge as a way for mechanics to elevate their cultural standing. Reformers such as Timothy Claxton and William Maclure saw it as a way for them to improve their social mobility. With increasing specialization and professionalization, the language of useful knowledge became increasingly more arcane, understandable only by the college educated and beyond the reach of the common people. As the knowledge gap grew, the

hope for social mobility lost its promise for many workers. Franklin had formed the American Philosophical Society with the purpose of spreading useful knowledge.

Treatises ranged widely, from Hebrew, to brewing malt liquors, to the use of manure. By the 1820s, the useful knowledge movement was focusing on mathematics. Members of learned societies spread their version of useful knowledge among their elite ranks. Where the early learned societies were geared to the *diffusion* of knowledge, the later societies, such as the American Association for the Advancement of Science (AAAS), formed in 1847, emphasized the advancement of knowledge. Organs such as *The American Magazine* published complicated scientific knowledge out of the reach of craft workers, and intended for those who had attended college.

To bridge this gap between the elite and artisans and to make the new specialized knowledge available to the working classes, Timothy Claxton (English) and William Maclure (Scottish), both immigrants, introduced mechanics institutes, newly developed in Britain, to the United States. Claxton founded *The Young Mechanic*, a magazine designed for artisans, published in plain language, on practical and scientific topics. Josiah Holbrook, Claxton's associate, founded the Lyceum movement intending to bring scientific and practical knowledge to all.

## **Shop Culture as a Basis of Engineering Education**

Pfammatter (2000) notes that shop culture was the cauldron of early engineering training. With the expansion of the western frontier, communication and transport needs (canal and river shipping, rail) became more sophisticated. As a result, scientifically based engineering education began to emerge among the shop culture class. As industrialization gained momentum, the practice of the workshop came to gain legitimacy as valid knowledge (Stevens, 1990). This knowledge gained ascendancy with the spread of mechanics institutes and through periodic presses. To engage this workshop culture, educators had to recognize that technical and scientific learning involved a dialogue between material and print traditions.

Learning in the context of the workshop had two basic tenets: the first was the traditional language of literacy and the second was spatial thinking, a non-verbal way of representing material culture. According to Stevens (1990), this convergence of discourses led to the interplay of the logic of mathematics and natural science, with the visual representations of technical drawing.

## Spread of Mechanics Institutes

Between 1830 and 1860, machine shops fueled industrialization, producing steam engines, mills, and agricultural equipment (Pfammatter, 2000). The shops were the basis of individual inventiveness. But as Stevens (1990) shows, shop culture had limitations that became magnified with the spread of technical literacy. There was now an increasing need for mechanics and machinists to be literate. New concepts such as interchangeability and uniformity came to replace customization and “rule-of-thumb” methods. As a result, the skill of expert machinists increased, and quality management was tightened. With production sophistication increasing, entrepreneurs sought machinists and technical experts who had the requisite factory management skills. According to Pfammatter (2000), efforts to apply science to fields of technology, industry, and engineering were spurred by the need to make new territories accessible and to find energy sources. Practical challenges such as river and canal shipping, and rail transportation drove the need for engineering.

## THE DECLINE OF APPRENTICESHIP AND THE RISE OF INDUSTRIAL TRAINING

At the 1876 world exposition, held in Philadelphia to commemorate the American Centennial, the Russian exhibit of manual training pedagogy caught the fancy of Calvin Woodward of Washington University in St. Louis and John Runkle of the Massachusetts Institute of Technology. Woodward saw the new method as a way to provide practical context for mathematics students at his university. Runkle saw it as a means of providing practical training for engineering students. Both saw its potential as an aspect of public schooling. Woodward was to establish the Manual Training School of St. Louis, where the focus was a blend of liberal learning inclusive of shop work and drawing. This of course was the birth of technology education in the United States. By the end of the century, manual training had spread across the country as an established subject in the public school curriculum. Fisher (1966) comments that while manual training took hold in the public schools, it did not materialize as a method for the training of mechanical engineers, attributable to the arrival of the land-grant colleges and engineering schools.

But manual training was evidence of a shift in the locus of industrial training from the workshop to formal education settings. Dawson (1999)

deals with this shift from the workshop to the classroom through an 1878 case study where the Baldwin Locomotive Works of Philadelphia, in association with the Spring Garden Institute, pioneered a new system of industrial training that replaced apprenticeship. He notes that by 1870, the company was able to increase capacity to produce several hundred machines annually, with volume production and standardized components. By the early 20th century, most workshop owners had accepted the need for formal industrial training, recognizing the limitations of OJT.

## **ENGINEERING EDUCATION BEFORE THE MORRILL ACT OF 1862**

The movement away from workshops to classrooms was also taking place with the education of engineers. Most mechanical engineers had been machine-shop artisans who had learned their craft through apprenticeship (Reynolds, 1991). The small shops and customized nature of the work enabled the development of design skills, as well as engineering economics (Reynolds, 1991). The leading figures in mechanical engineering in the United States were machinists who had established their own shops. According to Reynolds (1992), formal preparation of engineers in four-year colleges had begun well before the passage of the Morrill Act of Congress in 1862, which made possible the land-grant colleges. Apprenticeships, in combination with immigration, could not produce the quantity of engineers needed for the country's development. This became apparent after the war of 1812, when states and the private sector invested heavily in the expansion of transportation. The first civilian school of engineering was established at Norwich University around 1825. Many colleges established programs thereafter through a variety of models. Reasons for this diversity included a lack of precedent and an absence of clear consensus on how engineering training should be conducted. Six approaches were identified by the author; two (the *military college* and the *polytechnic school*) broke from the traditional classical university model. The remaining four were variations of engineering appendages to traditional classical colleges, seen in various forms in the first half of the 18th century at institutions such as the University of Vermont, Princeton, Brown, the University of Pennsylvania, William and Mary, the University of Georgia, the University of Alabama, and the University of Virginia. In the 1850s, Harvard, Yale, Dartmouth and the University of Michigan started engineering programs.

Despite the many college initiatives, by 1860 only a very few had been successful (Reynolds, 1991). With the passage of the Morrill Act, authorizing the creation of land-grant colleges, the military and civilian schools that had been functioning prior to the Act were able to provide the professors who were to staff and lead the new programs.

## **West Point**

Among the military academies that were established with an engineering focus, West Point was not just the first American college-level engineering school, but the exemplar of its time. It was founded in 1802 along lines of the French *École Polytechnique* to provide civil engineers for the U.S. Army Corps of Engineers, as well as other branches of the army. Under Sylvanius Thayer, who was appointed superintendent in 1817, the school adopted a four-year curriculum. Cadets gained as much civilian as military engineering and indeed could transfer their skills easily from the military to civilian sectors. Though it was a military academy, more attention was paid to science, mathematics, and engineering than to military science. French engineering curriculum and textbooks were imported, as well as instructors, until mid-century. West Point engineers mapped much of the frontier territory, charted the coasts, and improved waterways. The academy had trained 15% of all American civil engineers prior to the Civil War. In the 1950s, and with the spread of civilian engineering schools, West Point lost the preeminence it once held as a producer of engineers.

## **Rensselaer Polytechnic**

Another early American engineering institution was the Rensselaer Institute. Established in 1824, its purpose was to train students to teach science and its application to the New York farming community via experimental demonstrations. Engineering education did not form part of the curriculum until 1828 when the school began offering occasional engineering lectures. In 1835, a one-year civil engineering degree program was started, intended to supplement the training of students who had already completed a Bachelor of Arts degree. In 1850, the school adopted the name Rensselaer Polytechnic Institute. It abandoned its one-year engineering program in favor of a three-year program. The focus on scientific and engineering training superseded its traditional focus on agricultural education and teacher training.

## **PROFESSIONALIZATION**

As Reynolds (1991) observes, the formation of associations to promote and diffuse knowledge is a mark of fields seeking to professionalize. British civil engineers had started professionalization efforts in the 1770s that led to the creation in 1818 of the Institution of Civil Engineers, a professional society. In the United States, the geographic scale of the country and the poor state of transportation prevented the development of societies. An attempt in the 1830s had failed. Meanwhile mechanics institutes, such as the Franklin Institute of Philadelphia had been thriving. Engineers used these institutes, intended for artisans, as the seed material for establishing their own societies. By 1865, with improved transportation, engineers began to create professional societies. The American Society of Civil Engineers was reconstituted in 1867, becoming the first true engineering research body. Following closely were the American Institute of Mining Engineers (1884) and the American Institute of Electrical Engineers (1884) (Reynolds, 1991).

### **Layton on the Professionalizing of Engineering**

In his seminal work titled “The Revolt of the Engineers,” Edwin Layton argues that one of the more important forces driving the evolution of engineering societies in the United States was the balance between business and professionalism. Balancing occurs by circumscribing the field or by establishing professional standards of membership. Layton contends that those who favor engineering as an independent profession want a comprehensive body. Those who view themselves as businessmen want societies built around single industries. The societies have a technical nucleus that they define by membership standards. Four standards have emerged over time; namely (a) technical creativity, (b) ability to design, (c) being in “responsible charge” of engineering work, and (d) company or industrial affiliation. Engineers allied to science have seen full membership as reward for creative technical work. Layton writes that “The test that most clearly distinguishes the professional engineer from all other groups is his ability to design engineering works. Placing the emphasis on the application of professional knowledge, rather than on its creation, distinguishes the scientist from the engineer” (p. 25). The design criterion draws a sharp line between professional engineers and managers. Membership

based on design signifies engineering as an independent profession, while that based on industrial affiliation suggests solidarity between engineering and business.

Layton too goes back to the Franklin Institute as an important institution in the early turn by engineers to professionalism. Two societies predominated in the 1870s: the American Society of Civil Engineers (ASCE) and the American Institute of Mining Engineers. Layton notes that membership in the ACSE was based on design. He writes that without design knowledge and competence, the engineer was considered to be more of a workman than a professional.

## **Civil Engineers**

Civil Engineers, through the ASCE, devoted initial attention to technical issues, such as averting the failure of bridges and inter-oceanic communication (Wisely, 2002). Membership grew in the early years. In the first decade of the 20th century, the association set forth a professional development policy with a focus on education, ethics, professional competence, and practice. Early members brought a variety of backgrounds, some with West Point engineering degrees; others without a formal degree and many with little more than self study. In 1932, The Engineers' Council for Professional Development was formed to accredit engineering schools. In a 1944 study of 2700 members, it was revealed that graduates lacked oral and written communication skills. The society recommended a four-year bachelor's degree as the common coin for professional engineers.

## **Mechanical Engineers**

Rolt (1967) highlights tensions between theory and practice in the evolution of mechanical engineering as a profession. He writes that in 1847, the year of the founding of the Institution of Mechanical Engineers in Britain, wrought-iron production had increased dramatically, and steam power had revolutionized manufacture and air and sea transport. "Yet all of this had been achieved by essentially practical means and with little theoretical knowledge" (Rolt, 1967, p. 22). The steam engine had advanced with "practically no scientific knowledge of the properties of heat" (Rolt, 1967, p. 22). He goes on to note that where scientists are venerated "we forget that whereas science consists of the patient discovery of

new facts about our world, engineering is an art” (Rolt, 1967, p. 22). Art precedes science, argues Rolt, contending that “Before they can be of use to mankind, scientific facts must be translated into hardware by the art of the engineer” (p. 22). While the engineer must master scientific theory, he or she must master art as well. This basic historical tension regarding the difference between science and engineering as well as the importance of “art” is one that applies still as technology education contemplates adopting engineering as content. Rolt points out that when the laws of thermodynamics came along showing the relationship between heat and work, great strides had already been made in steam plant design. He was not dismissing the value of science; only highlighting the importance of praxis, at least in traditional engineering. The engineer has to be a good designer he noted, and “good design depends upon the successful fusion of knowledge with practical experience” (p. 127).

In the United States, mechanical engineers had the same tradition of practice as Rolt characterizes in the case of Britain. Fisher (1966) examined the development of professionalism among mechanical engineers in the United States. She notes that civil engineers had half a century’s head start on mechanical engineers toward professionalization, and that, while civil engineers were recruited from among the educated, the mechanical engineer had a more egalitarian base. She writes that “To a great extent, the problem of professionalization for the mechanical engineer was one of raising himself up from the status of the mechanic, yet the character of professionalization also devolved upon the particular upward direction” (Fisher, 1966, p. 33). Finding the professional space involved working out particular relationships with business or with science. The turn to science was intended to elevate the ranks, science surpassing mere Yankee ingenuity. One question was how much liberal arts should be included in course work; another concerned the appropriate pedagogy.

## **Chemical Engineers**

Reynolds (1986) speaks of the challenges involved in establishing chemical engineering as a unique society. Chemical engineering was a relatively small field throughout the 19th century. A first problem in establishing it was that many chemists could not see the need for a separate chemical engineering discipline, since chemists could scale up reactions to meet industrial demand. In Germany, the tradition was that research

chemists did scaling up to an industrial level, hence chemical engineers were not needed. Still the chemical society prevailed. Anxiety over the decline of analytical chemists and the concern that mechanical engineers were taking chemical engineering jobs, stimulated production chemists to define themselves distinctively. Only in the 1912–1925 period did such distinctiveness emerge. *Unit operations* became the key to defining the role of the chemical engineer. Unit operations focused on “the physical or mechanical operations involved in chemical manufacture, not on the chemical reactions or chemical products that concerned the traditional chemist” (Reynolds, 1986, p. 710).

## Electrical Engineers

In his *History and Development of Engineering*, Gregory (1971) observes that, unlike civil and mechanical engineering that were built on foundations of practical inventions, electrical engineering, which emerged in the 19th century, was built on a foundation of theory and scientific knowledge that blossomed in the 18th century. This is but one point of view, since in the development of the field in the United States, the claims of practical electricians had to be overcome in the march of electrical engineering toward professional status.

Still, Gregory’s point can be appreciated when one reviews the case he makes for the role of scientific theory in the evolution of electrical engineering. He explains that electrical engineering has as its foundation a body of knowledge of the interrelatedness of electrical and magnetic phenomena. Some of these accomplishments included Volta’s experiments with dissimilar metals, Cadvenish’s work in electrochemistry, and developments in electromagnetism by Oersted, Ampere, and Davy. Early applications in the United States included the invention by Samuel Morse of Morse Code and sub-marine telegraphic cable. Critical, according to Gregory, was Farraday’s electromagnetic work, generating electricity from magnetism and producing the first electric motor as well as the first transformer. Commercial applications included the work of Thomas Edison, who produced the first dynamo, the basis of using electricity for electric lighting.

Gregory raises the question, with respect to power systems, whether the work is science or engineering. He explains: “Science alone does not produce workable systems, and there remains...seen from the history of power systems, just as much art and just as much utilization of skills

and non-science-based technology as in other branches of engineering” (Gregory, 1971, p. 81).

He goes on to note that “engineering design in telegraphy or lighting or power generation or distribution has outpaced, and therefore stimulated rather than been dependent upon, the theoretical backing” (p. 81). This is akin to the point Rolt makes in the case of mechanical engineering that while engineering must be based on science, there is room for a pragmatic dimension. It may be that this point is more tellingly made the further back in time we go towards origins of engineering fields.

McMahon (1984) captures nascent electrical engineering in the United States. He describes the meeting of technical groups in 1884 in anticipation of an international electrical exhibition and the resultant formation of the American Institute of Electrical Engineers (AIEE). He notes: “It was becoming increasingly clear that the field was veering off sharply from America’s traditional engineering culture” (p. 1). One can deduce here that what he meant was that, unlike civil and mechanical engineering, there was underpinning electrical engineering a very strong underlying scientific basis, especially in the realm of physics. The United States Electrical Conference, organized by Congress in 1884, was examining the implications of expanding electrical industry for public policy. McMahon notes that the commission included the country’s most eminent *physicists* led by Henry Rowland of Johns Hopkins University, with Edwin Houston, a prominent electrical engineer, the only technologist. Rowland had an aversion to praxis, openly denigrating practical electricians and favoring pure science as the basis of electrical engineering. Rowland and Thomson, an English physicist who did not share his disavowal of practical work, called for standards, not just for industrial needs, but also for inquiry purposes.

McMahon contends that the making of the telegraph was the “seed-bed” of the profession of electrical engineering. Here is where the applications blossomed.

As the field developed in the United States, prominent figures such as Thomas Edison were as much inventors as they were entrepreneurs. Edison developed the idea of the central power station, creating electricity at a central location for distribution.

At the 1884 manufacturers' exhibition, according to McMahon, the largest displays were from the pioneering companies (e.g., Bell, Brush, Weston, Edison, and Thomson). He notes that "The names pointed to the fruitfulness of directed research that was attuned to the marketplace, to the development of precise electrical instruments, to the importance of engineering design aided by mathematical tools, and, most indicative of the immediate future of the electrical engineering profession, to the need to understand more precisely the challenges of designing, constructing, and maintaining large technical systems" (p. 27).

The Franklin Institute's call for an International Electrical Exhibition had spawned the development of a society, so that the United States electrical community could present a coherent front in the face of an international scrutiny. The first members met in May of that year. Membership was open "not only to electrical engineers, electricians, and teachers but also to inventors and manufacturers and officers...of all companies based upon electrical inventions" (p. 28). The officers of the AIEE included Alexander Graham Bell and Thomas Edison. With the formation of a society, the old issue of praxis versus theory once again reared its head. McMahon speaks of "ambiguous engineers" and the debate within AIEE over the nature of the engineer. The main focus, of course, had to do with who should not be considered to be an engineer. He writes that at the time, the designation of electrician "existed rather shakily in the Rules of the AIEE alongside that of electrical engineer, an ambiguity that held into the next century." It should be noted that in 1884, "electrician was not at the outset a pejorative term, being used to characterize inventors such as Alexander Graham Bell. In early years, electrician referred to workers in the telegraph industry.... But that changed because the industrial changes in the country brought obsolescence for the early telegraph electricians" (p. 37).

In the formative years, the training of electrical engineers took place in home laboratories and small shops; much as was the case for mechanical engineering. By 1870, training moved to colleges and technical schools, with physics departments being the primary programmatic homes. Electrical engineering departments were to come later.

## MODERN ENGINEERING (1940–PRESENT)

The modern engineering period is characterized by an increasing focus on scientific application (Harms, Baetz, & Volti, 2004). Harms, Baetz, and Volti begin with the epochal discovery in 1938 with the splitting of the Uranium-235 nucleus. Two military purposes came out of this, namely, the development of nuclear explosives, and the powering of nuclear submarines. The latter provided the insight for the development of nuclear power plants for civilian energy needs.

In the 1950s, computers emerged, triggering a *soft revolution*. Computer research has proceeded in the areas of hardware, software, and firmware (e.g., microprocessors employed in manufacturing, automobiles, etc.). Hardware progressed from the electronic tubes of 1906 to solid-state transistors in 1947 and on to large integrated systems in 1970. Software advanced from binary coding in the 1940s to multitasking operations in the 1990s. In the 1960s, following Sputnik, the United States space program expanded, culminating with the lunar landing. The space program yielded advances in global observation (satellites), deep space with instruments finding characteristics of planetary satellites, and space stations.

The 1970s brought engineering diversity in the realms of transportation, manufacture, and energy. In transportation, there were advances in the development of electric cars and high-speed trains. In manufacturing, advances were seen in integrated manufacturing while in energy, numerous advances were made in response to the quest for alternative energy technologies.

### Scientific Model

After World War II a scientific focus in engineering became evident. Modern physics, applied mathematics, and chemistry displaced hands-on subjects such as drafting, machining, and surveying in the engineering education curriculum. There were also disciplinary changes reflected in specialties such as industrial and manufacturing engineering, aeronautics and astronautics, plus new fields such as nuclear, biomedical, and software engineering. War circumstances had led to close collaboration between industry and the military, which yielded unique engineering practices including science/engineering integration, rapidity of device development, and an increased complexity of systems.

Harms, Baetz, and Volti (2004) deem the period from 1990 to the present as that of *contemporary engineering*. Factors identified as having influence on engineering practice include depletion of liquid-hydrocarbon petroleum and associated toxic and non-toxic waste products of mining and extraction, recycling, expanded emphasis on mathematical simulation, analysis in engineering education, and solidification of the scientific method as the foundation for theory and practical development of engineering. They point to the evolution of devices in realms such as telephony (fiber optics substitution) and computers (i.e., speed and memory increase, enhanced encryption, size and weight reduction, etc.). They also identify threshold and emergent devices in areas such as automobile engines (e.g., fuel-cell substitution), bio-engineering (e.g., genetic engineering; expanded prostheses), pollution abatement (e.g., filters), and nanotechnology (e.g., atom-scale construction).

Two features of this period include (a) matter-energy efficiency and (b) industrial ecology systems. Matter-energy efficiency refers to situations where the effectiveness of devices has increased while the matter and energy requirements have decreased. This is seen in jet engines where the weight requirements for the same power is reduced compared to times past. Also, the size of computers has decreased due to the invention first of the transistor, followed by integrated circuits and the microprocessor.

## **STRUCTURE OF THE MODERN ENGINEERING PROFESSION**

In this section, we reflect on the status of the profession of contemporary engineering. It is quite curious that while one can hardly look around a room and find something that has not been “engineered,” few people have an understanding of engineering. Students are confused by the array of choices among engineering disciplines and school counselors struggle to provide accurate and helpful information on engineering. It should be noted that organizations such as the American Society for Engineering Education ([www.asee.org](http://www.asee.org)) and various engineering professional societies have developed websites and other literature-based information to help describe this issue.

The goal of this section of the chapter is to reflect upon the current structure of the engineering profession by providing some perspective of different engineering disciplines and fields as well as information about the types of career opportunities available to engineers. Additional information will be provided to describe the accreditation of engineering education programs and professional registration of engineers.

## **Engineering Disciplines**

Engineering disciplines and fields are a primary source of confusion because the “outside” world generally thinks in terms of engineers by their disciplines while engineers often think of themselves by their field of interest. Disciplines are the traditional names that are commonly used to describe a type of engineer. Civil engineering is one of the oldest discipline names used to describe engineers who worked on civilian projects, such as roads and bridges, rather than military projects. Mechanical engineering became its own discipline as engineers associated with the design and construction of machines for power production systems and manufacturing machinery systems were developed. Another of the early engineering disciplines is electrical engineering which emerged from the growth and widespread use of electrical power systems. The increase in the formal understanding of electrical energy provided a basis for a formal education program. Over the years, many other commonly recognized engineering disciplines evolved, often as an outshoot of the more established disciplines. For example, computer engineering departments often evolved from electrical engineering departments. Many aerospace engineering entities have roots in mechanical engineering. Environmental engineering departments generally began within civil engineering. A list of many common engineering disciplines includes aerospace engineering, agriculture engineering, bio-engineering, chemical engineering, civil engineering, computer engineering, computer science, electrical engineering, environmental engineering, industrial engineering, materials science, mechanical engineering, mining engineering, nuclear engineering, and petroleum engineering.

The list is not meant to be all inclusive and additional disciplines continue to evolve (see for example Harms, 1996). Disciplinary change will continue to grow in response to technological change and societal need. What’s next? Maybe this will include systems engineering (already underway), nano-engineering, or sustainability engineering?

## Engineering Fields

Beyond disciplines, even more confusing are the fields by which many engineers describe themselves. For example, within civil engineering, there are “clean water” and “dirty water” engineers and vertical structures and horizontal structures engineers. Mechanical engineers may describe themselves as manufacturing, thermal science, or automotive engineers. A conference meeting for the fluid mechanics field may attract aerospace, biochemical, civil, mechanical, and petroleum engineers. The field may also attract mathematicians, atmospheric scientists, geophysicists, oceanographers, and astrophysicists.

A partial listing of engineering fields includes controls, thermal sciences, chemical sciences, structures, materials, dynamics, design, computational/numerical, and micro-nano sciences. Included within the thermal sciences field are specialty sub-field areas such as heat transfer, fluid mechanics, thermodynamics, transport properties, and energy conversion specialists. These sub-fields are further broken into smaller sub-fields. For example the heat transfer field includes specialists who concentrate in conduction, convection, and radiation heat transfer areas.

The breakdown of engineering disciplines into fields of interest is a major source of confusion and nervousness among students as they attempt to select a discipline. This is also a great source of confusion for counselors and advisors as they try to help their students find some direction for their interests. Rather than thinking in terms of engineering disciplines, students should examine the fields and specialty areas that are of most interest to them. Since “fields” stretch across many disciplinary boundaries, a student could find that he/she would be equally happy in a number of engineering disciplines.

Figure 1 depicts a simple schematic that describes the “controls” field relative to several engineering disciplines. Controls is broadly related to the sensing, processing (decision making), and actuation of a given system. For example, robots in a factory must sense what is happening to a product (possibly measuring temperatures, pressures, distances, color, aroma, etc.). After sensing the current state of a product or process, a decision must be made as to what the next process step should be. The decision is generally performed by some type of computing system, which could be a local microprocessor or a remotely located system. In today’s global world, the decision-making system may be halfway around the world or in space, linked through the internet. Once a decision is made, devices are

needed to actuate processes in order to cause a desired effect. A color sensor may send information to a microprocessor that indicates some additional paint is required at a certain location. Actuators would then move a paint-spraying nozzle to the desired location and open a valve to allow paint to be applied.

One can imagine similar “controls” processes requiring similar actions in many areas. The control of an aircraft or spacecraft requires sensing, decision making, and actuation processes. Nuclear power plants, artificial arms and legs, cars, chemical processing plants, a medicine dispensing machine, solar energy power systems, toys, and more, all require methods for sensing, processing, and actuation.

Figure 1. Interrelation of engineering disciplines with the “controls” engineering field and many of its associated sub-fields.

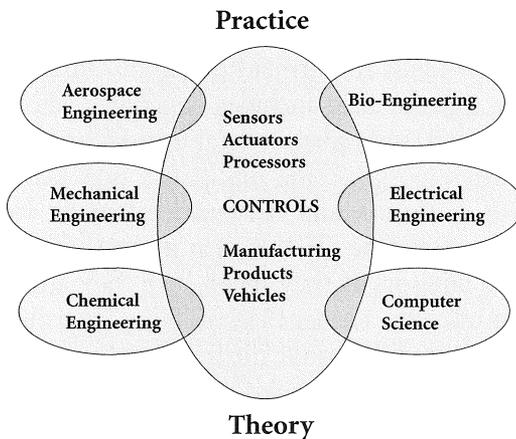
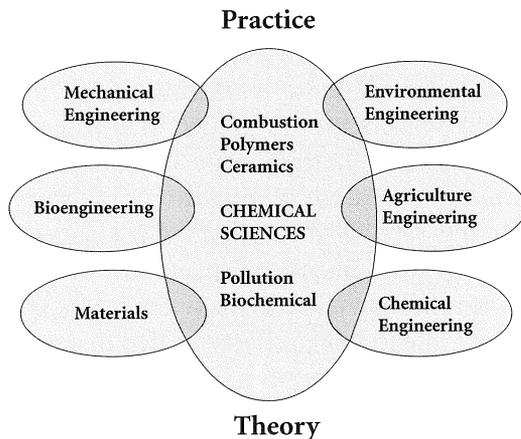


Figure 1 depicts *Theory* and *Practice* at opposite ends of the controls field spectrum. Theoreticians may be (but are not necessarily) those with a strong interest in mathematics while practitioners may be those with a strong aptitude for hands-on development. Along the continuum between the two are those who have a variety of interests.

How one applies a field of interest is also a consideration. The thermal science field forms the basis for designing solar energy systems for heating homes and for designing explosive weapons. The same equations and physical principles are used for both activities. There is no *good* or *bad* engineering discipline or field. People decide how they will apply their engineering skills. Figure 2 presents another example that shows some of

the overlapping relationships among a number of engineering disciplines with fields in the chemical science area. Chemical science is an expanding field due to our rapidly increasing ability to sense and manipulate from the nano-scale (molecular level) to the macro-scale. Additional engineering disciplines could be shown in Figure 2 as well.

Figure 2. Schematic of engineering disciplines and topics in the chemical sciences field.



## Engineering Careers

The combination of engineering disciplines and associated fields may seem daunting and confusing to students who are attempting to make engineering career decisions. Another consideration that factors into the student's decision process should be the career choice direction. While appearing to be an additional source of confusion, one can also view this way of viewing the career selection process as providing for additional flexibility and opportunity.

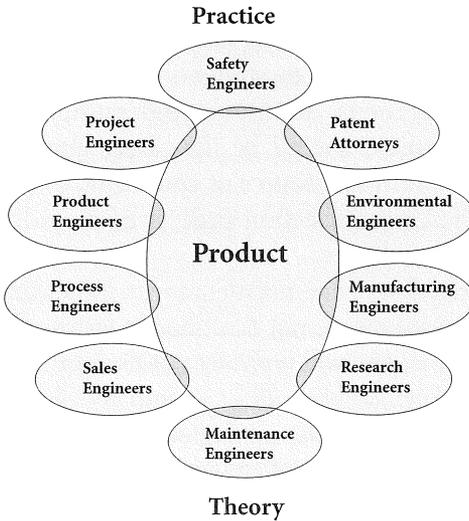
To make the selection of engineering careers somewhat more confusing, many engineering positions are not described in terms of engineering disciplines or fields. That is, one will typically not find an *Electrical Engineering Group* or a *Controls Engineering Team* at a company. More typical is a *Project Engineering Group* or a *Maintenance Engineering Group*, both of which are typically composed of a number of engineering disciplines and skills.

Consider the activities needed to develop a new product. A company will require several engineers, defined by several of the engineering names (shown in Figure 3) in order to take the new product from concept to reality. At the very beginning, research and development engineers work

to construct and test prototypes of the proposed product. As the product is developed, manufacturing engineers design the manufacturing system required for making the new product. Project engineers are then used to design the various types of machines that will be part of the manufacturing process. Process engineers continuously monitor the manufacturing processes as the product is manufactured. When changes in production rates or product characteristics are needed, process engineers determine how to adjust the manufacturing system to maximize the system and to obtain the desired production changes.

Also associated with the activities for developing successful products are sales engineers who assist the marketing people in communicating a product's technical capabilities to others. Maintenance engineers continuously inspect and maintain the production equipment, trying to avoid unexpected disruptions to product manufacturing since production line disruptions are costly. Safety and environmental engineers ensure that the factories comply with government and corporate policies and regulations. Patent attorneys are often lawyers with engineering backgrounds who help protect a company's intellectual property related to a product.

Figure 3. Engineering careers related to the creation and manufacture of a product.



## ENGINEERING PROGRAM ACCREDITATION AND PROFESSIONAL REGISTRATION

The formal education required to be an engineer typically involves obtaining an engineering degree from a four-year, college-level institution that is accredited by the Accreditation Board for Engineering and Technology (ABET). The ABET accreditation process requires a formal review by an ABET review committee. Program accreditation is required every seven years. Review committee members, representing each of the engineering disciplines to be accredited at an institution, examine instructional materials and interview faculty and students to assess each engineering degree program. Although each engineering discipline consists of topics that differ from other engineering disciplines, a common basis for assessing engineering programs relies on ABET Criterion 3, which specifies the skills and knowledge all engineering students should attain as a result of their education. ABET Criterion 3 states that “Engineering programs must demonstrate that their students attain:

1. an ability to apply knowledge of mathematics, science, and engineering, an ability to design and conduct experiments, as well as to analyze and interpret data;
2. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
3. an ability to function on multi-disciplinary teams;
4. an ability to identify, formulate, and solve engineering problems;
5. an understanding of professional and ethical responsibility;
6. an ability to communicate effectively the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;
7. a recognition of the need for, and an ability to engage in life-long learning;
8. a knowledge of contemporary issues; and
9. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.” (Engineering Accreditation Commission, 2007).

After graduation from an accredited engineering program, engineers may seek professional registration. The regulations for professional registration are controlled by state authorities. In some states, one must have professional registration before he/she can have “engineer” as part of his or her job title. Within a corporate environment, one often does not need professional registration for factory production systems that do not interact with the general public. Engineering systems and products that interact with the general public normally do require approval (called a “PE stamp”) by a professional engineer. Civil engineers, whose work often comes in contact with the general public, are more likely than their peers in other disciplines to seek professional registration.

## **SUMMARY AND CONCLUSIONS**

We set out in this chapter to show historical connections between the fields of engineering and technology education, and to suggest that common roots provide a basis for the collaboration that can lead to the infusion of engineering in the K–12 curriculum. In addition to the common roots, the chapter provided a broad view of the engineering profession, first by focusing upon the development of particular disciplines, then by examining modern advances from World War II through the present time, and finally by examining the structure of the engineering profession today, including the range of career possibilities this evolving structure now yields.

The engineering profession shares with technology education the common desire for all citizens to become technologically literate. Students can address this important literacy challenge by engaging in study that invites them to imagine, design, and construct engineering devices and processes. If the two fields can find a way to work together to achieve their common goals in the schools, the result will be to the good of young people and society as a whole. The alliance between the engineering profession and technology education is solidly anchored in history and poised to extend well into the future.

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## **INTRODUCTION**

While engineering education and technology education are separate academic areas, some clear conceptual alignment exists between the two. The purpose of this chapter is to present a synthesis of findings and conclusions about core engineering concepts from the literature with findings of an engineering outcomes study. This analysis is designed to inform curriculum and program designers for secondary level engineering and technology education. The analysis will also provide a clear indication of a baseline set of core engineering education concepts appropriate for secondary level engineering-oriented technology education curriculum.

## **RATIONALE FOR IDENTIFYING ENGINEERING CONCEPTS FOR GRADES 9–12**

While many of the core engineering competencies identified through research and in the literature are not necessarily related to attitudes and cross-disciplinary skills and knowledge, engineers also need to have a significantly broad set of knowledge and abilities beyond the scope of traditional technical engineering education. Bordogna (1997) emphasized this fact in an address to the National Science Foundation.

To be personally successful in today's world and simultaneously promote prosperity, engineers need more than first-rate technical and scientific skills. In an increasingly competitive world, engineers need to make the right decisions about how enormous amounts of time, money, and people are tasked to a common end. I like to think of the engineer as someone

who not only knows how to do things right but also knows the right thing to do. This requires engineers to have a broad, holistic background. Since engineering itself is an integrative process, engineering education must focus on this end. (n.p.)

The same might be said regarding all students who want to succeed in the new century—a century characterized by difficult to manage rates of technological innovation and technological influence on almost every aspect of life. In order to be prepared to succeed in such an environment, society (including aspiring engineers) must possess some level of what is termed “technological literacy” (Dyrenfurth, 1991).

To better position technology education in the public schools and to connect engineering to technology conceptually, Wicklein (2006) proposes the infusion of engineering design into the technology education curriculum. He outlines basic, broad categories for the infusion of engineering design into technology education. Those broad areas of engineering include, “...narrative descriptions [of engineering processes], graphical explanations, analytical calculations, and physical creation” (p. 29). Also described are courses that might typify a technology education curriculum based on the infusion of engineering design. The courses include, “Introduction to Technology, Engineering Graphics, Research and Design, and Engineering Applications” (p. 28). Among the engineering concepts deemed to be essential to such a curriculum are optimization, analysis, and prediction. Wicklein also asserts that students should take all of the science and mathematics courses that are available in high school to enhance learning through engineering design.

Teaching about engineering and engineering concepts in technology education is not a new idea. Olson (1957) promoted the inclusion of engineering concepts in industrial arts education in the late 1950s. Lewis (2004) summarizes the breadth of the effort to integrate engineering into the technology education curriculum as being fairly extensive. While the Massachusetts Department of Education (2001) has developed an extensive set of content standards for its own pre-engineering curriculum, Lewis documents that a variety of states are allowing students to take *Project Lead the Way* courses as part of their technology education. Lewis also characterizes the pre-engineering emphasis as a way of integrating science, technology, engineering, and mathematics (STEM), thus improving student achievement, as well as improving the perception of technology education among educators and professionals from other academic disciplines.

With the back-to-basics movement of the 1980s and with the publication of *A Nation at Risk* (National Commission on Excellence in Education, 1983), there began a sequence of national content standards development projects related to K–12 STEM education. Salinger (2003) describes the breadth of existing standards for STEM education and concludes that standards should cause cross-curricular teaching and learning. He also notes that standards should be geared toward higher levels of achievement, particularly designed to facilitate curriculum integration among STEM subject areas. More specific to engineering and technology education, it is clear that work remains to be done to prepare engineers with broad capabilities, ready for the demands of the year 2020 as well as to prepare citizens with a broad understanding of their technological world. Prerequisite to the design of curricula to address engineering and technological literacy is the identification of core engineering concepts.

## **STANDARDS EFFORTS TO IDENTIFY AND INTEGRATE K–12 ENGINEERING CONCEPTS**

One of the conundrums facing technology teachers is the need to address the ever-expanding nature of technological knowledge in a curriculum tempered by the realities of schooling. Simply stated, there is just too much to teach and too little time to teach it all well. Rather than attempting to address the breadth of technological knowledge in a superficial manner, technology teachers should focus their precious time and resources on teaching important ideas and essential skills with some depth in order to provide students an intellectual foundation for life-long learning. The challenge lies in the selection of concepts and skills that should be emphasized at the expense of other content.

The introduction of national curriculum standards has provided technology, mathematics, science, and engineering teachers a valuable resource for identifying the concepts and skills that are most worth teaching. Various professional organizations have assembled experts with diverse perspectives to think through the complexities of their disciplines to identify the core concepts and skills essential to the disciplines.

In 1996, the International Technology Education Association (ITEA), with funding from the NSF and the National Aeronautics and Space Administration began the *Technology for All Americans Project*. The project culminated in 20 standards with associated benchmarks for technology

education and other programs that contribute toward developing technological literacy in public school students. In 2000, ITEA published the *Standards for Technological Literacy: Content for the Study of Technology*. In addition to helping teachers develop curricula related to technology, the standards include elements of engineering, including optimization, trade-offs, engineering design, and design skills and knowledge (see also Massachusetts Department of Education, 2001; Australian Ministry of Education, 2004).

The American Association for the Advancement of Science (AAAS) developed a set of science standards and benchmarks, which included elements of technological and engineering design, as an outcome of their *Project 2061*. The final product, entitled *Science for All Americans* (1989), aspired to articulate the knowledge and skills needed to promote scientific and technological literacy. The understandings and abilities delineated in *Science for All Americans* were subsequently broken down into a series of scaffolding expectations for students that begin with simple ideas in the early grades and progress to sophisticated understandings upon graduation. Teams of teachers and administrators, informed by education specialists, engineers, and scientists, mapped how students would construct important ideas as well as their ability to “bring intellect to bear on practical matters” (p. 319). The final product was titled *Benchmarks for Science Literacy* (1993).

It is important to note that AAAS’s concept of science literacy was broadly conceived and it included important ideas from mathematics and technology along with science content. The importance of including mathematics and technology along with science was based on the premise that the disciplines are inherently integrative. The pursuit of science is dependent on mathematics and technology in much the same way as engineering endeavors are dependent on mathematics and science. It is this interdependence among the STEM disciplines that inspired the need to present important ideas and essential skills from all three disciplines in both publications.

*Project 2061*’s vision for what high school graduates should know and be able to do for the study of technology can be found in chapters 3, 8, and 11 of *Science for All Americans* (1989) as well as *Benchmarks for Science Literacy* (1993). These sections make numerous references to engineers and engineering in their treatment of technology as an integral part of science literacy. However, there was not any attempt to identify understandings or habits of mind specific to engineering.

Selecting standards to guide and inform pre-engineering curricula can begin by simply looking at engineers and the things they do. During the course of their work, engineers address ill-defined problems, confront constraints, model potential solutions, engage in analysis, make informed design decisions, balance trade-offs, optimize designs, and consider impacts (Kemper & Sanders, 2001; Koen, 2003; Vincenti, 1990; Wright, 2002). These concepts are closely related to those thought to contribute to technological literacy (AAAS, 1989, 1993; ITEA, 2000; National Academy of Engineering, 2002). For example, engineering involves making informed design decisions based on evidence that a process, device, or system will work in accordance with expectations, and within limitations, prior to implementation or prototyping. Mathematical models play an important role in testing potential designs. One standard that is consistent with this concept is: “The basic idea of mathematical modeling is to find a mathematical relationship that behaves in the same ways as the objects or processes under investigation. A mathematical model may give insight about how something really works or may fit observations very well without any intuitive meaning” (AAAS, 1993, p. 270). Another standard related to this concept is, “The usefulness of a model can be tested by comparing its predictions to actual observations in the real world. But a close match does not necessarily mean that the model is the only ‘true’ model or the only one that would work” (AAAS, 1993, p. 270).

*Science for All Americans* and *Benchmarks for Science Literacy* contain profound ideas and ways of thinking that can play an important role in the identification and articulation of concepts that are fundamental to the study of engineering at the secondary level. The most explicit statements of what students should know and be able to do related to interfaces among STEM subjects, and those especially related to engineering and technology are identified in the *Benchmarks for Science Literacy*.

## **RESEARCH AND DEVELOPMENT PROJECTS TO IDENTIFY AND INTEGRATE K–12 ENGINEERING CONCEPTS**

Projects such as the *Integrated Mathematics, Science, and Technology Project* (IMAST) (Satchwell & Loepp, 2002) and the *Technology, Science, Mathematics Integration Project* (Childress, LaPorte, & Sanders, 1994) are among the curriculum efforts designed to integrate STEM education that

were led by technology education professionals. There are also efforts outside of the field of technology education. Programs such as those in the NSF-funded Centers for Learning and Teaching (2005) are attempting to integrate STEM education at the public school level. NSF funding has also included money for informal STEM education targeted at the K–12 and family levels. The Boston Museum of Science (2005) is one example of such outreach efforts.

Mid-Continent Research for Education and Learning (McREL) (2004) is an example of a U.S. Department of Education effort to organize standards for the integration of STEM and other school subjects. McREL is charged with stimulating reform in education through systemic initiatives. McREL is an excellent resource identifying core engineering concepts that should be taught at the high school level. The engineering section is substantial.

Dearing and Daugherty (2004) conducted a modified Delphi study to identify those concepts that are necessary to teach high school students in order to prepare them for post-secondary engineering education, while preserving the mission of teaching technological literacy. The participants in this study included technology teachers, technology teacher educators, and engineering educators. Dearing and Daugherty developed a predetermined list of concepts based on information from *Project Lead the Way*, *Principles of Technology*, the *Standards for Technological Literacy*, American Society of Engineering Education, and others. Participants were asked to specify whether a concept should or should not be included in a curriculum. Fifty-two concepts on their list met the consensus criterion. The items were also ranked in order of importance.

One approach to infusing engineering into K–12 schools could be to pattern high school engineering curriculum after university engineering programs. University engineering programs, however, are driven by program accreditation. A review of the Accreditation Board for Engineering and Technology (ABET) standards indicates a clear focus on post-secondary, career-specific engineering education. The Dearing and Daugherty (2004) study and the one described near the end of this chapter indicate that engineers and technology educators see distinct differences between concepts and skills appropriate at the high school level and university levels (National Academy of Engineering, 2004).

Robinson, Sparrow, Clegg, and Birdi (2005) surveyed and interviewed 58 design engineers regarding the importance of competencies needed by design engineers in the coming decade focused on positioning design

engineering firms to remain competitive. The outcomes of their study indicate that many of the competencies are not necessarily engineering-specific. Engineering skills tend to blend into the skills required in other technical fields. In fact, it appears that many of the *emerging* concepts and skills that engineers will need in the future are the same concepts and skills needed by people in non-engineering fields.

For example, two of the core competencies identified in the Robinson, Sparrow, Clegg, and Birdi (2005) study are innovation and creativity. They assert that creativity is more important to the process of designing revolutionary inventions. Since revolutionary invention occurs less often, they reason that incremental innovation is going to be of higher importance. As companies struggle to gain a competitive edge, the importance of *sustaining incremental innovation* becomes even more important. On the other hand, creativity, associated with large breakthroughs and revolutionary improvements, is more difficult to sustain at a level that will make a difference in a highly competitive economy. Because of the changing nature of competition in the global economy, incremental innovation will emerge as an important competency in the future.

This perception appears to contradict what the National Academy of Engineering (NAE) (2004) postulates as engineering attributes needed for the year 2020. The NAE maintains that creativity is not only an important contemporary core engineering concept, but that it will become even more important as the global economy strengthens and the rate of technological innovation skyrockets in the future. In a similar vein, Robinson, Sparrow, Clegg, and Birdi (2005) assert that non-technical skills will emerge in the future as being so important as to rival technical skills. These competencies include skills such as managing projects well and being open minded. In the future, design engineers will increasingly be required to lead groups comprised of both engineers and non-engineers.

A number of other authors (see also Koehler, Faraclas, Sanchez, Latif, & Kazarounian, 2005) and documentation from 15 additional state-related or project-related outcomes are consistent with the more general approach to engineering concepts. Collectively, these findings tend to support what Bordogna (1997) has emphasized about the holistic engineer. It is also reassuring that, with the exception of creativity, the findings of the Robinson, Sparrow, Clegg, and Birdi (2005) study reinforce the opinions expressed by the NAE in *The Engineer of 2020...* as well as the findings of the Dearing and Daugherty (2004) study.

Robinson, Sparrow, Clegg, and Birdi (2005) define “core competency” as a competency that is currently essential and which will remain essential. If core competencies are not necessarily those things that are unique to engineering, what are those unique engineering competencies? Clearly, Wicklein (2006) believes that engineers, more than other designers, apply mathematics and science to the design of technological solutions to problems in deliberate, efficient ways. Because engineers seek to be efficient, engineering design has evolved into a relatively constrained process. Wicklein postulates that optimization, analysis, and prediction are the three things that separate engineering design from other forms of design. Optimization is the use of mathematics and science in order to create the most reliable designs. This is reinforced by the NAE that identifies the following core attributes for engineers in the year 2020. Engineers will continue to need strong analytical skills and the ability to apply principles of mathematics and science to the design process. Engineers will continue to be good design project planners who can structure a project and run it efficiently in order to achieve a desired outcome.

Thus, the literature presents a somewhat dichotomous view of engineering competencies. On the one hand, there is strong support for a set of general skills and attributes (e.g., project management, organizational and communication skills, etc.). Alternatively, there appears to be an ongoing demand for the kinds of analytical and technical skills that are specific to engineering. Part of the dichotomy is likely due to perceived differences in content appropriate at the secondary level compared with university level engineering education. The differences also reflect the evolving nature of the engineering profession, which extends beyond an exclusive focus on technical engineering skills. The implications are important as technology educators seek to identify the core concepts appropriate for K–12 education.

## **NATIONAL CENTER FOR ENGINEERING AND TECHNOLOGY EDUCATION: CORE ENGINEERING OUTCOMES STUDY**

The goals of the National Center for Engineering and Technology Education (NCETE) include infusing engineering design into the technology education curriculum and reforming technology teacher education to include an emphasis on engineering design. As a preliminary step in fulfilling these goals, Childress and Rhodes (2006) identified core *engineering*

outcomes needed by students in grades 9 through 12. Using a modified Delphi technique, they identified 43 items, representing a consensus among engineers and engineering educators, appropriate for high school students who want to pursue engineering at the post-secondary level. While there are a limited number of curriculum standards specific to engineering education at the high school level, most standards also include industrial technology-related and technology and society-related elements. The study conducted was an attempt to consolidate and validate engineering standards written by disparate organizations. The results are available to inform the development of the NCETE professional development model, the reform of pre-service technology teacher education, and the infusion of engineering design into the existing engineering and technology education curricula at the high school level.

The modified Delphi approach started with pre-existing outcome items selected from national standards projects, focus groups, and additional resources (Dalkey, 1972; Custer, Scarcella, & Stewart, 1999) and persisted for six rounds with 34 participants in Rounds 1 through 3. Nineteen of the participants agreed to continue their participation in Rounds 4, 5, and 6, which represented an extension to the main study. The researchers chose engineering outcomes developed by the following organizations and individuals: American Association for the Advancement of Science (1993), Mid-Continent Research for Education and Learning (2004), National Research Council (1996), International Technology Education Association (2000), Massachusetts Department of Education (2001), Dearing and Daugherty (2004), National Council of Teachers of Mathematics (2000), Koehler, Faraclas, Sanchez, Latif, and Kazarounian (2005), and Bordogna (1997). While some of these resources address broad sets of standards such as those for industrial technology and technology and society, they were nevertheless selected because they also contain standards and outcomes focused specifically on engineering and engineering design.

The participant selection criteria for the study were that each participant be either a practicing engineer, an engineering educator, or someone working in a field closely related to engineering or engineering education (e.g., curriculum writer or association/non-profit or government employee). Participants were nominated by a well informed program officer at the National Research Council and by a former employee of ABET. Some participants were, in turn, nominated by those identified in the first round of nominees. Table 1 shows participant demographics. Most participants teach engineering at the university level.

Table 1. Participant Demographics.

<b>Gender</b>		
Female		13
Male		21
<b>Ethnicity</b>		
White		26
African-American		4
Asian		1
Native American		1
Mixed		1
Missing		1
<b>Age</b>		
Mean Age: 50.67	Range: 71–33 = 38	Missing: 1
<b>Experience</b>		
Years of Experience as Engineer (26 are or have been practicing engineers)		Mean = 12.6
Years of Experience as Engineering Educator (28 are or have been engineering educators)		Mean = 14.18
Years of Experience in Engineering-Related Position (5 are in jobs related to engineering)		Mean = 2.61

Participants were asked to rate outcome items on a five point Likert scale (Clark & Wenig, 1999). The ratings were (1) Least Important—not necessary for an engineering-related high school curriculum, (2) Less Important—less than necessary for an engineering-related high school curriculum, (3) Important—necessary for inclusion in an engineering-related high school curriculum, (4) More Important—essential for inclusion in an engineering-related high school curriculum, and (5) Most Important—most essential for inclusion in an engineering-related high school curriculum. The interquartile range (IQR) was used as the statistic for variability of rating responses (Rojewski & Meers, 1991; Wells, 1994). An IQR of 1 was determined by the researchers to represent consensus on individual items with the median then representing the chosen rating.

Twenty-one items were rated at 3 (Important to include in the curriculum) and 21 items were rated at 4 (More Important to include in

the curriculum). One item was rated at a 4.5 median (Most Important). Because it would be difficult to rank outcome items in order of importance within each of the two rating groups (Important and More Important), the researchers decided to ask a group of carefully selected engineers to group outcome items into groups of conceptual likeness and then name the groupings with a category name, a process conceptually similar in intent to factor analysis. This prepared the Round 4 instrument, where participants were asked to *rank order* the categories (rather than individual items). The final ranked engineering outcome categories along with representative items are presented in Table 2. While it was possible to arrive at a rank ordering of the categories, it was not possible to achieve consensus on each of the categories. For example, while the Application of Engineering Design category was ranked second by the panel, an IQR of 1 was not to be achieved.

Table 2. Final ranked engineering outcome categories.

<b>Group Rank</b>	<b>Outcome Group and Description</b>
1st	Engineering Design: This category emphasizes the big picture when it comes to engineering design. It emphasizes the importance of creativity and confidence when it comes to designing engineered solutions to problems. There was also consensus within this grouping as to the importance of outcomes related to design iteration, varying design processes, and tradeoffs. Representative items included understanding that engineering design is iterative, knowing how to connect engineering principles to engineering problems and solutions, understanding the importance of creativity in design, and achieving the realization that designs involve trade-offs and compromises among constraints.
2nd No Consensus	Application of Engineering Design: This category focused on specific design activities. For example, students should be able to organize and optimize the overall engineering design process. Experimentation, prototyping, and reverse engineering are included in this grouping. Representative items included identifying engineering problems, organizing and managing the engineering design process, conducting and implementing designs, and applying the results of research to design and development projects.
3rd	Engineering Analysis: In this category, mathematics is emphasized. This is the grouping that includes using mathematics to optimize solutions, and it emphasizes the use of mathematics and science in the engineering design process. Representative items included using models to study processes, applying mathematics and science to engineering design, using measuring equipment to generate data, and using optimization techniques.

Group Rank	Outcome Group and Description
4th No Consensus	Engineering and Human Values: This category emphasizes the big picture when it comes to the interaction of engineering design and society. It includes, for example, the weighing of limitations with decisions about safety and the environment versus costs and ethics. Representative items included an awareness of how societal interests, economics, ergonomics, and environmental considerations influence design solutions, how constraints such as cost, safety, and environmental impact affect the design process, and how values constrain designs.
5th No Consensus	Engineering Communication: This category includes a variety of outcomes ranging from CAD to presenting solutions in a variety of formats, graphical, verbal, and numerical. It tends to characterize all sorts of communications important to the engineering design process. Representative items included understanding computer applications, developing and making technical presentations using a variety of tools and techniques, using computer imaging tools to solve engineering problems, understanding scale and proportion, generating and interpreting drawings, etc.
6th No Consensus	Engineering Science: This category includes many of the traditional engineering sciences such as statics and dynamics. It includes items like understanding material properties and materials processes, ergonomics, energy and power, etc. Representative items included understanding engineering career options, applying basic ergonomic concepts, and understanding the basic principles of energy, materials, mechanics, statics, dynamics, etc.
7th	Emerging Fields of Engineering: This category includes two items related to nanotechnology, but it is understood as being able to include such fields as genetic engineering, biotechnology, and smart materials, to name just a few of the possibilities. Representative items included understanding the convergence of nanoscience, biotechnology, information technology, how cognitive science creates opportunities for the improvement of industrial productivity and quality of human life, and how this convergence will lead to future innovations.

(For a complete listing of items, visit <http://www.ncete.org/flash/Outcomes.pdf>)

It is important to note some items and areas of emphasis that did not achieve consensus, particularly from the perspective of secondary level engineering education. Of particular importance is the use of mathematics and science to optimize design solutions. While Wicklein's (2004) premise, namely, that the use of mathematics and science to optimize solutions prior to implementation for modeling and predictive analysis, and to generally support the engineering design process, tends to be validated by these findings, it was only at a moderate level. One reason for this moderate level of consensus was that some panelists were skeptical about the ability of high school technology students to use advanced mathematics and science tools to solve engineering problems.

It is also interesting to note, again from the perspective of technology education, that while panelists could not reach consensus regarding the necessity of technical sketching, they did indicate that CAD is necessary. This contradicts the findings of the Dearing and Daugherty study, where sketching was found to be necessary but CAD was not. It is important to note that the Dearing and Daugherty study was designed to include the perspectives of both technology and engineering educators. It is likely that technology educators place more importance on sketching than engineers; or perhaps they believe that engineers depend on sketching more than they actually do. The current study included only engineers or engineering curriculum-related professionals who clearly believe that CAD is an important engineering tool.

Another finding of interest had to do with the use of prototyping for testing and analysis. While panelists indicated that prototyping is essential, some went on to comment that “this sounds suspiciously like shop class” and even suggested that such hands-on activities could turn off students. This perspective appears to contradict the guidelines developed by Douglas, Iverson, and Kavandurg (2004), which call for engineering education at the K–12 level to contain rich, hands-on learning experiences.

One additional item of non-consensus focused on the importance of teaming and group work. Robinson, Sparrow, Clegg, and Birdi (2005) and the NAE emphasize the importance of engineers working in teams, including teams with non-engineers. However, this study’s engineers and engineering educators failed to reach consensus on the study’s related item, “Works effectively in teams.” A number of comments associated with the item confirm the ambivalence about the importance of group and teamwork skills.

Finally, it is worth noting that a number of the highly rated items aligned substantially with the conclusions of Robinson, Sparrow, Clegg, and Birdi (2005) and the NAE. These include items focused on the importance of creativity, flexibility, efficiency, organizational ability, the ability to manage complexity, and an understanding of tradeoffs and ethics in engineering design. The findings also align with previous work (Robinson, Sparrow, Clegg, & Birdi, 2005) indicating that engineers will need to have broader foundations of knowledge regarding emerging or revolutionary technologies (i.e., nanotechnology and biotechnology).

The fact that the participants were only able to reach consensus on the rankings of three of the outcomes groupings, appears to be explained by fundamental disagreement as to which groupings of outcomes should be taught

first, second, and so forth. As in the first three rounds of the study, participants were required to post comments if they did not vote with the majority. These comments indicated a sustained disagreement. Nevertheless, with IQR's of zero, it is clear that participants were able to agree that Engineering Design should be ranked first in importance, or the most important to be taught in a limited time frame and that Emerging Fields of Engineering was last in importance, or the least important to get taught in a limited time frame. It is also important to note that engineers tend to maintain the perspectives unique to their particular engineering discipline. For example, engineers from the nanotechnology field would naturally emphasize this emergence more than engineers from other areas.

## **IMPLICATIONS FOR TECHNOLOGY EDUCATION CURRICULUM AND INSTRUCTION**

Because there are already many school systems in which proprietary pre-engineering curricula are required for use in pre-engineering programs, the researchers find less utility in making engineering *the* focus of technology education; rather, the preferred approach is to infuse engineering concepts into the existing technology education curriculum while retaining technology education's mission of technological literacy.

However, the implications of the core engineering outcomes identified in this study are evident. For example, it is clear that engineering education at the K–12 level should be hands-on (Douglas, Iverson, & Kavandurg, 2004), which points to the usefulness of activities having to do with such things as conducting reverse engineering, research and development, fabricating prototypes, and testing designs. Also important are activities concentrated on engineering communication including presenting findings, using CAD, and using computing tools and models to gather data, optimize solutions, and assess results. Engineering-oriented programs must also include experiences requiring students to apply mathematics and science principles to the solutions they design. In the midst of an extended back-to-basics movement with high-stakes testing, the ability to improve student achievement in, and attitudes toward, STEM subjects will provide a meaningful service to education. This emphasis hopefully will lead to increased diversity in students who would like to pursue STEM-related careers after high school and college.

What engineering outcomes should be included in a high school technology education program that focuses on providing students with technological literacy? Clearly, those outcomes that most closely correspond to the *Standards for Technological Literacy* should be included. Among these are optimization, the social and ethical dimensions of engineering design, and outcomes associated with prototyping, creativity, and managing the design process. Research, development, and analysis activities are also important.

What engineering outcomes should be included in a high school technology education program that focuses on pre-engineering? All of those consensus outcomes in the Childress and Rhodes (2006) study were identified on the premise that they were to be taught to high school students as foundational to post-secondary level engineering education. However, the curriculum designer should be careful. A crowded curriculum, which leaves scarce time for application, diminishes its effect on student achievement and motivation. Some outcomes need to be taught and applied repeatedly across the school year. These fundamental processes are the essence of engineering. Other outcomes need only be taught and applied once within a specific course. Perhaps the most pertinent approach to deciding what outcomes to include in a pre-engineering curriculum is building a course sequence that includes the outcomes in order of importance but also in order of prerequisite content. To the extent possible, pre-engineering content should be carefully sequenced by conceptual load, with sensitivity to developmental factors and prerequisite knowledge (particularly mathematics and science). Program planning should also include provisions for hands-on applications of engineering design in a manner that integrates knowledge from across the academic areas.

Having identified those core engineering concepts that should be taught to high school students, under what circumstances should one go about teaching the concepts? Douglas, Iverson, and Kavandurg (2004) in summarizing the results of an ASEE analysis of current practices in K–12 engineering education, developed the following guidelines for the future of K–12 engineering education. First, engineering education should be hands-on and applied in order to motivate students by embedding engineering problems within interesting and relevant social contexts. Second, engineering education should be taught using an interdisciplinary approach in order to show the relevance of mathematics, science, and other subjects, by making engineering a conceptual place for the application of these subjects. Third, develop standards-based K–12 lesson plans

designed to help teachers teach mathematics and science concepts in the classroom. Douglas, Iverson, and Kavandurg (2004) further suggest that state-level K–12 standards should be developed (similar to what has been done in Massachusetts). Fourth, improve teachers by increasing their pay, providing meaningful professional development, and involving them in writing curriculum. Fifth, make engineering a more attractive career choice for female and minority students by working with their schools through outreach efforts. Finally, engage more constituents in partnerships that cross all levels of the educational process.

Teachers, teacher educators, and administrators carry a heavy burden. Their mission is to provide students with the best education possible. Memorizing facts and studying textbooks has worked to some extent for the profession of engineering. However, contemporary engineering education will require new and innovative methods. The engineering profession and all STEM subjects can attract a more diverse population of participants by providing access. This is not simply access to a school and books but access to instruction that has meaning for students who have not traditionally pursued STEM professions. Teaching meaningful concepts and providing meaningful opportunities for application is part of what “access” to education is about.

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## INTRODUCTION

Engineers create, synthesize, solve problems, and innovate. Engineers use the basic principles of science and mathematics to optimally convert resources to meet a stated objective. Engineers develop economical solutions to problems. But most importantly engineers design.

Webster (Merriam-Webster's, 1989) defines "design" as:

to conceive in mind; to invent; to form a plan; to create or execute in a highly skilled manner; a reasoned purpose; intention; details of something according to a plan. Design is a mental project or scheme that was devised for a specific function. Design is an orderly, structured problem solving activity or process which through step-by-step changes can lead toward a required result (p. 343).

Design occurs not only in engineering, but also in art, architecture, graphic design, theater design, fashion design, architecture, and many other disciplines. Artists use their imagination and skill in the design and production of things of beauty. Architects design the form and function of buildings. Theatrical designers design the scenery, lighting, props, curtains, and costumes to create the effects and look needed in a scene. Fashion designers create a statement about a mood, a look, and the individual in the design of clothes. Graphic design is a form of visual communication in which information is provided in a given form and function. What differentiates engineering design from that of other disciplines is that engineers *predict the behavior* of the design and the *success of a solution* before it is implemented (Foutz, 2006). These predictions are made by applying the principles of science and mathematics to the solution of the problem.

## **ENGINEERING DESIGN**

Engineering design is an orderly, structured, problem solving activity or process through which changes can lead toward a required result. The engineering design process can be used in original design, redesign, or a mature design of a product (Foutz, 2006). Original design is the design of a product never seen before; redesign is the modification of an existing product to meet new or additional requirements; and mature design is the minimal modification of the product. In books on engineering design, this is often presented as an orderly process consisting of from six to 10 steps including such things as defining and refining a problem, establishing constraints, prototyping, design evaluation, and more (Burghardt, 1999; Dym & Little, 2003; Eide, Jenison, Mashaw, & Northup, 2002; Moaveni, 2002). This is not to say that a six-step process is more efficient than a 10-step process. Rather, the true difference is how authors describe the design process and what they identify as a step in the design process. While design is an orderly activity, it should not be considered to be a sequential process in which one step always follows another. It just does not happen that way with experienced engineering professionals. Engineering designers are constantly going back and forth between steps, revising and redesigning solutions until an optimal solution, often involving tradeoffs between competing design constraints, has been achieved. A list of the steps in the engineering design process is included later in this chapter (see Table 1 on page 70).

At one time it was thought that only senior engineers, with many years of experience, could be good designers. In effect, this approach suggests that design is a skill that can only be learned through many years of apprenticeship under a more experienced engineer. During this extensive apprenticeship period, younger engineers were taught the “magic tricks” of engineering design by those who were much older and wiser. However, design is no longer considered a skill that only comes over time. Rather, engineering design is a field of knowledge that uses a systematic approach to solving engineering problems. While younger engineers are still required to work under a registered Professional Engineer (PE) for licensing purposes, even these young engineers are expected to understand the engineering design process and to use it to solve problems. While some people are better designers than others, design is not limited to those who are creative, imaginative, and/or artistic. While designers must be imaginative and able to apply both science and art to their designs, they must also

be able to think independently, draw conclusions, use logical deductions, and combine solutions to do engineering design work.

## **ENGINEERING DESIGN EDUCATION**

In the teaching of engineering, students are normally asked to solve two very different types of engineering design problems. First, those in the engineering sciences, and secondly, open-ended design problems normally presented in their advanced design courses. The design problems presented in the engineering sciences (e.g., statics, strength of materials, dynamics, heat transfer, etc.) are more closed-form design problems with clear instructions that are well understood and normally have only one solution. These types of design problems are taught to help students understand the basic principles and laws of engineering science with less emphasis on learning how to design.

In the advanced engineering courses, open-ended problems are presented for students to solve. These types of problems are more like those that the students will experience after graduation. These open-ended design problems are normally poorly understood problems with many different solutions that draw on a student's knowledge gained from various subjects in engineering. In this case, the design solutions depend on feasibility, values, and preferences as well as the knowledge and experience gained by the student/engineer throughout his or her entire degree program. To help train students in the solving of open-ended design problems Accreditation Board for Engineering and Technology (ABET), the accreditation board for all engineering academic programs, requires that students be exposed to engineering design throughout their entire undergraduate engineering degree program.

## **PERSPECTIVES OF ENGINEERING DESIGN**

The following five sections present perspectives of engineering design as the process is applied by engineers.

### **Over the Wall Engineering**

The industrial revolution transformed civilization and the quality of life in the western world. Many schools of engineering were started in the

United States in the middle and late 1800s to meet the need for engineers. At that time, engineering went from an artisan profession to a science-based profession. Because of the rapid advances in technology of the day, designers and manufacturers often focused most of their efforts on making things. Product quality, product life cycle, and the fundamental needs and wants of the customer were secondary. Henry Ford, inventor and industrialist, typified this period of industrialization when he indicated that “the customer can have any color so long as it is black” (Collier & Horowitz, 2002). In those early days, the Ford Motor Company focused more on the manufacturing and production of an affordable car that the masses could afford to own and drive than the unique preferences and desires of customers. Ford was not alone. Much of American industry and manufacturing adopted these same attitudes in their design and production techniques.

Companies in those days utilized design techniques typically referred to as “over-the-wall engineering” (Bloch & Conrad, 1988). With this type of design, there was little or no interaction between the different parts of the design and manufacturing process. Marketing, engineering, and manufacturing all worked as separate, independent entities, each “throwing over the wall” to the next operation what they thought was needed and wanted by the customer. Based upon the strengths of each of these departments, a final design was produced. At the end of the process, the final product was “tossed” to the customers for their use. Because of this, design flaws and conflicts between marketing, design, and manufacturing, and even customer wants and needs, often occurred. This cost companies significant amounts of money while lengthening the development and production times of products. Ultimately, customers were delivered products that failed to meet their needs or preferences.

## **Team and Customer Driven Design**

One common misconception is that design is done by individuals—individual designers, working independently, create all of the mechanisms and inter-workings of new and complex devices. Design has changed dramatically in recent years. Most engineering projects depend on fundamental principles from many different engineering fields. Because of this, design has become a “team sport,” in which each member of the team is involved in the success of the project by contributing his/her ideas and technical expertise (Ullman, 1997).

Many in industry have not only adopted an integrated team engineering design approach, but have also come to recognize that a key missing piece in the team is the customer. Given this, design and manufacturing have evolved employing a “user-centered design process” (Usability Professional Association, 2006). In this design process, customer focus groups are integral parts of the design team, providing their opinions on all aspects of the design and manufacture of a product. Industry found that, in many cases, employing a “user-centered design process” resulted in better products, happier customers, and increased profits.

## **Sequential vs. Concurrent Design**

As industry has matured and the marketplace has become more global, many companies have found that they have had to modify their design and manufacturing processes to remain competitive. One such modification has been to change from a sequential design process to a concurrent design process (Burghardt, 1999). In sequential design, the design, development, and manufacture of a product are comprised of a long process in which one operation is followed sequentially by another. With the concurrent design process, all aspects of the design are developed at the same time, or concurrently. The concurrent engineering design process utilizes a team approach throughout the entire process. Design teams are not composed just of engineers; rather they include representatives from marketing, manufacturing, engineering, the legal department, distribution, packaging, and others. These teams are dynamic and can change from one part of the design and manufacturing process to another, depending on the needs. The success of concurrent design is dependent on how well the group functions as a team. Concurrent design teams work on identifying and overcoming potential problems which can impact the entire process. Because all aspects of a product are being considered at the same time, concurrent design enables the product to get to market sooner than if a sequential design approach had been used, generally lowering the overall product cost.

## **Design for the Environment**

Design for the environment (Wikipedia, 2006; National Park Service, 2006), sometimes called *Green Design* or *Sustainable Design*, is an alternative philosophy of design in which design engineers are no longer focused solely on delivering products to the customer more efficiently and economically;

rather, the design process extends to include the entire life cycle of a product or design. This type of design utilizes an alternative philosophy in which the design engineer is much more aware of environmental stewardship, social responsibility, and economic viability. This type of design takes into account the entire life cycle of a product or design, not only planning for the use of a product, but also specifically utilizing environmentally friendly materials during manufacturing or construction while minimizing the amount of energy and waste in producing the product. As a last step, design for the environment also takes into account how the product will be retired, reused, and/or recycled.

## **MODELING IN ENGINEERING DESIGN**

Engineers utilize both analytical and physical models in the design process. These models are used to provide them with a better idea of how design solutions will function during use. As information is gleaned from modeling, the designs are refined and redesigned.

### **Conceptual Modeling**

A conceptual model is a broad-based idea that engineers put on paper, which contains only enough detail to determine the feasibility of the solution (Foutz, 2006). Conceptual models are based on the problem definition that has previously been defined by engineers and related design professionals. A conceptual model is normally just a simple sketch or note about what might be the potential solution to the design. In this stage of design, the fine details of each component of the overall model have not yet been determined. Rather, the engineer is allowed to visualize a wide range of potential solutions, realistic or not, that could be implemented to solve a problem. With conceptual modeling, very little, if any, analysis has been performed. With conceptual modeling, subsystems may conflict with each other because not all of the technical issues have been addressed. Conflicts will be addressed once further development of the solution has been undertaken. With conceptual modeling, it is not unusual for some concepts to be drawn from ideas used in previous concepts, or existing designs adapted to the current problem situation. The more concepts a designer can identify, the better the final design will be. Because of economic and time constraints, not all design concepts can be explored in detail. Once all concepts have been proposed, they can then be compared

to each other to determine which are considered feasible for further exploration and analytical modeling.

## **Analytical Modeling**

With analytical modeling, conceptual models are subjected to a test to determine the feasibility of their success. The model is challenged analytically using mathematics, engineering, and the basic sciences to determine if it can work. Actual member sizes, parts, and so forth, are chosen and grouped together in a form to assess the extent to which the design can be a success. Analytical modeling is not a single pass-through operation. During the first iteration, optimizing the concept solution may simply involve comparing the concept to the engineering problem definition. As the number of iterations increases, the solution will take on system-level characteristics that are overviews of the design. In order to optimize the solution, simple models that involve the integration of the mathematical, natural, and engineering sciences will be required. These models could be simple analytical models described by a single equation or complex models utilizing huge matrices. The overall model may require many different refinements as more and more information is gathered from each phase of analysis. Constant reworking of the model is required as it is refined into a final product. As the model is refined, a clearer picture of all the fine details of the concept is determined. One of the last activities of analytical modeling is the development of mechanical drawings, a parts list, and a list of potential vendors.

## **Physical Modeling**

Physical modeling involves building and then testing an artifact. Physical modeling of a design is normally done to see how a design acts under simulated or real-world conditions, to verify the design assumptions utilized in the analytical modeling phase, or to determine the effectiveness of the design. Physical modeling of a design is also performed to better understand how to manufacture a product, to determine the cost of manufacturing, and specify which manufacturing techniques will be involved in production. Physical modeling can identify conflicts or interaction problems between sub-components of a design that were not determined during the analytical modeling phase. In this phase, as well as the other two phases of design, improvements and redesign of the product

are constantly made. The actual physical model may be only one small component of a complex design or the total design. The physical model can even be a scale model of the total project. Physical modeling and testing can be very expensive and time consuming. Test procedures must be developed and the product tested. Testing could be done by the design engineers themselves or it may require the use of outside expertise. In many instances, no physical model is built because of the expense involved and the magnitude of the designs. If the technology is mature and well-known, then a physical model does not need to be built and the design is based only on the analytical model.

## **APPLICATIONS OF ENGINEERING DESIGN WITHIN ENGINEERING DISCIPLINES**

The four largest branches of engineering in the United States are civil, mechanical, electrical, and chemical engineering. However, there are more than 20 different engineering disciplines in which engineering degrees are conferred (Moaveni, 2002). Within each major branch of engineering are specialty areas in which individual engineers normally concentrate their work efforts. These concentrations are normally specialized areas of interest, which are subsets of the broader branch of engineering.

Engineers within each of these disciplines approach design from a unique, yet very similar perspective. The following vignettes provide a glimpse of how engineering design is addressed from different engineering disciplines.

### **Environmental Engineering**

Greg Southworth, Environmental Engineer, Shell Oil Company, graduated from Louisiana State University and has worked as an engineer for 17 years.

His involvement with environmental design and project management is typically divided into three major categories: policy studies, environmental impact assessment, and traditional design. Policy studies (or development of environmental standards) are typically performed to identify areas where environmental controls are warranted and evaluate options for implementing policies, procedures, and controls to minimize or eliminate environmental impact. Policies can then be translated into operating practices/procedures, or engineering design specifications to meet the

policy objectives. Environmental impact assessments evaluate the impact on various environmental media (air, water, and soil/groundwater) from a planned activity, while also identifying mitigation strategies for minimizing impacts. Traditional design practices involve the engineering design of pollution control equipment, and include conceptual design, preliminary design, and detailed design phases prior to construction.

The primary difference between environmental engineering and other branches of engineering is the interaction the environmental engineer must have with other non-engineering science disciplines, government stakeholders, and the public. An environmental engineer often must include input for design from biologists, ecologists, and geologic disciplines, as well as ensure that designs and projects take into account public input, since most projects will affect a public resource—the environment. Emotional issues can be a significant factor and a technically feasible design may not be acceptable to stakeholders unless they have been involved in the design process. For example, the design of a wastewater treatment facility may provide an adequate level of environmental protection and meet governmental standards to allow the effluent to be discharged to a receiving water body. Environmental impact of the discharge may be studied and determined to be minimal/low. However, strong public opposition to the concept of effluent discharge (regardless of the true impact) may result in the design being altered to completely eliminate the effluent discharge in favor of reuse/recycle of the water stream. Environmental design often is not based solely on a technically correct engineering solution, but also on societal expectations of the proposed activity.

## **Mechanical Engineering**

Mark Evans, Mechanical Engineering, John Deere & Company, graduated from Ohio State University with a B.S. in Agricultural Engineering, Purdue University with a M.S. in Agricultural Engineering, and Texas A&M University with a Ph.D.

Dr. Evans is a licensed Professional Engineer and has worked in product development of compact utility tractors at John Deere for the last seven years. During that time, he has worked on hydrostatic transmissions, hydraulic systems, cooling systems, drive trains, and noise and vibration control. He also supervises four other engineers.

Management of new product design is governed by a rigorous, multi-disciplinary development process. In general, engineering and marketing

drive early product definition based on both what engineering feels can be done technically, and customer requirements determined via market research. This phase is often very chaotic and requires substantial work to separate opinions from facts. Multiple design concepts are sometimes developed for preliminary cost studies and customer evaluation. Once a detailed specification is generated, then engineering and supply management work together to develop and source designs with suppliers. For complicated parts, this is usually a cooperative design and test program with suppliers. Mark must work closely with the supplier who will do a significant amount of the design per specification. Once designs are finalized, quality engineering gets involved to determine if the supplier production and quality plans are sufficient to produce quality parts. Finally, he works with manufacturing engineers to move the product into production. Although the various disciplines have different work levels at various stages, all are involved throughout with regular design reviews.

## **Civil Engineering**

Tony Fagan (Starzer, Brady, Fagan Consulting Engineers) received a B.S. in Engineering with a structural emphasis from Vanderbilt University, and an M.S. in Engineering with a structural emphasis from Virginia Polytechnic Institute and State University. Mr. Fagan is a licensed Professional Engineer and has over 20 years of engineering experience in the civil/structural engineering field. He is currently Vice-President and Principal for Starzer, Brady, Fagan Consulting Engineers. In that capacity, he is closely involved on a day-to-day basis with office management and operations, plus short- and long-term decision making. He also acts as the principal-in-charge of some projects supervised by other project managers within his firm as well as serving as project manager and project engineer. He also markets to clients and potential clients, generates proposals for potential work, and helps determine what course the firm will take with respect to business opportunities. As part owner of a small engineering consulting firm, he must “step up and do” whatever is required when the work cannot be delegated.

Structural engineers have many responsibilities. They must protect the safety, health, and welfare of the public. They must produce efficient designs that are economical, are readily constructible, and meet the client's needs. They also must make a profit for the company to be able to pay the employees and stay in business as a structural engineering firm. As such, the office is generally not exactly at the forefront of innovative new types

of design or construction. Instead, structural engineers typically utilize methods that have been tested and proven to work for the long-term. They try to do so in a cost effective manner for a client's benefit and for the company's bottom line. However, they also understand that in today's world, the structural engineer (or engineering firm) that never takes steps forward is effectively falling behind. They work to learn appropriate new methods of design and construction techniques that may result in better solutions and ultimately be of more benefit to the clients.

## **Electrical and Electronics Engineering**

Deborah Williams received her B.S. in Engineering from Vanderbilt University. She worked as a practicing electrical design engineer for five years at Matsushita Communications Corporations of USA located in Peachtree City, Georgia, a subsidiary of Panasonic Corporation, in the Automotive Electronics Group. Deborah is responsible for designing and developing next-generation automotive entertainment equipment for specific manufacturers (e.g., Toyota, GM, Nissan, and Honda). She has designed several product lines of stereo systems where she has been involved with field testing and evaluating the electronic circuitry. In addition to designing, she is a liaison between the manufacturing division and the engineering design section of her company. Most of the engineers in her section are Japanese-speaking and need assistance communicating with the predominantly English-speaking assembly line workers. Communication is paramount in ensuring efficient and expected results. Project and product management comprise a major portion of her duties as 100% of the products under her supervision are maintained from conception to final mass production.

## **APPLICATION OF DESIGN IN TECHNOLOGY EDUCATION**

*The Standards for Technological Literacy (STL) (ITEA, 2000) were developed in 2000 for the purpose of aiding students and educators to understand, appreciate, and question the value of technology within society. Several standards specifically address the issues related to design in general and more specifically, engineering design. Standards 8–The Attributes of Design, 9–Engineering Design, 10–The Role of Troubleshooting, Research and Development, Invention and Innovation, and Experimentation*

in Problem Solving, and 11–Apply the Design Process have specific application to the goals and processes of engineering design. Additionally, standards 14–Medical Technologies, 15–Agricultural and Related Biotechnologies, 16–Energy and Power Technologies, 17–Information and Communication, 18–Transportation Technologies, 19–Manufacturing Technologies, and 20–Construction Technologies can be viewed as important aspects of the designed world, which is the product of a design process.

## **Common Design Practices Within Technology Education**

Discussions of design processes are common within most technology education programs. Technology teachers strive to have their students engage in solving technological problems by utilizing a design process to organize and guide their problem solving efforts. There are a number of different design processes in use within the technology education field, but all have common factors that channel the students' efforts to solutions. The *Standards for Technological Literacy* (ITEA, 2000) offers a 12-step design process which includes: (1) defining a problem; (2) brainstorming; (3) researching and generating ideas; (4) identifying criteria and specifying constraints; (5) exploring possibilities; (6) selecting an approach; (7) developing a design proposal; (8) making a model or prototype; (9) testing and evaluating the design using specifications; (10) refining the design; (11) creating or making the product; and (12) communicating processes and results (ITEA, 2000, p. 97).

Other sources within the field of technology education describe the design process in slightly different expressions. Gradwell, Welch, and Martin (2004) describe the design process in their high school textbook as an eight-step process consisting of: (1) defining the problem; (2) determining the design brief; (3) investigating; (4) developing alternative solutions; (5) choosing a solution; (6) making models and prototypes; (7) testing and evaluating; and (8) manufacturing (p. 28–34). Refining the process even more, Wright (2004) explains that the design process can be reduced to three primary steps which are (1) developing preliminary solutions; (2) isolating and refining the best solution; and (3) detailing the best solution (p. 192). Although the design processes expressed and taught in many technology education programs may vary in detail, they all have common components that revolve around four features:

1. Identifying or defining a technological problem;
2. Developing a design proposal;
3. Creating a model or product; and
4. Evaluating the model or product.

These design criteria focus primarily on three of the four languages used in designing products (Ullman, 2003). These are: (a) semantics or narrative explanation (written and/or oral communication regarding the technological problem); (b) graphical representation (sketching and/or technical drawing of the solution); and (c) physical artifact (producing a product that can be manipulated or tested). Each of these languages is critical in creating products. However, a fourth language is often omitted when students engage in technological design activities in technology education classrooms. The fourth language that sets apart engineering design is the ability to analytically evaluate a design prior to constructing a product to determine its optimal success. This analytical process typically includes a significant degree of mathematical calculation in order to establish the best solution for the problem.

## **Comparisons of Technology Education Design Methods with Engineering Methods**

There are many similarities between processes of design used by technology education and the engineering fields. In each of the processes, there is the initial need to identify and define the problem. This is followed by the strategies of brainstorming and searching for possible solutions from a conceptual perspective. There is a common need to identify design criteria and the limiting constraints of the problem followed by the need to generate alternative solutions and exploring additional possibilities. It is typically at this point that the two design processes begin to take different paths (see Table 1).

Table 1 represents a comparison of the design processes used by technology education programs and the engineering disciplines respectively. The similarities in the initial steps of the process are offset by the unique differences in analysis and mathematical prediction that are depicted in Table 1.

Table 1. Comparison of the Design Process

<b>Technology Education Design Process (ITEA, 2000)</b>	<b>Engineering Design Process (Eide, Jenison, Mashaw, &amp; Northup, 2002)</b>
Defining a Problem	Identify the Need
Brainstorming	Define Problem
Researching and Generating Ideas	Search for Solutions
Identifying Criteria	Identify Constraints
Specifying Constraints	Specify Evaluation Criteria
Exploring Possibilities	Generate Alternative Solutions
Selecting an Approach and Developing a Design Proposal	Engineering Analysis
Building a Model or Prototype	Mathematical Predictions
Testing and Evaluating the Design	Decision Making
Refining the Design	Design Specifications
Communicating Results	Communication

### **Strengths and Weaknesses of Current Technology Education Design Methods**

The differences represented by the design processes in Table 1 characterize a fundamental feature between the two methods. Technology education employs a systematic approach consisting of a test/revise/re-test, thus using a trial and error strategy.

The engineering methodology shares some of the same strategies initially. However, it also incorporates an analytical step of evaluating a design prior to construction, thus reducing or eliminating the need to build and assemble a product prior to final design. The ability to evaluate a product design prior to construction has a tremendous impact on every aspect (i.e., time, cost, safety, etc.) of the design process. Technology education teachers have been reluctant to address the analytical aspects of design primarily because of limitations with mathematics, both from the teachers' and students' perspective, and the level of scale (i.e., size, cost, application) of the problems and products that students typically work with in the classroom/laboratory.

## **TEACHING ENGINEERING DESIGN IN THE TECHNOLOGY EDUCATION CURRICULUM**

Two cases will be presented in this section, one from the university perspective and one from high school. Both represent efforts by technology education faculty to integrate the engineering design process into their curriculum.

### **University Level**

Efforts have been underway at the University of Georgia for the past three years to revise the technology education program in order to address a more serious commitment to integrating a STEM (science, technology, engineering, and mathematics) focus into the curriculum. To help facilitate this effort, the technology education faculty has made a concentrated effort to collaborate with faculty from the engineering disciplines to garner their help and advice in the revision process. The reason engineering faculty were solicited in this effort was because of the general nature of engineering and its goal of solving technological problems using a combination of engineering sciences and mathematics.

The first order of business was to have the original curriculum of the technology education program reviewed by a panel of engineering faculty. The result of this review was a recommendation that a stronger mathematics and science base be required for technology education majors. Therefore, changes were made in the general education portion of the curriculum to include pre-calculus, analytical geometry, calculus, and two courses in physics. In addition, the review panel suggested that several of the current technology education courses be revised to include a serious effort to introduce the engineering design process. This was deemed important to help integrate STEM concepts across the curriculum and to help the pre-service teachers get a better perspective on how engineering design can be applied within the technology education field. Therefore, in courses such as Manufacturing Systems, Energy Systems, Construction Systems, Research and Experimentation, Technical Design Graphics, and Appropriate Technological Development, the engineering design process can be used as the primary method in solving the technological problems.

As a common thread of the practical application of engineering design within these courses, the engineering design notebook is used by students to document their work and to demonstrate their knowledge of the various topics addressed in the courses. This form of authentic assessment has been a major step forward in the process of integrating STEM concepts into technology education.

Finally, two new courses, Principles of Technology and Applications of Engineering in Technological Studies, were introduced into the curriculum to serve as capstone experiences for students and help establish a stronger base for STEM integration and application of engineering design principles. Revision efforts continue to adjust and improve course content. The rethinking of common technology education activities (e.g., bridge construction, airfoil design, Metric 500, tower design and construction) requires faculty to identify new “hands-on” experiences for students that better facilitate the integration of STEM content.

## High School Level

Mr. Charles Kachmar, technology teacher at Grayson High School in Georgia, has taken monumental steps to revise his program to reflect important aspects of engineering and engineering design. In an effort to bring the essential components of the engineering science to his classroom, Mr. Kachmar has adapted the study of *Statics* (equilibrium of bodies subjected to forces) and *Dynamics* (forces in motion) for his high school technology education program. He has done this in such a way that encourages his students to apply engineering design processes while learning the relationships of forces in motion and forces in equilibrium. Through the design and development of cantilevers, modeled on 3-D CAD software and in Excel spreadsheets before construction, students gain a perspective of the comparison between analytical models and reality. Students use the engineering design process to design and create a cardboard “fishing chair” where they address such topics as strength of materials and experiment with manipulations of internal members to achieve balance of loads (statics and dynamics).

Mr. Kachmar’s rationale for making these major shifts in his curriculum was based on his analysis of student needs. With 85% of the student population seeking post-secondary education, he saw a need to create a program that went beyond the standard technology education curriculum. The

students in his classes are not viewed as academically elite; most are taking standard courses in algebra and trigonometry. His curriculum begins with a solid foundation in technical design (drafting and CAD) and then progresses through two engineering-based courses. Kachmar's efforts provide an example of a highly motivated teacher who has reviewed the relationship between the needs of his students and the expectations of employers, as well as universities, and has developed an engineering design-based curriculum that is making a difference in the future.

## **BENEFITS OF ENGINEERING DESIGN FOR THE TECHNOLOGY EDUCATION FIELD**

The rich products of technology education often go unnoticed or unfulfilled in many school systems around the country. Why is this? One explanation for this lack of understanding is the inability within the technology education field to formulate a clear and defined target for the curriculum that has both an understood goal (that is, the general populace can recognize a perceived purpose) and value (the general populace perceives positive worth). The goals of technological literacy do not provide the level of importance that is required by most people to cognitively connect on a long-term basis to technology education. It also lacks the specificity for the general populace to understand what technology education contributes regarding career purposes. Therefore, the perceived value of technology education programs is less than what it could be if they were able to capture and sustain the interest of students, parents, and school decision makers.

What could technology educators do to simultaneously meet the goals for technological literacy while at the same time providing a technology education curriculum that informs and motivates students, parents, and school decision makers with a clear and viable education program? By organizing the technology education high school curriculum around the study of engineering design, the goal of technological literacy can be accomplished and, at the same time a well defined and respected framework of study that is understood and appreciated by all can be created. The benefits of having engineering design as the academic focus for high school technology education are as follows:

- Engineering design is more understood and valued than technology education by the general populace;

- Engineering design elevates the field of technology education to higher academic and technological levels;
- Engineering design provides a solid framework to organize curriculum;
- Engineering design provides an ideal platform for integrating mathematics, science, and technology; and
- Engineering provides a focused curriculum which can lead to multiple career pathways for students (Wicklein, 2006).

The instructional components needed for a high school technology education curriculum centered on engineering would include a series of focused courses and instructional activities that lead a student through the engineering design process. Through systematic planning and coordination with administrative staff and academic faculty, technology educators could create a well-defined curriculum that provides a sound academic grounding in engineering design while addressing the *Standards for Technological Literacy* as well as local and state requirements. Curriculum planning done in this way will help to provide the needed consensus within the technology education profession as well as present an attractive option for many students. School administrators and counselors would have another strong academic option available for students.

Several high schools have already begun planning their curriculum around an engineering design focus. Table 2 illustrates how a hypothetical high school curriculum plan could sequence a technology education program leading to capstone experiences in engineering design applications. Other instructional plans could address engineering design in different formats.

Table 2. Engineering Focused Curriculum for High School

<b>Technology Education</b>	<b>Mathematics</b>	<b>Science</b>	<b>Foreign Language</b>
Foundations of Engineering and Technology	Algebra I	Biology	Foreign Language I
Engineering Concepts	Algebra II or Geometry	Chemistry	Foreign Language II
Engineering Applications	Geometry or Trigonometry	Physics	
Research, Design, and Project Management	Trigonometry or Calculus		

## SUMMARY

This chapter presented a rationale for creating an engineering design focused curriculum for technology education. Explanation was provided to establish a need and to provide an explanation of why an engineering design focused curriculum would be an appropriate program development model. The ramifications of the proposed curriculum focus would have a significant impact on technology teacher education. University programs that prepare technology teachers would be required to change their programs to address the needs associated with engineering design. A primary need that must be addressed in technology teacher education programs is the elevated mathematics and science requirements necessary to teach subjects such as engineering design and applications. Most technology teachers are not prepared to tackle the mathematics that is associated with the analytical components of engineering design. Serious reviews and changes of existing teacher education curriculum must be conducted if an engineering focus is to be attained and implemented at the high school level.

The benefits of an engineering design focused curriculum for technology education are significant. If done correctly, technology education will be viewed and understood in an entirely different light. Students and parents will see a curriculum that is organized and systematic, leading to valued career options. School administrators and counselors will have a curriculum that provides multiple options for students, both college-bound and non-college-bound. Engineering educators will receive a better prepared student who understands engineering design processes from the beginning of their college experience. Business and industry will have more U.S. citizens entering the engineering workforce. This is a viable future for technology education; are we willing to take the challenge?

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## INTRODUCTION

Technology education, with its goal of technological literacy and a curriculum grounded in technological processes, is in transition from the industrial arts paradigm of the past where its curriculum was grounded in industry (Sanders, 2001). Technological literacy has achieved increased support as the major goal of technology education, especially since the development of the National *Standards for Technological Literacy* (STL) (ITEA, 2000). Other groups, for example the National Academy of Engineering (NAE), are also concerned about technological literacy and have called for initiatives to achieve technological literacy for all (Pearson & Young, 2002).

The STL include standards that focus specifically on engineering design and related content. Likewise, in the NAE report, *Technically Speaking: Why All Americans Need to Know More About Technology* (Pearson & Young, 2002), it is suggested that a way to achieve technological literacy is to teach engineering in K–12 schools. *Technically Speaking* specifically recommends that “teachers of technology must approach the subject from an engineering perspective rather than an industrial arts perspective” (Pearson & Young, 2002, p. 108).

Some technology educators (Rogers & Rogers, 2005; Wicklein, 2006) are calling for the infusion of engineering content into the technology education curriculum. Others are recommending a more cautious approach (see the essay by Shown in Chapter 10.) Nevertheless, many would argue that the timing is right to infuse engineering into technology

education curriculum to add rigor, strengthen the content, link it with mathematics and science education, provide context for learning across the curriculum, and improve the image and status of technology education. Hence, the purpose of this chapter is to share some perspectives on general curriculum issues in light of engineering-oriented curriculum in technology education.

## **PERSPECTIVES ON K–12 EDUCATION POLICY IN THE UNITED STATES**

Education in the United States is considered a responsibility of the individual states. As a result, there is no one national curriculum in any school subject, including technology education. Rather, K–12 curriculum varies across the 50 states and is generally based on local and state needs, culture, resources, and teaching philosophies. Consequently, finding a unified scope and sequence for technology education is a daunting task.

Given no possibility of a national curriculum in the U.S., professional societies have focused their curriculum unification efforts on the development of voluntary national curriculum standards (e.g., *The Standards for Technological Literacy*, ITEA, 2000). National standards have driven some change in educational paradigms, especially in technology education as the STL have, in effect, codified the goal of technological literacy.

The No Child Left Behind Act of 2001 (NCLB) (U.S. Department of Education, 2002), mandating educational reform, also changed educators' paradigms. This standards-based model holds teachers accountable for outcomes related to student achievement instead of the instructional inputs used to deliver curriculum (Coffey & Lashway, 2002). It could be argued that NCLB, with its reliance on high-stakes testing and highly qualified teachers, may force curriculum congruency across states, at least in the school subjects that are included in the testing program. Unfortunately, technology education is currently not included specifically in NCLB.

## STATE TECHNOLOGY EDUCATION CURRICULUM FRAMEWORKS

National curriculum standards and federal laws like NCLB are having an impact on state education policies and state curriculum frameworks. Likewise, the call for infusing engineering content into the technology education curriculum, from both inside (Rogers & Rogers, 2005; Wicklein, 2006) and outside the profession (Pearson & Young, 2002), is starting to have an impact on state curriculum frameworks. But the real question is, “Will federal mandates and the call for engineering content have an impact on the curriculum delivered in local schools by classroom teachers?”

There are variations in how technology and engineering concepts are delivered, since curriculum decisions reside primarily at the state and local levels. Zemelman, Daniels, and Hyde (2005) state that, “. . . under the banner of ‘higher standards,’ forty-nine of the fifty states have developed their own often-idiosyncratic system of frameworks, targets, benchmarks, rules, and, above all, tests for both students and teachers” (p. v). A review of state technology education standards and curriculum frameworks supports this assertion.

A perusal of state Web sites reveals a wide range of state technology education/engineering curriculum standards, which can be divided into two general categories: The first category reflects technology-based concepts regarding human ingenuity, technical systems, and the nature and impacts of technology (similar to ITEA national standards). The second category can best be described as a hybrid that cuts across a variety of sources that may include national technology education standards, industry-based clusters, computer literacy, and engineering design standards.

In some cases the state curriculum standards are clearly aligned with the STL. In fact, several states, South Dakota for example, have actually adopted the *Standards for Technological Literacy* (ITEA, 2000) as their state standards for technology education (Note: Web links to selected state technology education standards are included at the end of this chapter). Other states like Wisconsin, Maryland, and Indiana use categories that correlate with the *Standards for Technological Literacy*, but do not constitute a direct match.

There are larger variations within the hybrid category. States like New Jersey and Nevada combine the *Standards for Technological Literacy* with computer and information literacy standards. Others states, like Connecticut, use clusters such as transportation, communication, and production, similar to areas defined in the *Jackson's Mill Industrial Arts Curriculum Project* (Snyder & Hales, 1981) to organize their standards.

In yet other states, there is evidence of a strong linkage with career and technical education. Iowa, for example, uses a career pathway model with standards and benchmarks organized around industry. In a similar fashion, states like Florida and Georgia have curriculum frameworks that are linked to career pathways. As stated before, a wide array of approaches are being used across the states, reflecting each state's interpretation of how and where technology education fits in the larger context of education.

## **ENGINEERING IN TECHNOLOGY EDUCATION CURRICULUM**

Should engineering content be infused into technology education curriculum? Where does, or should, engineering fit into the technology education curriculum mix? While the answers to these questions will vary depending on the state and its approaches to technology education, a brief description of the approaches that are being implemented in the state of New York provides an instructive case.

New York has seven learning standards. Technology Education (standard 5) is one of the seven along with science, mathematics, and other academic disciplines. Engineering design is a main organizing element of this standard. In this instance, engineering design appears to be more of an integral part of technology education standards in New York than in most states. Connecticut has a technology education standard that specifically addresses engineering design. Some states have not added engineering standards per se, but there is evidence that engineering is being addressed through curricular frameworks. Georgia and California have created engineering career pathways, identifying specific course sequences. Florida lists curricular frameworks for engineering along with other career-related sequences such as communications, construction, and electronics.

States involved in ITEA's Center to Advance the Teaching of Technology and Science (CATTS) consortium often have links to engineering resources. Indiana lists *Project Lead the Way* (PLTW) engineering courses as part of its state curriculum map. But just as no one state has addressed standards in the same way, there is also variation in the way states are addressing engineering in their standards and curriculum frameworks.

## **RATIONALE FOR INCLUDING ENGINEERING CONTENT IN TECHNOLOGY EDUCATION**

But how do (and should) standards and curricular frameworks influence classroom practice? Changing educational paradigms and the related classroom practices takes time when there are large variations in teachers' perceptions of standards-based reform (Haug, 1998). Teachers have always functioned with a significant level of autonomy. Current pedagogical practices often are determined by each teacher's personal interpretation of curriculum and personal philosophy of education, the financial status of the school district, and/or educational publishers (National Academy of Sciences, 2001).

Given the current state of affairs, could the infusion of engineering content benefit technology education? Will state budgets support the development of new curricula? Are educational publishers willing to back the development of pre-engineering texts and support materials? Will taxpayers be more willing to support programs with an engineering thrust? Could this pursuit be a unifying goal for the profession?

### **General Education vs. Career Preparation**

There is little consensus regarding the rationale for including engineering in technology education. Approaches could be drawn along vocational and general education lines, each with implications for curricula. This is not surprising in a field where, according to Sanders (2001), 60% of technology education instructors associate themselves with general education while 40% are more aligned with vocational education. A vocational or career-focused approach involves the preparation of a select group of students for successful entry in an engineering career pathway. The general education approach involves the infusion of engineering content into technology education courses to increase the technological literacy of all students.

Those promoting a more vocational approach often use labor force statistics to build a rationale for their programs. For example, *Project Lead the Way* (PLTW) was formed to address the shortage of engineers and engineering technicians in the U.S. PLTW's founders cite America's transition from an unskilled workforce (60% in 1960) to a skilled workforce (65% in 2000) as an impetus for their program. As noted on the PLTW Web site, the workforce transition and an increase in retirement of skilled workers left 1,300,000 engineering-related positions unfilled in the U.S. (PLTW, 2006).

The argument for a general education approach posits that adding an integrative, design-based engineering thrust to technology education could enhance the mission of technology education as general education. This approach supports the education of a technologically literate citizenry. Technological literacy requires that children and citizens have a knowledge base not only about technology but also about the mathematics and science that underlie it (National Academy of Engineering, 2000). The incorporation of engineering concepts into the technology education curriculum could thus serve the broader general education needs of society. Regardless of whether it is for a general education or a vocational education purpose, engineering could provide a more transparent focus, recognizable by the average citizen.

## **Improving the Status of Technology Education**

The precursors of technology education largely were crafts programs and, in far too many instances, these traditions persist. Teachers have been traditionally trained as crafts teachers with limited mathematics and science backgrounds. This would need to change if technology educators are to deliver a more rigorous engineering emphasis. A recent study reported that technology teachers who graduated 30 years ago took more mathematics as undergraduates than technology teachers graduating in recent times (Hofstra, 1996). A recent review of technology teacher education programs found that the specific mathematics requirements in technology teacher education programs varied greatly (McAlister, 2004) and that most programs require only one mathematics course for graduation (Hacker, 2005). College algebra was the most commonly required mathematics course (83%), but graduates in 25% of the programs could graduate with college algebra being the highest-level mathematics course they took (McAlister, 2004).

The science requirement in technology teacher education programs also varies. While the majority (58.3%) of technology teacher education programs require at least two laboratory-based science courses, most programs allow students to select which science courses they take (McAlister, 2004). The most commonly required lab science course was non-calculus based physics (33%).

Many technology teachers are still teaching in their comfort zones at the “crafts end” of the crafts-to-engineering continuum. An engineering direction with a concomitant change in the teacher education programmatic requirements would raise the academic level of the discipline and its status as a discipline.

## **EVIDENCE OF SUPPORT FOR MOVING TOWARD ENGINEERING**

There is strong evidence of support for moving toward an engineering focus in technology education curriculum. Lewis (2004) identified 19 states that had implemented pre-engineering programs. He further noted that three states, Massachusetts, Utah, and Wisconsin, include “engineering” in the official name of the subject (Lewis, 2004).

A foundation for relationship building is also being laid through cross-disciplinary participation in professional associations. Technology educators have successfully established a presence in the K–12 and Pre-College Engineering Division of ASEE.

### **Evolving Conceptual Base for Curriculum Content**

The integration of engineering into K–12 curriculum is a recent national development, and it is accelerating at a rapid rate. K–12 engineering education can provide a sound fundamental education that promotes knowledge synthesis and the development of critical thinking and problem solving abilities in students. Alarmed by the need for engineers, many colleges and universities have initiated summer enrichment programs aimed at stimulating K–12 students’ interest in engineering careers. Major science and technology firms, teacher associations, professional societies, and informal educational institutions have become engaged in promoting technology, science, and engineering activities (National Academy of Sciences, 2001).

## ABET Learning Outcomes and NCATE Program Standards

The movement to raise academic standards has gained momentum in this country over the past decade. Professional associations have developed learning standards across the STEM (science, technology, engineering, and mathematics) disciplines and beyond. Learning standards are intended to specify what students should learn and what teachers should teach (Anderson, Fiester, Gonzales, & Pechman, 1996).

It is important to note that many standards initiatives, both in and outside of technology education, include relevant content guidelines for technology and engineering. (See Chapter 3—Childress, et al, for a more extensive discussion of the ITEA *Standards for Technological Literacy*, the *National Science Education Standards*, the American Association for the Advancement of Science *Benchmarks*, and the English National Curriculum for Design and Technology). A discussion of the Accreditation Board for Engineering and Technology (ABET) and National Council for the Accreditation of Teacher Education (NCATE) standards follows.

A comparison of professional competencies required by ABET (2000) for accredited engineering programs and the ITEA/CTTE/NCATE accreditation standards (ITEA/CTTE, 2003) for technology teacher education programs is presented in Table 1. The comparison depicts a focus on technical content preparation for engineers and on pedagogical content preparation for teachers, but there also is a high degree of alignment with respect to other competencies (Hacker, 2004). This alignment includes professional practice, design and problem solving, team functioning, ethical and professional responsibility, communication skills, social and cultural impacts, and professional growth. One clear difference is how engineers are rigorously prepared in mathematics and science as compared to technology teachers. In the area of knowledge application, engineers are well prepared to solve real-world design problems requiring mathematics, science, and engineering topical knowledge, whereas teachers are well prepared to design instructional environments.

Table I. ABET vs. CTTE/ITEA/NCATE Standards

<b>Competency</b>	<b>Engineers</b>	<b>Technology Teachers</b>
Professional Practice	<ul style="list-style-type: none"> <li>•Develop an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.</li> </ul>	<ul style="list-style-type: none"> <li>•Design, create, and manage learning environments that promote technological literacy.</li> </ul>
Design and Problem Solving	<ul style="list-style-type: none"> <li>•Identify, formulate, and solve engineering problems.</li> <li>•Design and conduct experiments, and analyze and interpret data.</li> <li>•Design a system, component, or process to meet desired needs.</li> </ul>	<ul style="list-style-type: none"> <li>•Develop an understanding of design and select design problems, including establishing criteria and constraints of the problem.</li> <li>•Apply the processes of troubleshooting, research and development, invention and innovation, and experimentation to develop a solution to a design problem.</li> </ul>
Team Functioning	<ul style="list-style-type: none"> <li>•Function on multidisciplinary teams.</li> </ul>	<ul style="list-style-type: none"> <li>•Manage technological activities in both individual and group settings.</li> </ul>
Ethical and Professional Responsibility	<ul style="list-style-type: none"> <li>•Understand professional and ethical responsibility.</li> </ul>	<ul style="list-style-type: none"> <li>•Display a philosophy and understanding of technology education.</li> <li>•Apply multicultural and global perspectives as they relate to the study of technology. Apply values and ethics as they relate to content issues in the study of technology.</li> </ul>
Communication Skills	<ul style="list-style-type: none"> <li>•Communicate effectively.</li> </ul>	<ul style="list-style-type: none"> <li>•Promote and articulate technology education to internal and external public audiences.</li> <li>•Be able to develop and coordinate an external advisory committee for a technology education program.</li> </ul>
Social and Cultural Impacts	<ul style="list-style-type: none"> <li>•Understand the impact of engineering solutions in a global and societal context.</li> <li>•Develop a knowledge of contemporary issues.</li> </ul>	<ul style="list-style-type: none"> <li>•Develop an understanding of the nature of technology.</li> <li>•Develop an understanding of technology and society.</li> <li>•Investigate the impacts of products and systems on individuals, the environment, and society.</li> </ul>
Professional Growth	<ul style="list-style-type: none"> <li>•Recognize the need for, and develop an ability to engage in lifelong learning.</li> </ul>	<ul style="list-style-type: none"> <li>•Understand and value the importance of engaging in comprehensive and sustained professional growth to improve the teaching of technology.</li> </ul>

Competency	Engineers	Technology Teachers
Content Knowledge	<ul style="list-style-type: none"> <li>•Mathematics is beyond trigonometry and must include differential and integral calculus and differential equations. Work is encouraged in probability and statistics, linear algebra, numerical analysis, and advanced calculus.</li> <li>•Must include calculus-based physics and chemistry, with at least a two-semester sequence of study in either area.</li> <li>•Subjects have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These include mechanics, electrical and electronic circuits, thermodynamics, materials science, transport phenomena, and computer science.</li> </ul>	<ul style="list-style-type: none"> <li>•Develop an understanding of the designed world.</li> <li>•Identify various medical, agricultural, and related biotechnologies.</li> <li>•Analyze the principles, concepts, and applications of energy and power technologies.</li> <li>•Describe the principles, concepts, and applications of information and communication, transportation, manufacturing, and construction technologies.</li> </ul>
Pedagogical Knowledge		<ul style="list-style-type: none"> <li>•Use a variety of effective teaching practices that enhance and extend student learning of technology.</li> <li>•Base instruction on a contemporary teaching strategy that is consistent with <i>Standards for Technological Literacy</i>.</li> <li>•Apply the principles of learning and consideration of student differences to the delivery of instruction.</li> <li>•Select and use a variety of instructional strategies to maximize student learning about technology.</li> <li>•Apply appropriate materials, tools, equipment, and processes to enhance student learning.</li> <li>•Analyze instructional strategies to improve teaching and learning in the technology classroom by using self-reflection, student learning outcomes, and other assessment techniques.</li> <li>•Possess knowledge to organize classroom and laboratory experiences for technological study.</li> </ul>

Competency	Engineers	Technology Teachers
Application of Knowledge and Skills	<ul style="list-style-type: none"> <li>•Engage in an engineering design experience that builds on fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics, and communication skills. The design must include: development of student creativity, use of modern design theory and methodology, use of open-ended problems, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility, production processes, concurrent engineering design, and detailed system descriptions. Further, it is essential to include realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impacts.</li> </ul>	<ul style="list-style-type: none"> <li>•Develop, model, and evaluate a design solution and develop proposals for design improvements.</li> <li>•Select and use appropriate technologies in a variety of contexts including medical, agricultural and related biotechnologies, energy and power applications, information and communications, transportation, manufacturing, and construction.</li> <li>•Operate and maintain technological products and systems.</li> <li>•Analyze an item, and identify the key components of how it works, and how it was made.</li> <li>•Complete an assessment to evaluate merits of a design solution.</li> <li>•Operate a technological device or system.</li> <li>•Diagnose a malfunctioning system, restore the system, and maintain the system.</li> </ul>

## CORE ENGINEERING CONCEPTS

While the pursuit of high school engineering content may appear to be quite recent, it is important to note that meaningful work has been occurring for decades. In 1963, The Commission on Engineering Education and the National Science Foundation initiated the Engineering Concepts Curriculum Project (ECCP). The course, *The Man-Made World*, was a seminal work that identified and developed several powerful and transferable engineering concepts including modeling, feedback, and stability (Truxal, 1988). The New York State Education Department invited several of the original ECCP founders to establish a Principles of Engineering curriculum for New York State (NYSED, 1989). This curriculum expanded the set of overarching, generic engineering concepts and revisited them in a series of engineering case studies. These engineering concepts included systems, design, technology/society interactions, optimization, modeling, and engineering ethics. Others within the engineering field have also attempted to identify and clarify engineering concepts.

Vincenti (1990), in *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*, worked to identify the intellectual content of engineering. He identified six categories of engineering knowledge. His intent was to develop major categories that were broad enough to be inclusive, but acknowledged that they are not mutually exclusive and that there could be further major categories, while allowing for overlap and the possibility for developing additional subcategories. A brief description of each of these categories is provided to assist curriculum developers as they grapple with including engineering content in the K–12 curriculum:

- **Fundamental Design Concepts:** incorporate knowledge of the “operational principle” of the device, or what most technology educators would call “systems knowledge”;
- **Criteria and Specifications:** define constraints, so that they can be addressed during the design stage. Constraints are key to the success or failure of a design and provide the basis for their evaluation;
- **Theoretical Tools:** include the combination of mathematical methods and theories, and intellectual concepts. At times, preexisting theory in areas such as analytical geometry, physics, and calculus is applied. At other times, mathematical tools are developed specifically for engineering applications;
- **Quantitative Data:** allows engineers to build both descriptive and prescriptive knowledge. Descriptive knowledge includes material properties such as coefficients of viscosity of fluids;
- **Practical Considerations:** derived from experience and can be best described as rules of thumb. Koen (2003), in his work, *Defining the Method*, refers to these rules of thumb as heuristics or SOTAs (state of the art practices); and
- **Design Instrumentalities:** refers to “know how,” which incorporates procedures, ways of thinking, and judgmental skills.

In addition to identifying broad categories of engineering knowledge, Vincenti has also identified seven categories of activities used to generate

engineering knowledge, including transfer from science, invention, theoretical engineering research, experimental engineering research, design practice, production, and direct trial. Vincenti's work supports many of the concepts (e.g., systems, design, and modeling) that are addressed in a variety of engineering curriculum and standards initiatives (e.g., the *Standards for Technological Literacy*, *Principles of Engineering*, and *ECCP*). His list of activities that have provided a broad conceptual structure for the engineering profession could also inform technology education professionals as they design authentic engineering curriculum and activities for students.

## SCOPE AND SEQUENCE FOR ENGINEERING AND TECHNOLOGY EDUCATION

As noted previously, finding a unified scope and sequence for technology education curriculum represents a daunting task because technology education programs are shaped by local and state culture, available resources, and teaching philosophies. However, two national programs, ITEA-CATTS's *Engineering By Design* and *Project Lead the Way's* (PLTW) national curriculum, have developed a series of courses focused on engineering, in effect identifying scope and sequence. *Engineering By Design* targets the middle school with three 18-week courses. At the high school level, *Engineering By Design* includes seven 36-week courses, all founded on national technology, science, and mathematics standards. *Project Lead the Way* incorporates five 10-week courses into the middle school. High school students are required to complete three one-year, core courses before moving on to any of five specialized courses. PLTW also requires high school students to take a mathematics and a science course each year along with, and in support of, their engineering courses. High school students may obtain college credit for some PLTW courses, provided that the program is certified. Articulation agreements between K–12 institutions and colleges/universities are encouraged.

Table 2 presents the course titles and sequence for *Engineering By Design* and PLTW. *Engineering By Design* tends to present a broader, technological perspective, whereas PLTW has a narrower, engineering focus.

Table 2. Sequence Comparison: *Engineering by Design* and *Project Lead the Way*

Level	Engineering by Design	Project Lead the Way
Middle School	Exploring Technology Grade 6 Invention and Innovation Grade 7 Technological Systems Grade 8	Gateway to Technology Design and Modeling Magic of Electrons Science of Technology Automation and Robotics Flight and Space
High School	Foundations of Technology Grade 9 Impacts of Technology Technological Issues Technological Design Grades 10–12	Introduction to Engineering Design Principles of Engineering Digital Electronics Grades 9–12
	Advanced Design Applications Advanced Technological Applications Engineering Design Grades 11–12	Computer Integrated Manufacturing Biotechnical Engineering Civil Engineering and Architecture Aerospace Engineering Engineering Design and Development Grades 11–12

## ADDITIONAL ENGINEERING CURRICULUM PROJECTS

The National Science Foundation (NSF) has invested in several K–12 engineering-related curriculum projects. It would take more space than is available in this yearbook to describe all of NSF's efforts in K–12 engineering curricula; however, two NSF projects are described in the following paragraphs.

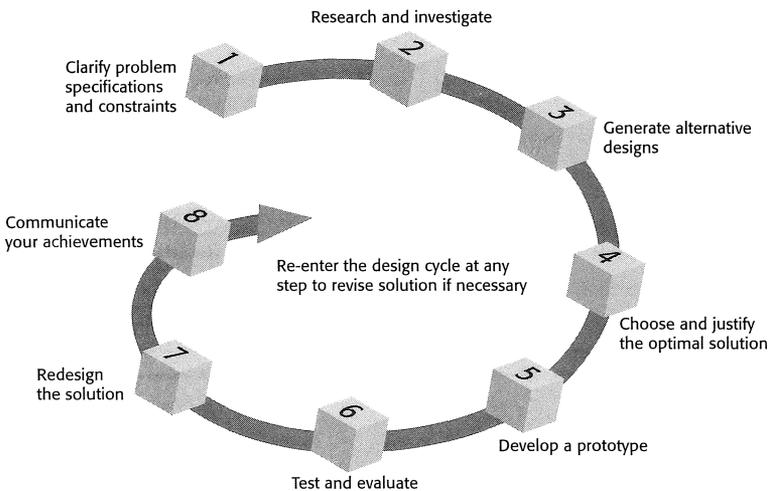
The NSF-funded INSPIRES Curriculum (INcreasing Student Participation, Interest and Recruitment in Engineering and Science) at the University of Maryland, Baltimore County (2004–2006), seeks to incorporate hands-on experience and inquiry-based learning with real-world engineering design exercises. The project also includes in-service training with the curriculum and professional development opportunities for technology education teachers prior to classroom use. A specific objective of the project is to increase the involvement of women and other underrepresented groups in engineering and technology by providing female and minority role models in the classroom, and in developing case

studies designed to encourage interest and participation by all groups. The case studies developed to date include: Engineering in Health Care, Engineering and Flight, Engineering and the Environment, Engineering in Communications and Information Technology, and Engineering Energy Solutions (<http://130.85.11.37/IMD>).

Another example is the NSF-funded New York State Curriculum for Advanced Technological Education (NYSCATE, 2002) at Hofstra University. NYSCATE has developed 13 curriculum modules that embed an “informed design” model into STEM activities in areas of materials and manufacturing, information technology, and biological and chemical technology.

Figure 1 depicts the informed design cycle in graphic form. As with most design cycles, the Hofstra informed design model is iterative and encourages users to revisit earlier assumptions and findings as they proceed. The model was created based on knowledge gained from *How People Learn* (Bransford, Brown, & Cocking, 1999) and related cognitive science and learning theory. A key differentiating factor in the informed design process is within the Research and Investigate phase. The use of Knowledge and Skill Builders (KSBs) provides structured research in key technology, science, and mathematics ideas that underpin design solutions. Rather than design from a trial-and-error approach, NYSCATE designs are informed by the knowledge and skills that students acquired in order to design and construct their solutions from a more knowledgeable perspective.

Figure 1. The Informed Design Process



## **POTENTIAL MODELS**

Our review and analysis of contemporary engineering and technology education programs indicate the existence of a set of common elements. These include:

- a focus on standards-based ideas in technology;
- the use of design as the core pedagogical strategy through which learning occurs;
- the use of engaging, age-appropriate, hands-on, minds-on activities;
- the inclusion of contemporary pedagogical methods including cooperative learning, learner-centered constructivist teaching, and authentic assessment;
- a focus on synthesis of knowledge from students' prior experience and learning in other subjects;
- incorporating mathematical modeling, analysis, and science investigations;
- making connections to and reinforcing communication and language skills; and
- student work that occurs in a laboratory setting where designs are modeled, simulated, and constructed (Hacker, 2000).

Based on these common elements, the conceptual foundations presented earlier in this chapter, and lessons learned from emerging engineering-based curriculum development efforts, we present two curriculum design models for discussion and consideration.

### **An Integrative Design Model**

An integrative design model is based on a set of assumptions, the inclusion of the elements presented in the previous paragraph as well as a focus on powerful concepts that should be revisited repeatedly in every class, regardless of level. These concepts and ideas include, but may not be limited to: systems, socio-cultural/technology interactions, modeling and analysis, optimization, and trade-offs. The scope and sequence for the integrative model is presented in Table 3.

Table 3. The Integrative Design Model

Level	Course
Middle School	Grades 6–8 <ul style="list-style-type: none"> <li>•The Designed World</li> <li>•Introduction to Systems</li> <li>•Introduction to Engineering Design</li> </ul>
High School	Grade 9 <ul style="list-style-type: none"> <li>•Engineering Materials and Processes</li> </ul> Grades 10–11 <ul style="list-style-type: none"> <li>•Socio-cultural Interactions with Technology—Engineering Ethics</li> <li>•Electronic Solutions in Engineering Design</li> <li>•Structural Analysis in Engineering Design</li> <li>•Fluidics in Engineering Design</li> <li>•Thermodynamics in Engineering Design</li> </ul> Grade 12 <ul style="list-style-type: none"> <li>•Engineering Design Capstone</li> </ul>

The integrative design model proposes three courses at the middle school level. “The Designed World” course is intended to encourage middle school students to learn about the nature of technology and the designed world. The “Introduction to Systems” course is intended to provide students with experiences interacting with and designing technological systems. “Introduction to Engineering Design” is intended to give students experiences using strategies that are commonly employed to solve engineering design problems.

The “Engineering Materials and Processes” course, offered at the ninth-grade level, is intended to provide students with a background in materials science. Understanding the properties of materials and how they can be altered or manipulated is essential to creating design solutions.

The “Socio-cultural Interactions with Technology—Engineering Ethics” course would allow students to explore the symbiotic relationship that exists between technology and society. Case studies should be used to allow students to explore how technology can be used to address social problems and how culture can impact the adoption or implementation of technology. Students should also be engaged in design activities that call on their understanding of various cultures in order to be successful.

The other series of courses offered in the 10th and 11th grades are intended to provide students opportunities to design solutions to problems that require expertise within each area. The instructor should use a combination of techniques to teach students new content and expose them to real-world engineering design problems. Case studies should be used so students can analyze authentic problems, design possible solutions, and compare notes on how the problems were solved by practicing engineers. Case studies should also be used to analyze design failures and provide opportunities to explore alternative solutions. Design portfolios and engineering notebooks should be relied on to document the design process in all classes.

The engineering capstone experience is a senior-level course that would be conducted as an independent research and design project. Students would be expected to apply to the course during their junior year. The application must include a proposal outlining a detailed scope of work the student wishes to investigate.

## **An Engineering Model**

An engineering model represents a synthesis of current work by the American Society of Manufacturing Engineers (1996–2007), the Society for Automotive Engineers Foundation (2004), Batty and Batty (2001), the Boston Museum of Science (2004–2005a; 2004–2005b, 2004–2005c) and NJCATE (2007). The underlying assumptions of the Integrative Design Model are present with some important additions. These additions include: (a) curriculum materials and hands-on activities containing diverse and gender-neutral examples; (b) real-world connections impacting students' daily lives; (c) strategies for collaboration among businesses, professional organizations, and educational institutions; and (d) career connections and pathways integrated throughout the curriculum. These ideas are included as students are exposed to STEM concepts from kindergarten through the twelfth grade. Concepts related to engineering include but are not limited to types of engineers, design challenges, career pathways, case studies, design and problem solving, and hands-on and minds-on activities.

Table 4. Engineering Model

Student	Curriculum	Teachers, Counselors, Principals
K-6 & Up	Introduction and Awareness, Design Challenges, Hands-On/Minds-On Cross-Curricular Integration in Classrooms	Ongoing professional development and training implemented as teachers become familiar with new STEM materials. Resources suitable for classroom integration identified. Community advisory teams, volunteers, mentors, and partnerships developed.
7-8 & Up	Introduction and Awareness, Design Challenges, Hands-On/Minds-On Themes Across the Curriculum Based on National Standards, Problem Solving Process	
9-10 & Up	Career Preparation, Design Challenges, Hands-On/Minds-On Problem Solving Processes, Teamwork Skills Cross-Curricular Ties Integrated into Lessons	

Elementary students would be exposed to different engineering and science topics as well as design challenges that incorporate lessons from across the curriculum. Examples include The Boston Museum of Science's *Engineering is Elementary* (2004–2005a) and *The World in Motion* (Society of Automotive Engineers, 2004). Activities are designed to introduce students to available careers and the types of activities that engineers and scientists perform.

Introduction and exploration continue at the middle school level as students would be exposed to the problem solving process and begin taking the STEM courses needed to build the mathematical and scientific foundation needed for the world of work. Curriculum such as *The World in Motion* (Society of Automotive Engineers Foundation, 2004) or *Engineering the Future* (Boston Museum of Science, 2004–2005b) target standards-based content as defined by ITEA (2000). Problem solving and problem selection models would be introduced as students complete design challenges related to topics such as electrical, fluid, construction, and manufacturing systems. Content may be delivered as middle school students explore engineering and technology in thematic units across the curriculum.

Courses at the senior high school level would provide an opportunity for students to work on cross-curricular projects tied to real-world scenarios within their community or to relevant case studies. Project-based engineering would be integrated into courses using texts such as those developed by Gomez, Oakes, and Leone (2004), *Project Lead the Way* curriculum, materials from projects such as the *New York State Curriculum for Advanced Technological Education*, or *Engineering by Design*<sup>™</sup>. Toward the end of the high school experience, students would explore career options through the use of job shadowing, workplace tours, guest speakers, and the like. Counselors, teachers, and administrators work to form collaborative education-industry teams with articulated pathways from high school through community college and the university level like those described by PowerUp! (Boston Museum of Science, 2004–2005c).

A concerted effort is made within this model to provide additional training to teachers, counselors, and principals as a new engineering curriculum is brought onto the scene. Methodology, STEM awareness, and resource utilization would be called for during in-service, summer, and formal/informal training sessions.

## IMPLICATIONS FOR TEACHER EDUCATION

Technology education teachers will need a new set of skills in order to successfully integrate engineering design into the technology education classroom. If requirements in technology teacher education have not changed since the findings of Hacker (2005) and McAlister (2004), mathematics and science requirements will need to be increased in most programs. Current teachers will also need professional development.

Evidence exists that changes are beginning to occur in technology teacher education. For example, Colorado State University's revised program utilizes course sequences that also serve undergraduate engineering majors and are delivered by engineering faculty (DeMiranda, 2006). In 2004, Virginia Tech implemented a new degree option that allowed those holding bachelor's degrees in engineering, architecture, design, and industrial technology to simultaneously earn a master's degree in technology education and technology education teaching licensure. Purdue University accepts courses aligned with *Project Lead the Way* to meet requirements in their teacher education program. New engineering foundations courses are being developed at universities such as Illinois State and the University

of Wisconsin–Stout. The ITEA (through their Engineering by Design initiative), *Project Lead the Way*, and the National Center for Engineering and Technology Education are all heavily involved in providing professional development activities for licensed teachers. It is difficult to predict the overall impact that these initiatives will have, but there is some indication that there will be profound implications from the adoption of an engineering focus for many years to come.

The adoption of an engineering focus in technology education curriculum will also impact teacher educators. There is a need to partner with engineering colleagues, especially those who have an interest in K–12 education. Engineering educators bring a wealth of content knowledge that future teachers need. However, engineering educators typically lack the pedagogical preparation that most technology teacher educators possess. Doctoral candidates that have backgrounds in engineering should be recruited. This is being addressed, in part, by the National Center for Engineering and Technology Education, which was funded by the National Science Foundation to provide fellowships for 20 new doctoral candidates to prepare new leadership in technology and engineering education (Hailey, Erikson, Becker, & Thomas, 2005).

Teacher certification practices will also need to be examined. According to the National Center for Education Statistics (2006), over 15,000 school districts in the United States have hired uncertified or under-qualified teachers. Many states have been turning to alternative routes for the certification of teachers in high demand/shortage areas. One approach is to create programs for licensed engineers to become teachers.

## SUMMARY

We have entered a new era in technology education. The call for the infusion of engineering content in technology education curriculum will impact what is taught, how it is taught, and how those who wish to teach it are prepared. It will likewise impact the perceptions of technology education held by the public, students, parents, educators, business and labor leaders, governmental leaders, and professional societies, among others. A question that remains concerns which focus technology education's infusion of engineering content will take—the general technological literacy approach or the more career-oriented pathway to engineering approach. This decision will likely be made by state and local education agencies,

and classroom teachers as they move to implementation. Regardless of the approach, the ultimate benefit accrues to K–12 students as they learn about engineering in authentic contexts.

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### State Technology Education Web Pages

- South Dakota: (<http://doe.sd.gov/octe/teched/TechCntntStndrds.pdf>).
- Wisconsin: (<http://www.dpi.state.wi.us/standards/pdf/teched.pdf>).
- Maryland: ([http://www.mdk12.org/instruction/curriculum/technology\\_education/vsc\\_technologyeducation\\_standards.pdf](http://www.mdk12.org/instruction/curriculum/technology_education/vsc_technologyeducation_standards.pdf)).
- Indiana: (<http://www.doe.state.in.us/standards/docs-Technology/2006-08-15-TechEd-Stds.pdf>).
- New Jersey: ([http://www.nj.gov/njded/cccs/s8\\_tech.pdf](http://www.nj.gov/njded/cccs/s8_tech.pdf)).
- Nevada: (<http://www.doe.nv.gov/standards/standcomp/comptech-standards.html>).
- Connecticut: (<http://www.sde.ct.gov/sde/lib/sde/PDF/DEPS/Career/TechEd/Frtech.pdf>).
- Iowa: (<http://www.iowa.gov/educate/content/view/263/404>).
- New York: (<http://www.emsc.nysed.gov/ciai/mst/pub/mststa5.pdf>).



# Essential Mathematics and Science Content as a Base for Understanding and Teaching Engineering Principles

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Chapter

6

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## INTRODUCTION

This chapter will describe some key mathematics and science skills and background needed by technology education professionals to successfully engage in engineering design activities. It will also discuss strategies for professional development necessary to cultivate requisite knowledge and skills, and outline collaborative opportunities available to mathematics, science, engineering, and technology educators.

The analytical component necessary to fully implement an engineering design focus in technology education programs is an issue that has received considerable attention. Some technology teachers and teacher educators have expressed concern about the level of mathematics required to complete engineering computations and questioned whether this content is within reach of most technology teachers.

Lewis and Zuga (2005) recommended that three possible approaches be considered by technology educators regarding the analytical component of engineering design. These options consisted of (a) limiting instruction to the conceptual portion of the engineering design process, (b) addressing the analytical component using worked out engineering design cases, and (c) using a collaborative approach where technology teachers team with mathematics and science educators as well as with practicing engineers. These recommendations reflect the academic rigor of mathematics and science included in engineering programs of study.

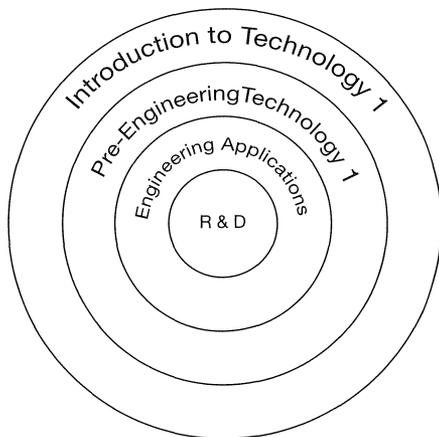
A key issue in determining an approach for preparing technology teachers to address engineering analysis is the choice of design problems used to engage students. The engineering design process can be applied to

problems that require only elementary levels of mathematics. Pre-service technology teachers might be encouraged to include mathematics through the first level of calculus, calculus-based physics, and chemistry within their programs of study. Teachers already in the field, however, would have limited opportunities to develop levels of mathematics and science competencies beyond those already acquired. For technology teachers to realistically address engineering analysis, careful choices are needed in the selection of design problems to be included in the curriculum.

This chapter is based on a premise that technology teachers can, with careful selection of the learning activities to be included, address the analytical component of engineering design as a component of their instructional programs (Hill, 2006). The materials presented here will also serve as a resource for pre-service instruction and in-service professional development activities, explaining and illustrating some basic applications of engineering science. We will also address strategies for improving mathematics and science competencies at the middle and high school levels and provide suggestions for collaboration between technology education and other disciplines.

The applications of mathematics and science in high school engineering and technology education courses can best be managed when the high school curriculum follows a model where engineering-related content is phased in as students move through a sequence of courses within a pathway. Following the pattern represented by the illustration shown in Figure 1, early courses would involve only low levels of mathematics and science. These courses would be appropriate for any student and would focus on engineering content appropriate for general education objectives. Students who continue on to the third and fourth level courses should be provided with increasingly complex applications of mathematics and science. This model would provide a curricular model to accommodate students at all levels of involvement in the engineering and technology education program.

Figure 1. Curricular Model for High School Engineering and Technology Education Coursework.



## REQUISITE MATHEMATICS AND SCIENCE KNOWLEDGE AND SKILLS

College or university graduates, having completed the equivalent of sixteen years of education, have participated in many hours of mathematics instruction, homework, drill and practice, and testing. Technology teachers are no exception. Nevertheless, the level of mastery of mathematical concepts varies widely from person to person.

The programs of study, and the levels of mathematics courses completed, also vary considerably from one technology teacher to another. For students who changed their major during their undergraduate program, college-level mathematics courses could range from a concepts class to calculus. Technology education degree programs have not traditionally had high-level mathematics requirements, and students often complete a program of study with the same mathematics courses required of liberal arts majors.

Another path followed by students transferring into a technology education major is to change from engineering, engineering technology, industrial technology, or some other technological program of study. In these instances the levels of mathematics courses completed are likely to have been more rigorous, but academic difficulties with mathematics instruction devoid of practical application might have actually been a motivator for the change of major.

For all technology teachers who are more than a couple of years removed from their undergraduate degree programs, retention of knowledge gained in even high-levels of mathematics coursework is often limited, unless practical applications have been found. Mathematics courses are usually completed during the first two years of a four-year college degree program and technology teacher education programs do not usually include additional upper-level mathematics courses unless it is in an area such as statistics.

The materials that follow are designed to assist both practitioners in the field of technology education as well as pre-service students to identify and apply mathematical theory and computational tools as they integrate engineering design into technology education learning activities. In some instances, the mathematics will be a review, while for others it might be a first exposure. The degree to which additional supplemental resources will be needed will vary accordingly. An underlying goal is to provide high school and middle school students with opportunities to make practical connections between mathematical theory and real-world technological applications. For both teachers and students, mathematics should become an integral tool for approaching technological problems in addition to the hand tools, power equipment, and modules that already are a part of the profession's repertoire.

## **Computational Tools**

Engineers use calculators, spreadsheets, and software such as MATLAB to help make calculations (Grose, 2007). In addition, PowerPoint is often applied to make presentations of engineering design solutions for clients or other external entities. When students develop skills with these tools at the high school level, they will be better prepared for college should they decide to major in engineering or a related field of study. This section will describe the advantages of using calculators and/or spreadsheets for computations.

## *Calculators*

Calculators are an essential tool for students solving engineering problems. At a minimum, students will need a scientific calculator that can handle trigonometric functions, roots, logarithms, powers, and reciprocals. These calculators are inexpensive, ranging from \$8.00 to \$20.00. An example of a suitable calculator is the Texas Instruments TI-30Xa. Scientific calculators are adequate for most computations that are relatively simple and not repetitive.

More complicated engineering problems and those that are repetitive in nature require the use of more advanced graphing calculators. Graphing calculators have the capability to graph functions (2 and 3 dimensional), solve sets of simultaneous equations, solve equations with symbolic representations, and create tables of values for a given function. Some graphing calculators have the capability of downloading information to and from a computer. Graphing calculators are more expensive than scientific calculators, generally ranging from \$60.00 to \$220.00. Examples of common graphing calculators used in engineering programs are the Texas Instruments TI-83, Texas Instruments TI-84, and the Hewlett Packard HP 48g.

Scientific and graphing calculators are a staple to every engineer's toolbox. However, there are many engineering problems in which it is much more efficient to use a spreadsheet.

## *Spreadsheets*

Spreadsheets enable the user to analyze data and effectively communicate results of analysis. Spreadsheets are very useful when a problem is going to be solved multiple times using different data sets, when graphing capabilities are more demanding, and when the output is to be displayed digitally for a presentation or in a word processing document. A user can enter numerical data into a spreadsheet to produce tables and graphs. Users can also write equations within spreadsheets using the data in the spreadsheet. Additionally, they can run statistical routines on data sets to determine the average or standard deviation.

Students often learn to use the basic features of spreadsheet software either on their own or through business education courses. Fundamental instruction in the use of spreadsheet software is usually not considered to be required content within secondary engineering and technology education coursework. Providing opportunities for students to apply spreadsheet

applications as they solve technical problems can provide valuable learning opportunities. Instructional activities should require use of the “chart” and “add trendline” features provided within the spreadsheet software, since these items are especially useful for engineering work, but might not have been included in self-taught learning or other prior coursework.

## Fundamentals of Mechanics

Mechanics is the term used for analyzing the effects of forces being exerted on bodies. There are three different types of bodies that can be considered when the field of mechanics is applied to real-world problems: (a) rigid bodies, (b) deformable bodies, and (c) fluids. Two additional terms related to the mechanics of rigid bodies are statics and dynamics. Statics refers to situations where a rigid body is in equilibrium, either remaining at rest or moving at some constant velocity. Dynamics involves the study of unbalanced forces on a body where acceleration comes into play.

For purposes of this chapter, the primary focus will be constrained to explanation and examples involving statics. Solutions to these problems primarily involve basic algebra and trigonometry and are relevant to the types of mechanical systems often used in technology education hands-on activities.

### *Scalars and Vectors*

A *scalar* is a physical phenomenon that can be quantified but is not directional in space. Mass, time, temperature, and dimensions of height, width, and depth are all examples of scalars. A *vector* is a physical quantity, but it also has a specified direction. *Magnitude* is the term used to refer to a measured quantity of a scalar or vector and *sense* is direction or line of action of a vector.

Scalars and vectors are both essential components in working with technological problems, but vectors are particularly applicable to the field of mechanics. Forces have both a measurable quantity and a line of action, so vectors are well suited to represent the systems examined in statics problems.

Analysis of vectors can be done either graphically or with mathematical calculations. Graphical vector analysis involves constructing drawings where the length of each line is proportional to the vector magnitude and angles correspond to the vector senses. Lines are drawn to represent all

vectors within the system and a *resultant* connecting start point to end point in the vector diagram enables a solution.

When vector problems are solved using mathematical calculations, the Cartesian coordinate system is typically used. Vectors are drawn and identified using angles with respect to the  $x$ ,  $y$ , and  $z$  axes and magnitudes are labeled adjacent to the lines. Vertical and horizontal components are often identified and used in solving vector problems, and mathematical computations usually involve algebra and trigonometric functions for right triangles.

A system of notation is needed when vector problems are represented on paper. In printed materials, vectors are typically shown using a bold typeface. A vector might be identified by **A** or **B** whereas the magnitude of these vectors would be noted by  $|\mathbf{A}|$  or  $|\mathbf{B}|$ . Field work involving vectors is common where work is being done in a laboratory real-world setting, so handwritten techniques for representing vectors on paper are also needed. The convention used for writing that includes reference to a vector is to place an arrow above the letter used to identify a vector so it is written as  $\vec{\mathbf{A}}$  or  $\vec{\mathbf{B}}$ .

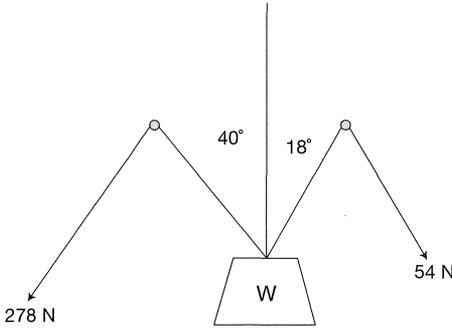
### *Forces and Types of Force Systems*

Force occurs when the action of one body influences the motion of another body. Newton's third law of motion states that when a body  $D$  acts on another body  $K$  with a force with a specified sense and magnitude, then the body  $K$  will react on body  $D$  with a force of equal magnitude and opposite direction. When solving problems involving forces, they must be described with sufficient detail to determine the line of action, magnitude, and direction.

When problems involving forces are presented, vectors are often used to represent the various details of the problem. A *space diagram* is usually provided to illustrate the key components of the force system. This graphic does not use lines and arrows that are drawn using a vector scale, but it is labeled to provide pertinent details related to the problem.

Space diagrams are often used in conjunction with word problems to help portray the significant features needed to compute a solution. Figure 2 provides an illustration that could be used to clarify the following word problem: Given a frictionless system of pulleys, how much mass can be lifted by the system illustrated in the figure provided?

Figure 2. Example of Space Diagram for Mass Lifted Using Pulleys.



To solve a problem involving one or more forces, mathematical computations can be used or graphical analysis applied. In mathematics and science classes, the usual approach is to *resolve* the force or forces into vertical and horizontal components. This allows trigonometric functions to be applied to determine a desired solution. In some problems, only the vertical or the horizontal components of the forces are relevant to the solution. For example, in the force system represented in the space diagram above, only the vertical components of the given forces would be useful in lifting the weight against the downward force of gravity. Trigonometry allows this portion of the forces to be isolated and then used to calculate an answer. These calculations might include the following:

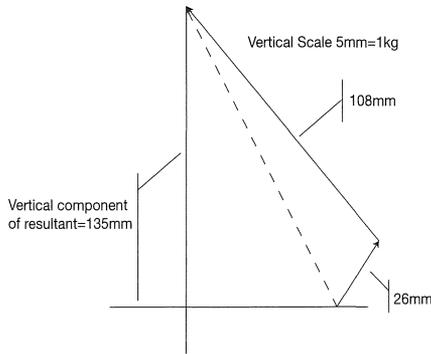
$$\begin{aligned}\Sigma F_y &= 0 \\ 278\cos 40^\circ + 54\cos 18^\circ - W &= 0 \\ 212.96 + 51.36 &= W \\ W &= 264.32 \text{ N} \\ W &= mg \\ 264.32 &= m(9.81\text{m/s}^2) \\ m &= 26.94 \text{ kg}\end{aligned}$$

An alternative approach to solving a force system problem is to use graphical vector analysis. This method uses vectors drawn with a vector scale and angles matching the senses of the forces. Graphical vector analysis is seldom used as a computational method for identifying the resultant of a force system by engineers. It does, however, provide an alternative approach to explaining vectors and resolution of force systems.

Technology educators have sometimes included this content in engineering graphics and drafting courses over the years as a technique for enhancing understanding of vectors and vector analysis. High school engineering and technology education courses should cover both use of trigonometry and graphical vector analysis in the treatment of vectors as a tool for solving problems involving physical phenomena having both magnitude and direction. This provides students with some alternatives for gaining the conceptual understanding that leads to mastery of vectors as a tool for solving real-world problems.

Figure 3 illustrates solving the same problem involving a mass and frictionless pulleys through the application of graphical vector analysis. In the example provided, data is either converted to kg in the given problem or actual apparatus set up in a laboratory setting is used to provide the magnitudes of the vectors. Spring scales attached to cords passing over pulleys and attached to an unknown weight, for example, could provide a physical model that matches the illustration in Figure 2. Vectors are then drawn to scale using either manual drafting techniques or CADD software. Angles of the vectors are matched to those given in the problem. The end result should be approximately the same as that provided by mathematical computation. Precision is dependent on the vector scale selected and the accuracy of the drawing, but in most instances a comparable solution can be demonstrated. For a visual learner, this can provide an excellent complement to the mathematics used to find a solution and can lead to understanding where it might otherwise be elusive.

Figure 3. Graphical Vector Analysis for Resolution of a Force System.



## *Moments and Couples*

When a force is applied directly to an identified point within a force system, a vector can be used, but if the force is applied to a lever arm or in a manner such as to create rotational motion, a *moment* is produced. In some instances, parallel forces are applied to opposite sides of a wheel or other device where rotational force is being generated, and if these parallel forces are equal in magnitude and opposite in direction, a *couple* is produced.

Moments, couples, and other types of problems involving rotational motion are more complex than those problems involving straight line forces, and would likely be reserved for advanced level high school courses. For those students, however, that are taking a fourth course in high school engineering and technology education programs, working with problems involving moments and couples could provide a helpful complement to the physics coursework in which students might be enrolled.

## **Representation of Mathematical Data**

Engineering design problems often have large data sets. These data sets must be organized so that engineers can make sense of the data. These quantitative data can be displayed graphically in the form of a table, graph, or chart. The engineer or engineering student collects data from experiments and records it manually (with pen and paper) or enters it directly into a computer. Typically engineers use a computer to assist with displaying numbers graphically, although it can be done by hand. Spreadsheets enable the user to graph large data sets with ease.

Tabulated data is arranged in rows and columns. The first column shows the independent variable, and the second column and any following columns show the dependent variables. Tables help organize the raw data; however tables do not visually display the relationships between the different numerical values. Displaying data from tables in graphs enables the user to visualize patterns in the data. Engineers commonly use tables and graphs to display quantitative information.

## **Mathematics**

For technology teachers and teacher educators seeking to infuse engineering design into their curriculum, decisions about what mathematics would be needed quickly arise. Wicklein (2006) suggested that attention to optimization as an activity to be included in the creative process was an

important reason for moving to an engineering design focus. Optimization typically involves the application of mathematics to identify an efficient or most effective solution.

In preparing for greater inclusion of mathematics, it is important to consider what topics or concepts within the field of mathematics are most likely to be needed. Certainly technology teachers should not be expected to be proficient in mathematics at the level of those who have majored in this content area or prepared to teach in that discipline. Selected topics, however, should be added to technology teacher preparation curricula so that the level of comfort and competence in applying mathematics to the solution of technical problems within the field is enhanced.

This section includes material on basic algebra, trigonometry, and geometry. Algebra, trigonometry, and geometry are commonly used when solving engineering problems. The tables and figures can be used as a quick reference or review of the most essential algebra, trigonometry, and geometry topics that are likely to be needed.

## *Algebra*

Algebra is an extension of mathematics that uses symbols to represent numbers. Typically, letters of the alphabet are used as symbols in algebra. Many traditional engineering problems are solved using algebraic equations. A linear equation is an algebraic expression that involves constants and variables that are raised to the first power. In other words, the relationship between the input and output is directly proportional. These equations are linear because they represent straight lines when graphed. A quadratic equation is an algebraic expression in which one of the unknowns is squared. Quadratic equations are often used in engineering to describe paths of objects. An exponential equation is an algebraic expression in which one of the unknowns is raised to a power. For example, exponents are used in biological engineering to describe biological growth.

## *Geometry and Trigonometry*

Geometry is a branch of mathematics that involves points, lines, curves, planes, and shapes. Geometry describes the relationships between and the properties of objects in space. Geometry is used in engineering to describe a physical object, such as the surface area and volume of a cylinder. The geometry of an object is often the first step in analyzing a traditional engineering problem.

Trigonometry is a branch of mathematics that involves triangles. It describes relationships between the length of the sides of a triangle and the angles between the sides. Trigonometry is often used in engineering when the length of a side of a triangle, or an angle is unknown. Trigonometry is used often in mechanical and civil engineering problems.

### *Geometry and Trigonometry Examples*

This section will consist of equations from geometry and trigonometry. Equations of area, volume, length of triangle sides, and angles of triangles will follow.

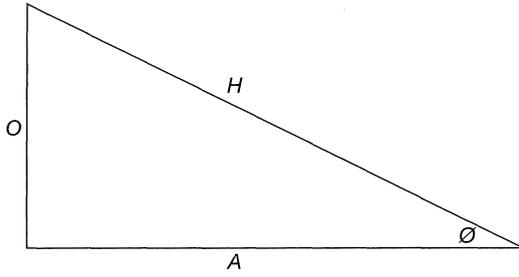
Table 1. Common Equations for Area.

Shape	Equation	Variables
Rectangle	$l \cdot w$	$l$ is the length, $w$ is the width
Triangle	$\frac{1}{2} b \cdot h$	$b$ is the length of the base of the triangle, $h$ is the height of the triangle
Circle	$\pi \cdot r^2$	$r$ is the radius
Sphere	$4 \cdot \pi \cdot r^2$	$r$ is the radius
Cylinder	$2 \cdot \pi \cdot r(r+h)$	$r$ is the radius, $h$ is the height

Table 2. Common Equations for Volume.

Solid	Equation	Variables
Cube	$s^3$	$s$ is the length of a side
Rectangular Prism	$l \cdot w \cdot h$	$l$ is the length, $w$ is the width, $h$ is the height
Sphere	$\frac{4}{3} \pi \cdot r^3$	$r$ is the radius
Cylinder	$\pi \cdot r^2 \cdot h$	$r$ is the radius, $h$ is the height

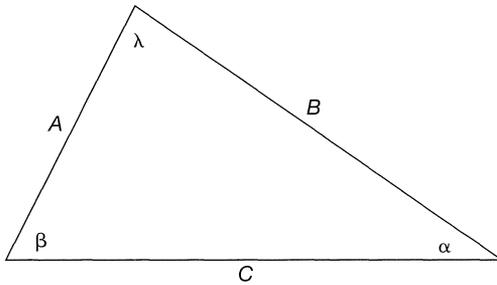
Figure 4. Right Triangle with Sides and Angles Labeled.



O is the length of the side that is **opposite** of alpha ( $\alpha$ )  
H is the **hypotenuse** of the right triangle  
A is the length of the side that is **adjacent** to alpha ( $\alpha$ )

$$\sin(\alpha) = \frac{O}{H}$$
$$\cos(\alpha) = \frac{A}{H}$$
$$\tan(\alpha) = \frac{O}{A}$$

Figure 5. Obtuse Triangle with Sides and Angles Labeled.



**Law of Sines**

$$\frac{A}{\sin(\alpha)} = \frac{B}{\sin(\beta)} = \frac{C}{\sin(\lambda)}$$

**Law of Cosines**

$$A^2 = B^2 + C^2 - 2 \cdot B \cdot C \cdot \cos(\alpha)$$

$$B^2 = A^2 + C^2 - 2 \cdot A \cdot C \cdot \cos(\beta)$$

$$C^2 = A^2 + B^2 - 2 \cdot A \cdot B \cdot \cos(\lambda)$$

## Science Knowledge and Skills

In addition to an understanding of fundamental mathematics concepts (algebra, geometry, and trigonometry), an understanding of fundamental science will be necessary when completing different types of engineering problems. The science knowledge and skills needed vary widely from engineering problem to engineering problem. Traditional engineering problems are fundamentally based in physics, which is often not taken as a separate course by K–12 students or by technology education teachers. Rather, physics is typically integrated into K–12 studies. The National Science Education Standards (National Research Council, 1995) include fundamental physics concepts in the physical science, life science, and Earth and space science standards. The Web site provides information about the Standards and describes how levels K–4 should address position and motion of objects and levels 5–12 should address motions and forces. More biology, life sciences, social sciences, and chemistry are involved as engineers and students solve real-world problems. The teacher can choose engineering science problems or engineering design challenges that are within the particular science domain of their choice.

An appropriate starting point for identifying key science concepts to be included in the preparation of technology teachers would be the CORD Principles of Technology materials. An overview of the topics and description of content covered can be found on the CORD Web page.

## Engineering Science and Engineering Design

An important concept for technology education teachers to understand is that engineering science and engineering design are not equivalent.

Engineering science is based on Newtonian concepts of physics and relies heavily on the use of mathematics and science concepts. In order to solve engineering science problems, a strong understanding of mathematics and science is essential. However, this changes when working on an engineering design problem. Mathematics and science are necessary components of engineering design, but are not sufficient. Engineering design requires a much broader set of competencies than simply mathematics and science. It requires an understanding of social, cultural, ethical, environmental, global, and economic aspects of a problem. Within the engineering design process, there is a need for analytical mathematics and science skills, but these are not sufficient. There is an assumption that is common among non-practicing engineers, that engineering design only consists of mathematics and science. This is a misconception that needs to be addressed not only in technology education but also engineering education. Engineering graduates quickly find that their mathematics and science backgrounds are not what will make them successful engineers. Success instead rests in the non-technical skills that set them apart from other engineering graduates. This is an important concept, since introducing engineering design into a K–12 classroom can have a large focus on non-technical areas in addition to technical ones, which will be attractive to a broader audience of students and technology educators alike. It should also be noted that, while technology education has historically concentrated on concepts and activities related to the physical sciences, the technology standards extend the scope of the field to areas more closely aligned with the biological sciences (e.g., agricultural, medical, and bio-related technologies).

## **Example Applications Using Physics**

It is critical that the distinction between engineering science and engineering design be conveyed to students by way of classroom instruction and hands-on activities. A sequence of two engineering science activities and one engineering design activity are given below as example operatives for accomplishing this objective as well as for instilling a deeper understanding of science and mathematics skills within practical engineering design activities. Instruction should focus on science principles and predictive mathematics that comprise the engineering sciences needed to solve problems in a design framework that is analytical, predictive, and repeatable. Concepts from Newtonian physics, geometry, trigonometry,

calculus, and engineering sciences are incorporated into the instructional paradigm. Each activity is briefly explained and is accompanied by the science, mathematics, engineering science, and engineering design concepts and objectives that will be achieved. Activities are sequential and build on knowledge developed in the preceding activity. Thus the basic concepts and objectives listed are cumulative.

### ***Activity 1—Engineered Beam***

Fundamental principles of algebra and trigonometry will be applied using the basic laws of force and mass systems in the engineering design of a wooden beam. The design should be constrained based on pre-determined requirements of length, width, load, and beam material. Topics covered will include:

- I. Identification and development of relevant science, engineering science, and mathematics principles
  - A. Basic science concepts and objectives
    1. Laws and governing equations of mass and force systems
    2. Units of measure
    3. Equilibrium
    4. Calculations
      - a. Angles
      - b. Forces (tension, compression)
      - c. Components of forces
      - d. Direction of forces
      - e. Bending
      - f. Moments
    5. Beam types
    6. Physical properties of beam materials
    7. Construction of predictive mathematical models from physical measurements
  - B. Basic mathematics concepts and objectives
    1. Elements of geometry
    2. Elements of trigonometry
    3. Coordinate systems

4. Rigorous understanding of “function”
  5. Introduction of mathematical models as analytical and predictive tools
  6. Introduction of concepts of rates and limits
- C. Engineering science concepts and objectives
1. Engineering mechanics
    - a. Statics
    - b. Strength of materials
  2. Free-body diagrams
  3. Governing equations
  4. Engineering constants
- II. Application of engineering design process
- A. Identification and definition of problem
  - B. Generation of concept
  - C. Optimization of concept
  - D. Confirmation
  - E. Production

### *Activity 2—Projectile Launcher*

Fundamental principles of algebra, trigonometry, and differential calculus will be applied to the basic laws of mass, force, and motion in the engineering design of a mechanism to launch an object. The design will be constrained based on pre-determined requirements of distance launched, height launched, angle of trajectory, and object material. Below is a topical outline:

- I. Identification and development of relevant science, engineering science, and mathematics principles.
  - A. Basic science concepts and objectives
    1. Laws and governing equations of motion
    2. Units of measure
    3. Time as a variable
    4. Gravity, speed, velocity
    5. Graphical description of motion
    6. Rates of change

7. Friction
  8. Construction of predictive mathematical models from physical measurements
- B. Basic mathematics concepts and objectives
1. Elements of geometry
  2. Elements of trigonometry
  3. Rigorous understanding of “function”
  4. Predictive mathematical models
  5. Coordinate systems
  6. Extension of rates and limits
  7. Time introduced as a variable
  8. Maximum/minimum concepts
  9. Differential calculus
- C. Engineering science concepts and objectives
1. Engineering mechanics
  2. Free-body diagrams
  3. Governing equations
  4. Engineering constants
  5. Thermodynamics
  6. Heat transfer
- II. Application of engineering design process
- A. Identification and definition of problem
  - B. Generation of concept
  - C. Optimization of concept
  - D. Confirmation
  - E. Production

### *Activity 3—Hydroponics Water Delivery System*

Fundamental principles of algebra, trigonometry, differential and integral calculus will be applied to the basic laws of energy conservation and thermodynamics in the engineering design of a hydroponics

water delivery system. The design will be constrained by pre-determined requirements of water flow, plant characteristics, location, and materials.

- I. Identification and development of relevant science and mathematics principles
  - A. Basic science concepts and objectives
    1. Conservation of mass
    2. Force
    3. Acceleration
    4. Momentum
    5. Motion
    6. Equilibrium
    7. Conservation of energy
    8. Biological function
  - B. Basic mathematics concepts and objectives
    1. Elements of geometry
    2. Elements of trigonometry
    3. Rigorous understanding of “function”
    4. Predictive mathematical models
    5. Coordinate systems
    6. Extension of rate and limits
    7. Time as a variable
    8. Maximum/minimum concepts
    9. Differential calculus
    10. Integral calculus
    11. Areas and volumes
  - C. Engineering science concepts and objectives
    1. Engineering mechanics
      - a. Statics
      - b. Fluids
    2. Free-body diagrams
    3. Governing equations

4. Engineering constants
  5. Hydrostatics
  6. Buoyancy
  7. Mass flow
  8. Work
  9. Power
  10. Energy conversion
- II. Application of engineering design process
- A. Identification and definition of problem
  - B. Generation of concept
  - C. Optimization of concept
  - D. Confirmation
  - E. Production

The activities outlined above are examples of the types of activities that have been developed through collaborations between engineers and technology teacher educators working together under the auspices of the National Center for Engineering and Technology Education (NCETE), funded by the National Science Foundation. Levels of science and mathematics included in these activities are appropriate for upper-level college work, but would be reserved for engineering applications or capstone courses at the high school level.

## **Complementary Activities in Support of Engineering Activities**

As complementary activities to the technical knowledge developed through the engineering science and design activities, technology teachers should integrate an ethics of integrity through the use of the engineering design notebook. A staple tool in the engineer's repertoire, the engineering design notebook will facilitate the fostering of a disciplined and rigorous approach to documentation of technical and creative processes. In addition, a final written report coupled with reflective journals can enhance students' abilities in creatively communicating technical information in written format. Suggested outlines for maintaining an engineering design notebook, written reports, and reflective journals are offered here.

## *Engineering Design Notebook*

A good engineering design notebook is one that can be used to reconstruct work even years after the original project has been completed. Others competent in the engineering design process should be able to use the notebook to reconstruct the work. It is also used for determining the rightful owners of patents and other proprietary ideas.

1. On the front of the notebook, enter the project title, the designer's name and other information needed to return the notebook in case it is lost.
2. Maintain a table of contents at the front of the notebook.
3. Make all entries in ink.
4. Ensure that all entries are legible.
  - a. Do not be obsessed with neatness at the expense of faithfully recording all activities as they take place.
  - b. Do not crowd the materials on the pages.
5. Make entries at the time the work is done.
  - a. Include all results and learned information whether favorable or unfavorable.
  - b. Include all information even if it is not fully understood at the time of entry.
6. Cross out errors with an X or a single line.
  - a. Do not mark through anything to the extent that it becomes illegible
7. Do not erase.
8. Never tear a page out of the notebook.
9. Include all data in their original form (e.g., calculations, charts, pictures, sketches on scrap paper, etc.), not after recalculation or transformation.
10. Draw and sketch directly in the notebook.
  - a. More careful drawings such as machine drawings or computer-generated plots should be made and entered in the notebook.

11. Enter information that is documented on loose sheets of paper in the following manner:
  - a. Tape the loose paper to the next available blank page in the notebook.
  - b. Tape each corner of the loose paper.
  - c. Use tape that will accept ink permanently.
  - d. Place your signature on the loose paper, continue across the tape and end on the design notebook page.
  - e. Sign across each corner of the taped page.
  - f. Date the signature.
12. Do not enter information that can be retrieved easily (such as research articles from journals) into the notebook.
  - a. Enter only the needed information and the location of the information in case you must retrieve it again.
13. Title each page of the notebook and enter the information in the Table of Contents.
14. Sign and date the notebook page at the space provided at the bottom.
15. Have design entries witnessed and have the witness sign and date at the space provided.
  - a. The witness needs to have the technical ability to understand the entry.
  - b. The work can be witnessed periodically.
16. Number every page of the notebook.
17. Do not skip pages as this is a chronological record of design work.

### *Written Reports*

The engineering design notebook provides a mechanism for documenting the processes used to develop an innovation or technological solution, but it is primarily used for internal purposes. The sketches, mathematical computations, notes regarding potential solutions, and applications of engineering science are used to record engineering activities and can facilitate a structured approach to problem solving. Often,

however, some communication of the design will be needed for clients or others outside the design team working on a problem. In those instances, a written report that follows the guidelines outlined below can be useful.

- I. Introduction
  - A. Define goals and resources
  - B. Explain what is being solved
- II. Problem definition and design specification
  - A. Identify constraints
  - B. Specify functional requirements
- III. Conceptual design
  - A. Provide an overview of the preliminary design solution without getting into details
  - B. Use sketches to help describe the idea
- IV. Optimization and analysis of the solution
  - A. Design and develop product that meets the problem specification
  - B. Develop process for manufacturing final product (use drawings to help communicate the idea). Should include:
    1. Identification of critical components/processes
    2. Critical theories, principles used in engineering analysis
    3. Results of analysis
    4. Confirmation of results
    5. Conclusions relating results to design solution
- V. Construction
  - A. Describe how to manufacture the product using drawings as needed
- VI. Cost of the product
  - A. Development costs
  - B. Direct production costs
  - C. Indirect production costs
- VII. Testing and design improvement
  - A. Verify design assumptions and design effectiveness. Should include:

1. Identification of testing method or procedures
2. Results
3. Confirmation of results
4. Conclusions relating results to design solution

VIII. Recommendations

A. Corrective action plan

IX. Sections following the report include:

A. Figures

B. Graphs

C. Tables

D. Appendices (information in appendices should only supplement the report and should not include materials needed to understand the report.)

Data and information for written reports can be identified and collected from engineering design notebooks as well as other reference materials. The report should be prepared using word processing software and other appropriate document preparation procedures and should be professionally presented. In educational settings, students at all levels should be encouraged to develop good written communication skills to accompany the analytical portions of the engineering design process.

## **PROFESSIONAL DEVELOPMENT**

A major issue brought by the shift to an engineering design focus for technology education is the impact on professional development. This includes not only the preparation of new teachers for the field, but also instructional programs and resources needed to equip existing teachers for addressing new content.

As can be seen by the content presented in this chapter, mathematics and science are key content areas for preparing technology teachers to address engineering design, particularly with regard to the analytical component. Additional learning in these areas will enhance the requisite skills technology teachers will need as they infuse engineering design problems into the curriculum.

## **Pre-service Technology Teacher Preparation**

Programs of study for pre-service preparation of technology teachers vary considerably among colleges and universities. The list of courses students will complete is influenced not only by the professional judgment of technology teacher education faculty, but is also constrained by requirements of state government agencies responsible for teacher certification and university policies limiting the total number of hours required for an undergraduate degree.

One of the significant trends in recent years has been the alignment of core coursework taken by education majors during the first two years of their degree programs. Initiatives have been implemented to assure that students who complete the first two years of study at a two-year college can transfer core coursework to a four-year institution. Departments within university colleges of education often exert considerable influence on the selection of core courses, and are sometimes able to prescribe a set of courses specific to a particular major to be taken as a part of the core.

In the field of career and technical education, technology teacher education has often been housed within departmental units that include business education, marketing education, family and consumer sciences, and other career and technical specializations. Coming together to formulate a departmental recommendation for major-specific core courses becomes more complex when technology education faculty seek the addition of higher levels of mathematics and science requirements.

## **In-service Professional Development**

Participation is among the greatest challenges to be addressed when in-service professional development is an essential element in the transformation of a discipline. Teachers are constantly juggling demands of work with busy schedules. Paperwork is sometimes burdensome and there is almost constant tension between important instructional tasks and duties necessary to maintain discipline and some semblance of order.

In-service professional development typically takes place through after-school meetings, weekend workshops, programs included as a part of professional conferences, or summer events. The range of participation varies from persons who are reliable and provide leadership to those who

are only interested in meeting minimum requirements. Providing professional development to equip technology educators to address the mathematics and science needed for an engineering design focus will require high quality materials, multiple delivery mechanisms, and motivational encouragement from within and outside the profession.

To best meet the needs of practicing teachers as they acquire enhanced skills needed for the analytical component of engineering design focused technology instruction, a full complement of in-service professional development opportunities will be required. Some of these experiences can be scheduled in conjunction with national and state conference activities. Workshops and other structured experiences can also be provided through regional or school system structures.

Professional development programs should include group engineering design activities that model the types of problems appropriate for middle and high school students. Emphasis should be given to all engineering design activities with special attention to the analytical components. Expertise should be provided within the professional development workshops for one-on-one or small group instruction of any concepts that might not be understood.

To provide additional support for in-service teachers, resource materials available on the World Wide Web should be identified and enhanced through the addition of Web pages designed specifically for technology teachers. Mechanisms for sharing online resources are already in place through technology education professional organizations. It will be important that these resources be leveraged and further developed in support of the shift to a focus on engineering design.

## **Requisite Student Knowledge and Skills**

Students participating in an engineering design focused technology teacher education experience at the collegiate level need to have a sound background in mathematics and science. The ideal would be completion of a mathematics sequence through at least the first level of calculus and science coursework that includes biology, physics, and chemistry. In reality, many students participating in technology teacher preparation programs have not completed mathematics or science core courses that extended to this level of difficulty. For some, even if these courses were completed, concepts might have been forgotten and significant review might be needed to enable computation skills as well as the recall of relevant scientific principles.

Collegiate faculty should be prepared to offer significant support to technology teacher education students as they participate in engineering design problems. In some instances this can be accomplished by partnering students possessing a stronger or more recent background in mathematics and science with those who appear to be less proficient. In other instances, workshops, seminars, or tutorials might be provided to assist students with requisite knowledge and skills.

From an instructional design standpoint, the most effective strategies provide assistance as it is needed during engineering design activities. For example, students working on a problem involving force systems will find instruction of trigonometry more pertinent than if this content were to be treated in isolation from a contextualized problem. Learning activities where mathematics and science instruction are embedded along with opportunities to work with real-world design problems are the essence of why engineering and technology education holds great promise for improving STEM education.

## **Secondary Level Pre-requisites**

If the curricular model illustrated in Figure 1 were to be adopted, the requisite mathematics and science for entry into the engineering design focused technology education program need not be at a very high level. Teachers need to be prepared to work with students at all levels—both basic and advanced. Content can be adjusted, however, to accommodate students with a broad spectrum of requisite knowledge.

For courses such as engineering applications and research and design, higher levels of requisite mathematics and science should be expected. These higher level classes should be geared toward students who are considering a college major in engineering or some related field. High school programs of study for these students should equip them to be successful with sophisticated mathematical computations and applications of science by the time they are in the last two years of high school.

## **Middle School Pre-requisites**

Middle school engineering and technology education programs should provide students with opportunities to learn about engineering design and technological problem solving, but requisite mathematics and science knowledge should be very basic. Students should be able to perform basic

arithmetic operations and also should be familiar with middle school level physical science. Middle school engineering design activities should focus on the related processes and include step-by-step guidance for any optimization computations that students are unfamiliar with.

## **INTERDISCIPLINARY COLLABORATION**

Technology education has always provided a wealth of opportunities for collaboration, but historically the field has been more aligned with other career and technical education content areas than with mathematics, science, or engineering as a discipline of study. The Carl D. Perkins Career and Technical Education Improvement Act of 2006 has influenced greater alignment between career preparation pathways and academic coursework in public school settings. As a result, cross disciplinary initiatives are being encouraged and sometimes required as school curriculum and instructional programs are updated.

### **Mathematics and Science**

Traditionally collaboration between technology educators and mathematics educators has been among the most challenging to accomplish. Mathematics educators are under tremendous pressure to cover content specified by their state and national standards, and accountability is often reinforced by achievement tests and other forms of assessment. Technology educators should continue to look for opportunities to collaborate with mathematics educators, but they should avoid being critical if these efforts appear to be unsuccessful.

Collaboration between teachers in technology and science could greatly enhance student learning opportunities in both areas of study. Science teachers, however, are also faced with pressures to cover specified content and to prepare students to achieve on standardized tests. Technology teachers should look for opportunities to interact with colleagues in science and be prepared to communicate specific areas where work in one area might complement or reinforce the other.

One strategy that can be used to encourage collaboration with mathematics and science educators is obtaining and sharing assessment data that demonstrates gains in learning and comprehension of mathematics and science content as a result of participation in engineering and technology education coursework. Evaluation tools such as that developed by a Georgia

Department of Education initiative include mathematics and science sub-scales. This particular assessment, available on the Web at <http://www.uga.edu/teched/assess>, illustrates the type of data-based strategy that can produce convincing evidence to support interdisciplinary collaboration.

## **Engineering**

Collaboration between technology educators and engineering faculty at the collegiate level can be very beneficial when it is achieved. Sometimes it is difficult, however, due to differences in the professional expectations typical within each discipline. Engineering faculty are often faced with high expectations for acquiring external funding for research, and tenure decisions are often largely determined by success in this area (Grose, 2007). Education faculty members, while often encouraged to seek grants, are more likely to be tenured based on refereed journal publications. In the absence of funded projects that support collaborative activities, engineering faculty sometimes cannot afford to participate in activities needed to support engineering design as a focus for technology teacher education.

For technology teachers at the middle school and high school levels, collaboration with engineers is more likely to come from parents or members of the community who are working within the profession. Whether serving on an advisory committee or having direct involvement with students as guest speakers or competitive event judges, engineers can be a great asset when they become involved.

## **CONCLUSIONS**

Addressing the essential mathematics and science needed for infusion of engineering design as the focus for technology education brings both challenges and opportunities. In some instances, technology educators have confidence in their abilities to deal with this content, but in many cases they are uncertain and anxious. It is important for the field as a whole to become more aligned with these essential areas of academic content, and the profession of engineering has much to offer as a partner in this effort. The key to success will be collaboration where that is possible, sharing of innovative ideas and resources within the profession, and a clear understanding that engineering design activities can be developed with a wide range of levels within mathematics and science.

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# Preparing Technology Teachers to Infuse Engineering into Technology Education: Pre-service, Professional Development, and Outreach

## Chapter

## 7

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## INTRODUCTION AND BACKGROUND

Few issues evoke more passionate conversation than the education of our children. As the economy becomes increasingly global and technologically complex, our educational programs need to be strengthened to prepare today's students to be tomorrow's productive workers, citizens, and leaders (American Society of Mechanical Engineers, 2002a). Recently, the Institute for Electrical and Electronics Engineers (IEEE) cited the growing influence and complexity of technology as a compelling reason to consider technological literacy fundamental to a citizenry's capacity to make informed decisions about public and private life, and to maintain a reasonable quality of life (United States Department of Education, 1996).

The National Science Board's (NSB) Task Force on National Workforce Policies for Science and Engineering (2003) has raised concerns about declining numbers of students pursuing engineering, technological, and scientific careers in the United States. Likewise, an analysis of ACT data found that the percentage of high school seniors who took the ACT test and reported plans to major in engineering in college has declined from 8.6% in 1992 to 5.6% in 2002 (Noeth, Cruse, & Harmston, 2003). The declining percentage of high school students who reported that they plan to major in scientific, technological, engineering, or mathematical (STEM) fields in college exacerbates the workforce situation noted by the NSB.

Given the declining numbers of people pursuing engineering, and the need to attract underrepresented minorities and women into science and engineering, the engineering profession has great interest in strengthening the educational pathways to engineering for K–12 students. In effect, many in the engineering profession want engineering content and methods to become part of the K–12 curriculum. However, engineers are generally unaware of the efforts of K–12 technology educators to include engineering in the schools. Recently, engineering societies have initiated projects to bring engineering into the K–12 schools through both formal and informal outreach, professional development for teachers, and accessible resources for teachers. The American Society of Mechanical Engineers (ASME) proposed legislation through state by state efforts to include and strengthen science, technology, engineering, and mathematics (STEM) education content in the schools. According to ASME:

There appears to be a logical educational continuum within which the knowledge of science, technology, engineering, and mathematics is cumulative. This implies that, without a strong and vibrant K–12 education system, the potential educational and economic impact is severely diminished. Yet...the cumulative benefits of science, technology, engineering, and mathematics are less than they could be. (ASME, 2002b)

## **Closing the Gap Through K–12 Teacher Education**

According to the American Association for the Advancement of Science, the four STEM disciplines should not be taught in isolation in a school curriculum, but rather in an interdisciplinary manner and continually cross referenced, as part of a dynamic triangle that ultimately researches, designs, and creates the way we live, work, and play. Therefore it makes solid academic and professional sense to prepare teachers who are highly qualified to deliver this integrated content in a K–12 setting (American Association for the Advancement of Science, 1993). This is a powerful, yet critical void in most public education and professional teacher preparation programs.

Significant questions exist around the content knowledge required of a technology teacher in order to infuse valid engineering concepts into the K–12 classroom. What are the appropriate mathematical and analytical levels required of pre-service teacher preparation? Can a professional not trained in engineering deliver instruction and teach engineering design

lessons that are valid in content and context at the K–12 levels? These and many more questions remain as the technology teacher preparation community begins to join with other key stakeholders in preparing teachers to respond to the national call for a stronger STEM emphasis in K–12 education.

Therefore, engineering and technology education, as the pre-service academic preparation for the technology education teacher, would add a dynamic element to our K–12 schools. The potential outcome—a highly qualified teacher versed in the engineering sciences, technology, engineering design, physical sciences, and mathematics who could close the teaching/learning gap through authentic application, exploration, design, and inquiry in our nation’s classrooms—is a goal not yet realized.

### *Why Engineering and Why Now?*

K–12 STEM education has commanded the attention of people far beyond the community of educators typically involved in the field. Policy-makers, industry leaders, and thoughtful leaders in the media have registered concerns regarding problems with how science and mathematics are taught and how technology fits into the curriculum. Meanwhile, engineering has largely remained a shadowy presence in discussions about the K–12 STEM education, a spectral “E” quietly inserted among its more concrete complements, yielding, if nothing else, an acronym that lends itself nicely to speech and writing.

Engineering is an important national resource in efforts to keep America competitive in a knowledge- and technology-driven global economy and safe in an uncertain geopolitical climate (National Research Council, 2006). Technological innovations result from the work of people trained in engineering and technology fields. Educated across disparate areas of science and mathematics, these professionals translate their understanding of fundamental science and mathematics into usable objects and applications that improve our lives, create new jobs and industries, and extend the frontiers of human possibility. They also play a fundamental role in national security strategies, combating threats to a country’s citizenry through research and development of technologies that can neutralize threats to civilian and military populations.

Engineering also conveys practical classroom benefits for educators and students by contextualizing sometimes abstract mathematics and science concepts. A number of studies have demonstrated that students’ par-

participation in engineering design activities can significantly advance their academic, creative abilities, and cognitive functioning (Dillenbourg, 1996; Hetland, 2000; Seeley, 1994). The integrative, applied nature of engineering can enhance student learning, boosting test scores and helping schools meet standards-driven education requirements (Baker, 2005). The collaborative, socially beneficial aspects of engineering have also been shown to appeal to students whom the field has traditionally failed to engage, including females and underrepresented minorities (Guertin & Jennifer, 2004; Wiest, 2004).

## **Interdisciplinary Perspectives and Influence**

The expansive range of arguments cited for change in K–12 STEM education, including a new role for engineering, is matched by the remarkable diversity in approaches that people have taken to infuse engineering into K–12 education practices. Engineering-based K–12 education often takes place inside and outside the classroom, in museums, at discovery and science centers, during the school year and during breaks in the form of camps for students, in elementary, middle, and high school classrooms, on university campuses, in industry, and in government laboratories. It involves teachers, students, and parents; faculty members, administrators, undergraduates, and graduate students; local, state, and national government representatives; and private-sector and non-profit employees. Infusing engineering content and concepts into formal and informal educational settings can encompass full-scale curricula with sequenced electives for high school students, stand-alone textbooks, classroom assistance from engineering students and professionals, online curriculum resources and lesson plans often mapped to state and national standards of learning, cognitive and behavioral research into teaching and learning engineering, experiential weekend and summer programs designed to excite and inspire students and teachers, new approaches to teacher training and curriculum development, collaborations among engineering and technology educators and their education colleagues, alternative pathways to post-bachelor teacher certification, and legislative and policy reforms designed to institutionalize engineering as a durable part of K–12 STEM education.

This ferment might well indicate the birthing of a new discipline within K–12 education, namely, “K–12 engineering education.” Under a recent award from the National Science Foundation (NSF), an interdisciplinary group of stakeholders, including higher education faculty, teach-

ers, K–12 school administrators, professional association representatives and College Board® staff have collaborated on forming a *Strategies in Engineering Education K–16* (SEEK-16) taskforce (SEEK-16 Team, 2007). The focus of SEEK-16 was to research the rationale, feasibility, and requirements for an Advanced Placement (AP®) course of study in engineering. The intent of the pre-engineering AP concept is for students to gain a higher level of competence in basic science and mathematics through content and experiential activities grounded in engineering science concepts and practices. The research component of this work elicited the opinions, attitudes, and expertise of individuals and focus groups from diverse segments of the engineering and education professions. During 2007, a field study was also conducted involving 155 secondary school students. The research for the AP in Engineering addressed issues related to:

- need;
- inclusion of students from a range of learning styles and abilities;
- potential content for the course of study;
- requisite scope of the professional development for teachers;
- sentiment of higher education faculty to awarding engineering credits; and
- relevance to the College Board’s Vision and Mission for an Engineering AP.

The convergence of several national reports, including *Rising Above the Gathering Storm* (NRC, 2006) became “calls to action” for more students to become better prepared to enter into science, technology, engineering, and mathematics (STEM) academic studies and STEM careers. In response to this need for the better preparation of pre-college bound students in engineering, the College Board AP staff requested the SEEK-16 taskforce to submit a plan for an AP pre-engineering course of study. The timeline called for a plan to be submitted to the College Board Trustees at their June, 2007 meeting (SEEK-16 Team, 2007).

The vision of the interdisciplinary effort to articulate and design an AP pre-engineering course of study was guided by the notion that such an AP pre-engineering course of study would enable students from varying socio-economic backgrounds, learning styles, and abilities to gain the skills and knowledge to succeed in advanced studies and STEM careers. An AP pre-engineering course of study offers the potential to promote student STEM learning through the practice of design, which aligns to

problem solving through discovery and construction of artifacts (SEEK-16 Team, 2007).

This level of attention marks new flows of money, political pressure, resources, and expectations for K–12 STEM education and, in so doing, alters the environment for change. No longer the province of just the science and math teachers and teacher training communities, the structure and substance of K–12 STEM education have become part of the terrain on which a broad set of powerful participants working in diverse, non-education arenas negotiate and engage in discourse over large-scale issues of national importance. The expanding scope and higher profile of K–12 STEM education suggests intriguing prospects for re-conceptualizing and restructuring K–12 education in general. With K–12 engineering curricula, teachers, and an emphasis on academic learning standards all entering the K–12 education arena from non-traditional vectors, a template for broader change could take shape, catalyzed by the introduction of engineering into the system. These high-stakes conditions for change make it all the more urgent that K–12 reforms under the banner of engineering and technology education yield tangible results.

## **PRE-SERVICE TECHNOLOGY TEACHER INNOVATION, PROFESSIONAL DEVELOPMENT, AND OUTREACH LEADERSHIP**

### **Re-engineering Technology Teacher Education**

A recent report from the National Academy of Engineering (Pearson & Young, 2002) recommends that universities transform teacher education programs to better prepare technology teachers. Technological literacy is seen as an important skill for all people in our increasingly complex technological society. Technology education will play an important role in developing students' technology literacy (Cunningham, Lachapelle, et al., 2005; Koehler, Faraclas, et al., 2005).

Lewis (2004), a technology educator, talks about the need to transform technology education by placing it in an historical context of a field moving from the blue-collar trades towards the white-collar professions. His concern is that technology education continues to make important contributions to the education of students while at the same time is accepted as a valuable topic for K–12 education. Later Lewis suggests that technology

education can be enhanced through cooperative efforts with engineering educators (Lewis, 2004; Lewis, 2005).

Clearly technology education is an important component of the K–12 curriculum. As the complexity of technology increases and becomes a more pervasive element of the entire work environment, technological literacy becomes a critical aspect of the education of all students. Therefore, new approaches are needed that expand the scope of technology education to broaden its appeal to students and better serve societal needs. Re-engineering technology teacher preparation to work with engineering educators will require careful thought, not just on the engineering science and content side of the equation, but to think carefully about transforming the pedagogical content knowledge technology teachers need to effectively integrate engineering into their classrooms.

### *Pedagogical Content Knowledge to Reflect Engineering and Technology Education*

Through the work of Shulman's (1986) *Knowledge Growth in Teaching (KGT)* project, pedagogical content knowledge (PCK) emerged. The focus of the project was on developing a model for understanding teaching and learning (Shulman & Grossman, 1988). The KGT project studied how novice teachers gained new understandings of their content, and how these new understandings interacted with their teaching. The researchers of the KGT project described pedagogical content knowledge as the convergence of three knowledge bases including subject matter knowledge, pedagogical knowledge, and knowledge of context. Subject matter content knowledge is described as knowledge that is unique to teachers and separated, for example, an engineering and technology teacher from an engineer. Similarly, Cochran, King, and DeRuiter (1991) differentiated between a teacher and a content specialist:

Teachers differ from biologists, historians, writers, or educational researchers, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. For example, experienced science teachers' knowledge of science is structured from a teaching perspective and is used as a basis for helping students to understand specific concepts. A scientist's knowledge, on the other hand, is structured from a research perspective and is used as a basis for the construction of new knowledge in the field (p. 5).

Geddis (1993) described pedagogical content knowledge as a set of attributes that help someone transfer the knowledge of content to others. According to Shulman it includes “most useful forms of representation of these ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others” (Shulman, 1986, p. 9).

In addition, Shulman (1986) asserted that PCK is made up of the attributes teachers possess that help them guide students towards an understanding of specific content in a manner that is meaningful. He further argued that PCK included “an understanding of how particular topics, problems, or issues are organized, presented, and adapted to the diverse interests and abilities of learners, and presented for instruction” (1986, p. 8). “The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students” (1986, p. 15).

Therefore, the intersection of engineering science (i.e., knowledge of engineering design) with teaching in technology education will depend on the ability of teacher educators and pre-service teachers to transform this knowledge into adaptive and engaging instruction. The use of PCK as a knowledge base for infusing engineering principles, content, and methods into the study of technology has yielded a desperate need for the field to produce a conceptual framework and taxonomy.

### *A Shifting Paradigm: Involvement of Schools and Colleges of Engineering in K–12 Education*

Engineering educators have long been active in K–12 education efforts. Several different approaches have been taken:

- Providing curriculum content for K–12 classrooms (Ross, Wheeler, et al., 2005; Walia, Yu, et al., 2006);
- Offering post-service teacher professional development (Lohani, Sanders, et al., 2005); and
- Having engineers delivering content directly into the classroom (Brown, Kavetsky, et al., 2006).

Recently, engineering colleges have become involved in preparing technology teachers in the pre-service environment. In the following sections we explore some of these existing approaches along with new efforts at creating collaborative approaches between technology educators and engineering educators.

The involvement of engineering colleges in teacher education is motivated by a range of factors including a perceived need to develop a pipeline of students to enter the engineering profession (Vallas, Richards, et al., 2006) as well as into other STEM majors (Madhally & Maase, 2006). Pipeline concerns have led engineering programs to explore ways to attract students by exposing them to engineering careers at an early age (Marshall, 2005).

Technology educators are becoming aware of this pipeline issue, as well as the need to prepare a more technologically literate citizenry (Bybee & Starkweather, 2006). The engineering and technology education communities have much to gain by working together on these common problems (Alpert, Isaacs, et al., 2005; Gattie & Wicklein, 2005; Genalo & Gilchrist, 2006; Hailey, Becker, et al., 2005; Hamann, Hutchison, et al., 2006; Lohani, Sanders, et al., 2005; Ollis, Kennedy, et al., 2005; Padmanabhan, Lin, et al., 2006; Reid & Feldhaus, 2005; Sparks, Kadekar, et al., 2005).

## **NOVEL INITIAL TEACHER PREPARATION MODELS**

Around the nation, several models have begun to emerge for preparing technology education teachers for initial certification as well as for professional development. These are being delivered in a variety of configurations in universities with and without engineering degree programs.

### **Engineering-based Model**

Colorado State University has created a joint education-engineering degree program between the School of Education and College of Engineering. One of the distinguishing features of this program is that students receive a nationally accredited Accreditation Board for Engineering and Technology (ABET) engineering degree in engineering science along with a nationally accredited National Council for Accreditation of Teacher Education (NCATE) technology education teaching license. The objectives of the program include:

- improving secondary education through highly qualified technology teachers;
- placing engineering graduates in the secondary classroom where they can encourage a more diverse group of potential engineering students at an early age;
- attracting a more diverse student population into engineering undergraduate programs; and
- better preparing students in science, technology, engineering, and mathematics (STEM) for entering into an engineering undergraduate program (Colorado State University, 2006).

The program requires four-and-one-half-years (or nine semesters). Students start with a traditional engineering program, including calculus, physics, and chemistry, along with engineering science courses. As they progress through the third and fourth years, education courses related to technology education licensure and practice in school settings are also taken to build the foundation for the pedagogical content knowledge required to teach in an engineering and technology education classroom. Students also develop depth in a traditional engineering discipline: chemical and biological, civil and environmental, electrical and computer, or mechanical engineering plus a fourth year senior design capstone experience in one of these disciplines. During the last few semesters, students are placed in Professional Development Schools (PDS) where they apply their engineering knowledge in an educational context with secondary students under the supervision of a university supervisor and a cooperating K–12 teacher. The educational program, built on a strong engineering foundation and pedagogy, culminates by placing students in a student teaching position or internship for one semester. This program produces graduates who have an ABET accredited degree, making them eligible for the Fundamentals of Engineering exam and qualified for licensure as secondary teachers—a unique combination of skills and credentials.

## **Hybrid Models—Universities with Engineering Programs**

Other technology teacher education programs have responded by enhancing the engineering content preparation of their pre-service teachers. The Department of Engineering and Technology Education in the

College of Engineering at Utah State University recently has made it a priority to hire engineering-educated faculty. Driven by an analysis of the technology teacher preparation curriculum, the program has added an engineering education block to the required curriculum, which now includes one course in engineering systems and one in principles of engineering for all program graduates. The infusion of engineering principles is also integrated into the technology content and pedagogy sequence to strengthen pre-service teacher pedagogical content knowledge. The Department of Engineering and Technology Education is also affiliated with *Project Lead the Way* (PLTW) and provides opportunities for students to become certified to teach selected PLTW courses. PLTW is a national commercial program that has developed a series of courses that, when combined with college preparatory mathematics and science courses in high school, introduces students to the scope, rigor, and discipline of engineering and engineering technology prior to entering college (Utah State University, 2006).

In January 2006, the technology education program at Virginia Tech began to offer its new “STEM Education” option at all graduate degree levels. The technology education program strives to prepare a new generation of leaders and scholars from (and for) each of the STEM education disciplines. The program requires students to complete a cognate in one of the STEM disciplines that includes engineering. The focus is on interdisciplinary research, teaching, and leadership at the graduate level. The program information states:

The findings of cognitive science, the national curriculum and accreditation standards, and our increasingly “flat world” make it clear that tomorrow’s STEM education leaders must better understand these interdisciplinary connections. Our new STEM Education degree options seek to provide this critically important foundation. This option includes courses such as “STEM Education Foundations,” “STEM Education Pedagogy,” “STEM Education Research,” and “STEM Education Trends and Issues,” as well as STEM Education Intern/Externships.” (Virginia Tech, 2006)

The STEM emphasis at Virginia Tech is designed to remove the silos of understanding that often separate the STEM disciplines by weaving together in an innovative graduate program that emphasizes the foundations, pedagogy, research, trends, and issues in STEM education.

In 2005, the University of Arkansas sought to hire a new technology teacher educator with the purpose of designing a new technology teacher education program that would integrate engineering and technology into the pre-service preparation program. Similar to other hybrid programs, cooperation and course content from engineering were integrated into the plan. Students take introduction to engineering, engineering design, manufacturing systems design, mechanical engineering principles, and bio-engineering design studio in regular engineering courses offered and delivered by the College of Engineering. This high level of cooperation and curricular integration supports the incorporation of engineering design principles into the pre-service preparation of technology teachers (University of Arkansas, 2006).

## **Hybrid Models—Universities without Engineering Programs**

Technology teacher education programs at universities that do not have engineering programs are currently weighing curricular options that would enable them to deliver technology teacher pre-service education with an engineering content component. In some instances universities without engineering programs, like Illinois State University, have partnered with engineering faculty at a university in the area to enhance technology teacher preparation. Additional options being considered include an assembly of curricular and faculty professional development choices that include *Project Lead the Way* training and courses, collaboration with the International Technology Education Association's Center to Advance Teaching Science and Technology (ITEA/CATTS), and other funded projects. Each of the options under consideration will require an intensive faculty professional development to equip current technology teacher education faculty to teach engineering concepts and methods.

Technology teacher education programs that do not have formally trained engineering faculty on their campuses face some unique challenges. One of these has to do with the knowledge of the engineering discipline. Shulman (1986) argues that teachers need to understand subject matter deeply and flexibly so they can help students create useful cognitive maps, relate one idea to another, and address student misconceptions.

A significant question arises: Does a non-engineering educated technology teacher education faculty possess the depth and breadth of engineering knowledge needed to achieve the level of teaching and learning that Shulman asserts is required?

Research with science teachers (Hashweh, 1987) reinforces the importance of discipline-specific content knowledge. The Hashweh study clearly demonstrated the close connection between (a) disciplinary content knowledge, and (b) the quality of instruction, selection, and deployment of pedagogical techniques, and understanding of learning misconceptions. Within their own fields, teachers were more sensitive to subtle themes presented in textbooks, were able to modify material based on their teaching experiences, and were more likely to discover and act on student misconceptions. The teachers used about the same number of examples and analogies when planning instruction in both fields, but those analogies and examples were more accurate and more relevant in the teachers' field of expertise. This research has profound implications for engineering-oriented technology education. In order for these programs to be successful, the critical issue of engineering and science content deficiencies (with both faculty and students) must be addressed. Could the results from the study conducted by Hashweh be supporting the theoretical assertions regarding teacher content knowledge and PCK made by Shulman? If so, this could be a telling indicator of what to expect when technology teacher educators and indeed technology education pre-service teachers are asked to infuse engineering into their instruction without the in-depth and flexible content knowledge.

While the undergraduate- and graduate-level technology teacher education program models do not represent all possible models of delivery, they represent the common direction that was presented in the introduction of this chapter. These include forces of change from both inside and outside technology teacher education that have influenced the evolution of programs. The consensus-building and forging of alliances between technology teacher educators and our partners in other STEM disciplines serve to catalyze program innovation, risk-taking, and change. Yet the process of preparing technology teachers to infuse engineering into the teaching of technology is not complete without careful consideration of enormous professional development and outreach needs in the K–12 community.

## **PROFESSIONAL DEVELOPMENT AND OUTREACH: INFUSING ENGINEERING INTO K–12 EDUCATION**

The challenge of providing quality professional development for teachers has a long history, particularly in disciplines where the content knowledge and pedagogy are changing rapidly. In addition to fostering collaboration and collegiality, professional development provides a mechanism for motivating teachers to learn more about their field and how to teach it. Professional development is particularly imperative for engineering and technology professionals. As practice-oriented fields, both engineering and education require professionals to hone skills and build knowledge throughout the course of their careers in order to advance and in some cases, to maintain their employment. In fact, preparing engineering graduates to engage in life-long learning is a required outcome for program accreditation.

Specific features of delivering high-quality K–12 engineering instruction make professional development particularly important. The education policy environment seems to be changing more quickly and making more demands on the K–12 system than teacher training programs will be able to respond to. In Massachusetts, where engineering and technology have been part of the K–12 curriculum frameworks since 2001, educators report that the biggest challenges in implementation have been with preparing teachers to meet the requirements of the revised frameworks. With many other states embarked upon similar reforms to their standards of learning, the need for teachers able to deliver classroom instruction in engineering and technology fields unlike what they learned in college will become increasingly common.

The capacity of the current teacher pool, working with available textbooks, to teach technical areas in the ways that policy-makers are envisioning is a matter of some doubt. Research shows that teachers, especially elementary teachers, feel less confident and have less knowledge about the physical sciences and mathematics than other areas in which they provide instruction. These deficiencies can translate into a de-emphasis of mathematics and science as well as an inability to help students understand and experience the exciting and interesting applications in engineering and technology fields.

## **Collaborative Partnering Required**

What are the most significant challenges that must be addressed by the providers of professional development for teachers who want to or are required to integrate engineering and technology into their classroom work? How can these challenges be addressed in a manner that is grounded in a large body of professional development research, which addresses the cognitive aspects of professional development and the need for solid assessments of actual practices?

The content of professional development activities should build on existing areas of knowledge that teachers bring with them into the enterprise. Engineering lends itself to such learning because it builds on the science and mathematics knowledge that many middle and high school teachers already possess. Furthermore, the content of much engineering-based professional development consists of teaching design, which lends itself to creative, engaging, and collaborative activities. Experiences with design enable students to find their own way towards one of many workable solutions to a problem. This open-ended application of content, familiar to technology and engineering teachers, has great potential for enhancing learning in mathematics and science courses. Because the content of the classroom design activities can often be drawn from existing mathematics and science materials, it becomes easier to map these activities to mandated standards of learning.

As technology and engineering teachers gain mastery of engineering content and techniques, performance expectations can be raised, both for them and for their students. However, it is apparent that technology teachers and technology teacher educators will need to work closely with their engineering partners in industry and engineering faculty to accurately identify the professional development needs of the field. Consequently, incorporating methods of assessing and recognizing achievement in professional development activities will become ever more important in the future.

## **The Role of Professional Development**

Exemplary professional development is a long term effort, requiring careful attention to sequencing activities. It depends on stakeholder buy-in from all sides and demands a careful balance of complex intellectual, interpersonal, policy, and curricular elements. Not surprisingly, the prevailing

models of successful professional development in engineering and technology education have developed into substantial activities in their own right. Many universities offer master's degree programs incorporating all these elements, such as Michigan Technological University's "MS in Applied Science" and Hofstra University's "MS in Mathematics, Science, and Technology Education." Both of these programs offer courses in engineering and technology content as well as pedagogy.

Other providers also offer sustained, group-based professional development, though not necessarily through a degree program. Often these programs are integrated into a portfolio that also includes pre-service teacher training programs and outreach activities. Iowa State University and Pennsylvania State University offer examples of such professional development activities with a record of success and durability. Non-university based professional development providers are becoming increasingly active in this area. As a key part of off-the-shelf curriculum programs, professional development features prominently in both *Project Lead the Way* and the *Infinity Project* programs, which many school districts have adopted as a way to make electives in engineering and technology available to students.

## **The Role of Outreach**

Outreach programs serve a range of purposes much more diffuse than the teacher-focused pre-service and in-service training programs. Designed generally to stimulate interest in engineering and technology as well as to encourage students to pursue additional knowledge and experience, outreach activities take a wide range of forms. Among these are Web sites, public relations campaigns, regional and national student competitions and summer camps, guest speakers, and much more. Providers of outreach activities reside both inside and outside of academia and offer activities for a variety of audiences including prospective students, engineering and technology professionals, policy-makers, the general public, and members of the media. Because outreach activities also represent a chance for providers to advance their own organizations' or constituents' profile within engineering and technology, the activities often are designed to serve multiple interests beyond general awareness. The variety of shapes and purposes can make it difficult to evaluate or even make sense of outreach as a coherent field of activity; but it is widely practiced by stakeholders in all areas of engineering and technology.

The motivation of engineering and technology organizations to engage in outreach activities stems from a conviction that public awareness of the fields is deficient. For example, many technology educators are concerned by the general public's association of technology with computers and other "high tech" devices; thus the need for outreach to clarify the differences and promote the broader concept of technological literacy. Cooperation with the field of engineering helps to clarify the broader influence of the study of technology. Deficiencies in public awareness tend to discourage students from pursuing study and careers in technology and engineering. Misinformation also yields uninformed public debates about policy issues shaped by technology-related issues, produces disproportionately few technically sophisticated government leaders, and leads to generally poor comprehension and regard for engineering and technology professionals. This is particularly unfortunate, given the enormous contributions that engineers have made to our standard of living, economic capacity, health care, environmental management, national security, and a host of other public goods. The public's attitudes and knowledge about engineering strike many in the field as out of step with reality. In fact, both the National Academy of Engineering and the National Science Foundation have gathered data documenting alarming levels of public ignorance or misunderstanding about technical and scientific issues. This information provides substantial quantitative evidence supporting the need for engineering and technology outreach activities. The effectiveness of these types of outreach activities will ultimately hinge on well documented and credible assessment of outreach activities.

The range of activities that can fall under the heading of outreach is enormous. Recently, for example, elaborate, expensive, and high-profile outreach activities have emerged from the efforts of Northrop Grumman and Intel, two companies urgently concerned with the future supply of engineers in the U.S. workforce. Northrop Grumman sponsored a program called "Weightless Flights of Discovery," in which teachers from across the United States and around the world take a flight aboard a parabolic or "zero-gravity" aircraft that creates temporary weightlessness comparable to what humans would experience during space travel to the moon or Mars. Intel is a prime backer of a live-action children's television show called *Design Squad*. On this show, teenagers compete to design and build all manner of machines, from peanut-butter-and-jelly-sandwich-making machines to race cars. The award is a \$10,000 college scholarship from the

Intel Foundation to study science, engineering, math, or technology. At the other end of the spectrum, countless individual engineers and engineering faculty members volunteer time and energy in local classrooms to convey the excitement and rewards they get from their work with teachers and students. This form of outreach can consist of anything from public speeches or presentations, to providing assistance with in-class projects and activities, to going on field trips to their home institution.

A number of agencies and organizations are targeting their outreach activities at the K–12 level. In a 2002 National Academy of Engineering survey, over 80 percent of organizations active in outreach were conducting activities directed at K–12 students and nearly 60 percent addressed programs to K–12 teachers. This preference for K–12 audiences was consistent across all types of organizations operating outreach programs, including engineering societies, industry, colleges and universities, museums, government agencies and laboratories, and other non-governmental organizations. Driven generally by a concern over where the next generation of engineering students and professionals will come from, organizations involved in outreach devote the bulk of their efforts to conveying the fun, excitement, and importance of engineering to K–12 audiences. Other audiences include the general public, engineering professionals, thoughtful leaders in government and the media, and other education audiences. However, K–12 work attracts the greatest interest in the field.

Outreach activities can be organized into communications activities, resource development, and in-person promotion or information activities. Electronic and print publications, direct mail, and advertising or sponsorship activities serve to reach large numbers of people with messages about engineering, typically meant to draw attention and highlight the fun or the rewards of the field. One high-profile example of such an outreach activity is the American Society for Engineering Education's *Engineering, Go For It!*, a guidebook to engineering for high school students with over one million copies in circulation around the U.S. Outreach also can deliver educational resources and services that supplement in-class activities or stand alone as extracurricular activities. A multi-university partnership called "Teach Engineering" offers online K–12 engineering education curriculum modules, mapped to state and national standards and open to postings of new lessons from educators with K–12 engineering materials to contribute (Teach Engineering, 2007). The Museum of Science in Boston operates the National Center for Technological Literacy, which

produces effective elementary engineering education materials and conducts outreach to teachers. Engineering societies often excel at preparing their members to visit schools and deliver messages to inspire students to consider engineering as a field of study and work. The culmination of these activities occurs annually in February with National Engineers Week, a large-scale collaboration among societies, industry, and government agencies seeking to promote engineering to K–12 communities, combining publicity activities, educational activities, meetings and media presentations, and other events designed to showcase engineering and technology across the country.

As a vehicle for directly addressing teachers, outreach offers a different set of opportunities that are distinct from pre-service and in-service education programs. Much less bound by institutional or scholarly constraints, outreach can deliver a great variety of messages, with content that can range from ambitiously academic to whimsical and entertaining. These freedoms allow organizations to exercise creativity and imagination in how they frame engineering and technology, calibrated to different audiences' potential interests in the field.

These freedoms can also yield an array of, at times contradictory, messages to recipients, especially if they are targets of multiple organizations' outreach efforts. Organizations view outreach as an opportunity to promote their unique agenda relative to the broader engineering and technology world. Disciplinary engineering societies, industry sectors, like information technology and aerospace, and government mission agencies (defense, energy, etc.) are frequently under pressure to promote their specialized niches within the country's engineering and technology enterprise. Non-technical audiences (particularly at the K–12 level), rarely possess the expertise or sophistication to make meaningful distinctions among technically based varieties of engineering and technology activities. As a result, outreach activities that employ the jargon of a field or promote one sub-discipline over a general message about engineering and technology can fall on deaf ears. The 2002 study by the National Academy of Engineering entitled "Raising Public Awareness of Engineering" estimated, for example, that stakeholders in engineering had spent nearly \$400 million on outreach activities (David & Gibbin, 2002). At the same time, enrollments in undergraduate engineering programs reached a low point in the late 1990s (to approximately 6% of all degrees earned), compared to nearly 8% in the late 1980s. In addition, the general public's esteem for

engineers remained very consistent in national surveys. While the study does not attempt to correlate specific particular outreach practices with outcomes, the findings are worrisome, particularly during a time when the fruits of high technology have enjoyed such prominence in the media and in people's home and work lives.

The apparent disconnect between outreach efforts and demonstrable outcomes highlights one of the primary criticisms that funders, operators, and audiences of outreach programs regularly issue. Reliable, systematic assessment of outreach is almost non-existent. For individual organizations, assessment is difficult and can cost money that would otherwise go into developing or improving programs. One of the major barriers to improved assessment is the diversity of activity in the field. The development of protocols capable of assessing diverse outreach efforts is daunting.

## **CONCLUSIONS**

Innovations and changes to teacher training programs and outreach activities in engineering and technology education are assuming many forms. As these efforts continue to evolve, it is critically important that educators and other stakeholders carefully monitor their outcomes in order to insure their success. STEM education is currently assuming a higher profile as a public policy issue as high-tech workforce demands, globalization, economic competitiveness, and security threats emerge in interconnected and frequently unpredictable ways. Renewed emphasis on the linkage of STEM education to a country's national science and technology enterprise, similar to what happened in the post-Sputnik era of the 1950s and 1960s, means new, different standards and expectations will be shaping the development and delivery of instruction in these fields of study.

For traditional stakeholders, this represents a time of both challenge and opportunity. A subtext throughout this chapter has been the urgent need for educators in the engineering and technology fields to find common cause in framing their contributions to STEM education as central to enhancing teaching and learning in the classroom. Moreover, engineering and technology educators must be making this case, in unison, to the larger audiences now paying attention to STEM education issues in order to earn the recognition, and attendant resources, allotted to groups playing pivotal roles in activities of vital national interest. A broad, inclusive message reflecting the principal tenets of an engineering and technology

education, delivered effectively and widely, can both spark internal reform within institutions of education as well as inspire a widespread appreciation of how engineering and technology educators serve interests and causes far beyond their immediate horizons.

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## INTRODUCTION

Over the past ten years, engineering has greatly increased its interest in K–12 education, primarily through mathematics and science education. At the same time, technology educators have developed national standards for K–12 education that include engineering content. It is reasonable, therefore, to assume that engineering and technology education would both benefit from working together in the K–12 arena. Currently there are few examples of engineering and technology education working together to provide engineering content to K–12 students. The purpose of this chapter is to examine the question, “How can technology education be valued by the engineering community as a key component in delivering engineering instruction to K–12 students?”

Broadly defined, the engineering community consists of professional engineers working in private practice, industry, and government, and engineering educators at universities. The National Academy of Engineering (NAE) and engineering professional societies are significant representatives of the engineering community. A starting point for technology education to develop connections with the engineering community is with an assessment of the engineering community’s interests in K–12 education. Therefore, the first section of this chapter provides a historical overview, as well as a contemporary assessment, of the primary interests of the engineering community in K–12 education. Next, a business model is proposed as a strategy for understanding existing successful connections and to guide developing future connections with the engineering community. The third part of the chapter describes several successful partnerships between engineering and technology education, providing insights into factors that contribute to these successful connections. The chapter concludes with a discussion of the opportunities and challenges for technology education in developing connections with the engineering community, focusing on engineering education for K–12 students.

## **THE ENGINEERING COMMUNITY INTEREST IN K-12 EDUCATION**

Engineering has been interested in working with K-12 education in promoting technological literacy for over 30 years. In the early 1960s, with NSF support, a course entitled the "Man Made World," was developed by the Engineering Concepts Curriculum Project as an attempt to introduce technological literacy concepts to grades 11-12 (David & Truxal, 1971). The initial concepts were formulated by engineers and high school science teachers, and subsequently refined by practicing engineers and scientists, engineering educators, and secondary school science teachers and administrators. The course was well received with enrollments doubling each year. During the 1970-71 school year, the "Man Made World" course was offered to nearly 15,000 students in over 300 secondary schools. David and Truxal (1971) noted that "lack of a home department is the greatest handicap to wide adoption of the program in school systems. Closely associated with this is the lack of suitable teachers" (p. 929). It is interesting to note that the concerns of David and Truxal regarding the lack of a home department and suitable teachers remains an issue for some members of the engineering community who are grappling with a home for K-12 engineering education in this century.

In addition to technological literacy, the engineering community has shown interest in working with K-12 schools for over 50 years as a means to attract young people to the engineering profession with an emphasis on increasing the number of women and minorities in the profession (the pathway problem). The Junior Engineering Technical Society (JETS) was established over 50 years ago to inform pre-college teachers and students about engineering (Coppula, 1997). By the mid-1970s, professional engineering schools, professional societies, and industry were approaching the pathway problem in a variety of ways, including: providing career information to parents, guidance counselors, and science and mathematics coordinators; providing demonstrations and hands-on engineering experiences in schools; and providing special summer or weekend programs (Burks, 1975; Conliffe, 1974; Popovics, Popovics, & Johnson, 1974; Toba, 1975). In examining the work of the engineering community in the 1970s, it can be seen that they were comfortable working with math and science teachers; however there was no mention of working with industrial arts teachers.

In the mid-1980s, the knowledge and skills required for professional engineering changed as the United States shifted from Cold War defense competition to commercial competition on a global scale. “As the twentieth century nears its close, the world of engineering work is undergoing dramatic change. American technology, preeminent after World War II, is being challenged by foreign competitors” (Bucciarelli & Kuhn, 1997, p. 210). As the work of professional engineers shifted, pressure was placed on higher-education engineering programs to prepare “graduates with stronger skills in communication, teamwork, knowledge integration, and economic understanding, in addition to sound technical competencies” (Prados, 1998, p. 2). K–12 engineering education has received increasing emphasis in response to pressures to compete in a global economy. As evidence of the growing interest in K–12 engineering, an electronic literature review in the Institute of Electrical and Electronics Engineers (IEEE) database covering the period from 1980 to 1990 using key words “education” and “K–12” or “high school” revealed 10 articles, mostly proceedings from Frontiers in Education conferences. The same literature review conducted from 1990 to 2000 revealed 100 articles, an increase by a factor of ten.

Currently, the engineering community is interested in working with K–12 education in support of technological literacy, mostly at a national level. With leadership from William Wulf, the National Academy of Engineering (NAE) undertook the cause of technological literacy and developed a report directed at a broad community including schools of engineering and K–12 education (Pearson & Young, 2002). The National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) believed in the importance of technological literacy and provided funding for the development of the *Standards for Technological Literacy* (ITEA, 2000). The NAE continued to show support for technological literacy and completed a formal review of the *Standards for Technological Literacy* (STL), as did the National Research Council.

Further evidence of the engineering community’s interest in technological literacy is the Summit of Deans of Education and Deans of Engineering organized by IEEE (Sechrist, Batchman, Feisel, Gmelch, Gorham, & Stoler, 2002). Among the collaborative activities proposed by attendees of the summit was a proposal to integrate engineering concepts in K–12 schools by requiring engineering courses and expanding the engineering/education role in promoting technological literacy.

The National Academy of Engineering sponsored a futuring project to determine the knowledge and skills needed by engineers in the year 2020. One of the recommendations of the NAE's *Engineer 2020* Project is for the engineering education community to participate in a "coordinated national effort to promote public understanding of engineering and technology literacy of the public" (National Academy of Engineering, 2005, p. 57). It is important to note that Ollis and Pearson (2006) point out that the engineering community appears to be interested primarily in design thinking and problem solving within the broader topic of technological literacy.

The establishment in 2004 of the American Society for Engineering Education (ASEE) K-12 Division was a significant event in the history of the engineering community's involvement with K-12 education. The goals of this new division encompass many aspects of K-12 education.

This group strives to provide a focus for development of innovative K-12 engineering education curricula and delivery approaches and a forum for the presentation and sharing of K-12 engineering educational initiatives and methods; to create a vital community engaged in K-12 engineering initiatives; to encourage the professional development of teachers in K-12 engineering education methodologies; to increase awareness and participation of university faculty and industrial educators/partners in K-12 engineering initiatives; to promote engineering as the context to integrate science and mathematics with all subjects in the K-12 setting; to encourage the participation of K-12 educators in the creation and delivery of K-12 engineering content; and to synthesize and broadly disseminate lessons learned. (ASEE K-12 Division, 2006).

Clearly, the engineering education constituents within the broader engineering community feel there is a direct role for involvement in K-12 education.

The pathway to engineering problem has received considerable attention from the engineering community in the 21st century. The ASEE magazine, *Engineering, Go for It!* is a comprehensive guide to careers in engineering and technology written for an audience of high school students and parents from multiple populations. Two editions have been distributed to high schools and universities across the country. Again, to provide effective career-related information, professional engineering societies have pre-college links on their websites that support K-12 teachers, students, and parents including career information and curriculum

materials. The National Academy of Engineering and several government agencies, including NASA, have also developed Web sites that contain K–12 outreach materials. The K–12 component of the Integrated Teaching and Learning (ITL) program at Colorado University, Boulder, is an example of a program that was initially developed to create a pathway for students into the College of Engineering and Applied Sciences at CU-Boulder and to improve technological literacy as well (Sullivan, Davis, DeGrazia, & Carlson, 1999). The program has grown to include professional development for teachers, and leads the development and expansion of the *TeachEngineering.com* digital library, an online, standards-based curricular resource for K–12 engineering. A description of many other K–12 engineering initiatives can be found in Chapter 9.

In summary, an examination of the historical and current involvement of the engineering community in K–12 education points to two primary areas of interest: a) technological literacy for all students with an emphasis on problem solving and engineering design, and b) increasing the number of high school students with both abilities and interests in entering professional engineering programs in higher education, especially the number of female and minority students.

## **MARKET PULL AND TECHNOLOGY PUSH**

Technology education provides opportunities for the engineering community to value it as a key component of early engineering education for K–12 students. However, to take advantage of these opportunities, challenges have to be addressed. One of the significant challenges is that technology education has not been viewed historically as a provider of early engineering education. Mathematics and science education has been “pulled” into teaching engineering, often reluctantly. The opposite is true for the technology educators who have to take the lead and “push” their way into the engineering community.

One way for technology education to think of “pushing” connections with the engineering community is to look at a business model of “market pull” and “technology push.” The “pull” approach requires identifying a market need and then developing a new product to meet the need. The “push” approach requires interesting the market in a new product based on a new solution. Business has learned that successful pushes require senior management involvement, research and development, and taking the product to test

markets early, and that end users have to be taught the benefit of the product. Technology push companies need cash reserves in case the newly-developed product does not have a market. In a technology-driven marketplace, the end users usually have no idea that the product will benefit them and the technology developers must educate the end users on the value of the product (Himmelfarb, 1992). For technology education, a successful push will require the involvement of key stakeholders from the engineering community, research into the educational impact of K–12 engineering experiences, successful examples in place showing the benefits of partnerships with technology education, “investors” with cash reserves, and a continual dissemination effort to let the engineering community, parents, and school districts know of the benefits of K–12 engineering experience.

## **SUCCESSFUL CONNECTIONS**

Selected examples of successful partnerships between engineering and technology education are presented in this section. These examples can be viewed through the technology push model described above. The Massachusetts Science and Technology/Engineering Standards is a good example of a “push” where engineering played a role as a key stakeholder, partnering with technology education, to push engineering into K–12 education. The following examples demonstrate several successful “pushes” where the National Science Foundation has provided the investment dollars necessary to develop relationships between engineers, technology educators, and K–12 engineering experiences.

### **Massachusetts Science and Technology/Engineering Standards**

One of the success stories in developing effective connections between the technology education and engineering communities was the development of the Massachusetts curriculum framework in science and technology/engineering. The Science and Technology/Engineering framework derives from two reform initiatives in Massachusetts: the Education Reform Act of 1993 and Partnerships Advancing the Learning of Mathematics and Science (PALMS). Since 1992, the PALMS initiative has been funded by the National Science Foundation in partnership with the state and the Noyce Foundation. The initial science and technology framework was approved in 1995 and was implemented at the high school level. Groups of technology/

engineering educators contributed to the development of a comprehensive set of core standards for technology/engineering courses at the high school level. The 2001 framework articulated standards for full-year high school courses in Earth and space science, biology, chemistry, introductory physics, and technology/engineering, making an effective connection between technology education and engineering (Massachusetts Department of Education, 2001).

The 2006 revised Massachusetts science and technology/engineering curriculum framework calls for the highest quality engineering high school courses. High school courses should provide students with opportunities for hands-on experiences to design, build, test and evaluate (and redesign, if necessary) a prototype or model of their solution to a problem. Students should have access to materials, hand and/or power tools, and resources needed to engage in these tasks. Students might also engage in design challenges that provide constraints and specifications they must consider as they develop a solution (Massachusetts Department of Education, 2006).

### *A State Model for Technology Education*

A major proponent of including technology education in the Massachusetts framework was Ioannis Miaoulis, former Dean of Engineering at Tufts University and current president of the Boston Museum of Science. In 1997, after observing a science classroom, he noted a curriculum that contained much about flowers and rocks and nothing about the science of everyday things such as planes and power plants. As a result, in that same year, Miaoulis started a statewide campaign to introduce engineering concepts into schools, making him a passionate advocate for technological literacy.

In 1998, Miaoulis was appointed to the Commissioner's panel that revised the Massachusetts state standards, and he saw the opportunity to improve the state curriculum. He reached out to the state's association of technology education teachers, many of whom had been losing jobs as schools closed down construction and automotive shops to fund computer labs. Miaoulis indicated that going to science teachers did not seem like a good idea because teachers that were secure in their positions would not see a need to change. "If I partner with technology education teachers, and make the case that adding engineering could upgrade their whole profession, and save their jobs, I'd have the backing of that entire community" (Bhattacharjee, 2006, p. 1237).

It did not go smoothly. Many technology education teachers without engineering degrees worried that they would be left behind. Others thought that science teachers would be asked to carry the load because of the strong math and science foundation needed. State officials did try to throw technology out of the standards, arguing that shop skills such as metalworking and woodworking did not fit with higher level academic standards. Miaoulis convinced them that technology education would become as academically relevant as physics when blended with engineering. David Driscoll, Massachusetts education commissioner, noted that “He showed a lot of political savvy during the process. He made a connection with people from the governor to state education officials and he was relentless in a nice way. He sold engineering to us in a way that demystified it and made a compelling case for teaching it to kids from an early age” (Bhattacharjee, 2006, p. 1238). As a result, technology education personnel participated in the development of the framework.

### *Technical Difficulties*

Though the documented successes with pre-college engineering in Massachusetts have been shared with hundreds of politicians and school administrators throughout the country, no state has yet followed Massachusetts’ lead. Even within the state, most middle and high schools have been hard-pressed to implement the new standards. One hurdle is the lack of clear guidelines in the standards and the absence of curricular materials for the middle school grades. James Surowski noted that “In the 185 days available during our school year, an eighth-grade science teacher already has to cover the Earth’s history, change in ecosystems over time, the Earth and the solar system; ... the list goes on. We can’t hire a specialty engineering teacher who must make time for technology topics as well” (Bhattacharjee, 2006, p. 1237). Some Massachusetts teachers worry that many high school students may not have a sufficient foundation in mathematics and physics to benefit from the engineering course. “We’re currently designing a model deck for which students need to calculate live loads and dead loads, which requires algebra,” noted Richard Skrocki of Shepherd Hill Regional High School, who is implementing the high school engineering course developed by the National Center for Technological Literacy (NCTL). “I can see that some of my students who are weak in math are having difficulty. But I don’t have the time to teach them algebra before proceeding with the class” (Bhattacharjee, 2006, p. 1237).

## Successful NSF Projects

The National Science Foundation (NSF) has emphasized the importance of developing connections between engineering and K–12 education programs through various program solicitations. There are several good examples of successful relationships that have been developed between engineering, technology education, and K–12 education because of the availability of NSF funds to support the relationships.

The Bridges for Engineering Education (BEE) program was a collaborative effort between the Directorate for Engineering and the Directorate for Education and Human Resources. The program provided an opportunity to develop projects that would improve engineering content in K–12 education. Wicklein and Thompson (2007) provide a good example of a technology educator teaming with an engineer in response to the BEE program solicitation. They were funded to develop the “University of Georgia—Summer Engineering Education Institute” a summer workshop for 12th-grade students that focused on the integration of engineering content with mathematics, science, and technology education. One of their important goals was to stimulate the inclusion of engineering content within the public school curriculum. Unfortunately, the funding for the BEE program was not continued by NSF, thus Wicklein and Thompson were only able to complete a single summer workshop.

Another program funded by NSF was the Centers for Learning and Teaching (CLT) with a goal to enrich and diversify the national infrastructure for instruction in K–12 science, technology, engineering, and mathematics education. A team of technology educators and engineering educators collaborated to develop a successful proposal to obtain CLT funding for the National Center for Engineering and Technology Education (NCETE) (Hailey, Erikson, Becker, & Thomas, 2005). NCETE engineering and technology education partners have successfully recruited two cohorts of doctoral students to become the next generation of leaders in understanding the learning and teaching of engineering-infused high school technology education. NCETE engineering and technology education faculty have partnered to develop and present four doctoral-level core courses on the theoretical framework for engineering education in high schools. Technology education and engineering faculty have also developed research-based professional development for high school teachers in sites across the country. One of the goals of NCETE is to

sustain the connections developed between the engineering and technology education communities beyond the life of funding by intentionally developing a community of scholars that focus on research in learning and teaching engineering design concepts in high schools.

## **OPPORTUNITIES FOR DEVELOPING CONNECTIONS WITH ENGINEERING**

An examination of the historical and current involvement of the engineering community in K–12 education points to two primary areas of interest: a) technological literacy for all students that emphasizes problem solving, engineering design and engineering content, and b) increasing the number of high school students that major in engineering in higher education, especially the number of women and minority students. Technology education needs to employ strategies of the “technology push” business model to demonstrate that it has the obvious solution to satisfy the first interest area of the engineering community: technological literacy for all students. Technology teacher education programs prepare teachers that can teach standards-based technological literacy to K–12 students. Technology education has an opportunity to develop connections with the engineering community by bringing the importance of technological literacy into focus at a state and local level. This could be accomplished by technology educators hosting regional equivalents to the IEEE Dean’s Summit described earlier. Technology education program leaders and state superintendents could be paired with engineering leaders from the National Academy of Engineering and industry in a summit format to discuss options for preparing K–12 students for an increasingly technological world. Planning for the regional summits could be facilitated by CTTE and the K–12 Division of ASEE in order for summits to occur across the country. An added bonus of a jointly sponsored CTTE and ASEE summit would be the increased understanding of each community by working together.

Technology education must continue to engage in organized regional and national campaigns to inform the engineering community of the role of technology education in providing K–12 engineering education. Technology education has developed core concepts that are unique to engineering and appropriate for high school technology education (see Chapter 3). These concepts must be shared with the engineering community at national meetings, through various kinds of dissemination, and in regional face-to-face

meetings with key stakeholders in the engineering community. Technology education must disseminate information about the realities of the middle school and high school curriculums. There is an opportunity to pursue technology education as a logical provider of K–12 engineering education since science programs at the junior and senior high school levels already have a very tight curriculum. With the national science standards requiring teachers to follow a scripted curriculum, it can be difficult for the discipline to find time in the curriculum for engineering. Laura Bottomley, past president of the American Society for Engineering Education’s K–12 division, notes that “we have trouble getting schools to teach science, let alone engineering” (Bhattacharjee, 2006, p. 1238).

Technology education, on the other hand, has room in the curriculum for engineering. There is also opportunity to point out the similarities between engineering and technology education with regard to design and problem solving (Dugger, 1993). The NAE/ITEA brochure “Hey Mom, I Want To Be An Engineer” is a good example of how technology education can disseminate information about its role in providing engineering and technological literacy to K–12 students. Additional materials that are targeted to the engineering community will help position technology education as the provider of engineering experiences in K–12 schools.

One of the key lessons learned from the development of engineering/technology standards in the state of Massachusetts, and from the “technology push model,” is the importance of an engineering champion. Ioannis Miaoulis is a passionate advocate for technology education in the context of K–12 engineering education. Without a doubt, there are deans of engineering in other states that have the same passion for introducing engineering into K–12 schools. Deans can also demystify engineering and build the base for teaching the subject in K–12 education. Technology education has to cultivate relationships with deans of engineering in each state to become champions for engineering experiences at the K–12 level.

Similar to mathematics, where mathematicians are the disciplinary faculty for mathematics education, technology education could promote engineering as the disciplinary faculty for technology education. This is a relatively new idea that could borrow some of the lessons learned from the math and science education community and how they are or are not valued by their disciplinary faculty. The relationship between the disciplinary faculty in engineering and technology education has to be developed with mutual respect for the other’s abilities.

The very best opportunity for technology education to be valued as a key component of the engineering education of K–12 students is to solve the pathway problem. Since the 1970s, the engineering community has tried a number of approaches through K–12 education to increase the diversity of students entering professional engineering programs at universities, and it has not been successful. Since technology education is often required in middle school, there is a tremendous opportunity to reach students at an early age with the appropriate materials and pedagogy to excite them about taking additional courses in engineering in high school. Students who are introduced to engineering and technology education in the middle grades and high school can decide—prior to college—whether they are interested in engineering-related careers (Southern Regional Education Board, 2001).

One of the keys to solving the pathway problem is to understand how all students learn engineering and technology concepts. In fact, one of the “needs” of the engineering community that technology education can meet is to develop strong research programs. To date, the engineering community has not spent much time conducting research in how students learn design and problem solving, how to assess student learning, and how to best prepare teachers. Technology teacher educators have access to K–12 teachers and students and the knowledge and skills to design and conduct research studies to understand learning, assessment, and teaching. Turning to the “technology push model,” technology education must become the leader in research into the educational impact of engineering experiences on all populations in order to demonstrate the value of the product.

Currently, technology education does not have a strong reputation for attracting multiple populations in its current high school programs, nor in conducting research about learning and teaching. However, technology education is well positioned with the necessary background in research methodology, and access to students and teachers, to change this situation. Both the engineering community and technology education would gain by developing new approaches to instruction based on principles of learning gained from cognitive science and to provide evidence of their usefulness in educational settings.

A critical component of the “technology push model” is cash reserves in case the “product” ultimately does not have a market. The field of technology education is hardly awash with cash reserves; however, there are

opportunities to compete for funding that would provide the necessary research to demonstrate the value of the “product” and to bring it to market as soon as possible. Funded projects can be utilized to stimulate discussion in developing and planning of future engineering outreach activities in ways unfunded projects cannot (Rushton, Cyr, Gravel, & Prouty, 2002). NCETE has benefited from funding that supports teams of engineering educators and technology education faculty to work together. It appears these relationships will endure beyond the lifetime of funding, but might not have formed originally without funding.

Engineering education at the K–12 level has received funding from various organizations over the years, especially the National Science Foundation (NSF). Today, NSF places its emphasis on research, preparing the next generation of science, technology, engineering and mathematics (STEM) professionals and developing a robust research commitment to conduct rigorous research and evaluation. In addition, NSF supports excellence in STEM education that integrates research and education, and increases the technological, scientific, and quantitative literacy of all Americans (Haney, 2006). A successful program funded by NSF is the Graduate Teaching Fellows in K–12 Education (GK–12). The GK–12 program, initiated in the late 1990s, spawned the development and classroom testing of quality K–12 engineering curricula in more than 20 engineering colleges. From these geographically distributed sites, localized initiatives share an evolving repository of hands-on engineering curricula so that educators—university professors and K–12 teachers alike—are able to engage in K–12 engineering without a large resource commitment or steep learning curve (Sullivan, Cyr, Mooney, Reitsma, Shaw, Zarske, & Klenk, 2005).

In addition to federal funding sources, appropriate funds can provide necessary cash reserves to continue research and development efforts in ways that introduce engineering into K–12 education. For example, the Museum of Science in Boston houses the National Center for Technological Literacy (NCTL), a nonprofit organization with funding of \$32 million from businesses and the federal government. NCTL developed an elementary school curriculum and an engineering course for high school students. Seven states utilized the elementary school curriculum, and numerous high schools have piloted the advanced course (National Center for Technological Literacy, 2006).

## CHALLENGES FOR THE TECHNOLOGY EDUCATION COMMUNITY

Technology education provides opportunities for the engineering community to value it as a key component of engineering education for K–12 students. However, to take advantage of these opportunities, challenges have to be addressed. One of the significant challenges is that technology education has historically not been viewed as a provider of engineering education. Mathematics and science education has been “pulled” into teaching engineering programs, often reluctantly. The opposite is true for the technology education community who has to take the lead and “push” its way into the engineering community. The risk is clear: The “market” might not want technology education, and there may be a waste of time and money with little or no gain. The gain is also clear: A successful “push” is converted into “pull” and the market share grows, benefiting technology education.

Another challenge for technology education is for the discipline to understand the importance of research. Zuga (1999) contends that “technology education research does not suffer from a lack of questions, but from a lack of people willing to ask the difficult questions and study them in a rigorous manner” (p. 19). A critical challenge in the technology education community is the preparation of doctoral students with the ability to develop rigorous research programs in institutions of higher education that are in a position to sustain and reward such research. At some such institutions, such as University of Illinois at Urbana-Champaign and the University of Minnesota, there is a single faculty member conducting research in technology education. When these solo faculty members retire, it is not clear they will be replaced by new faculty with research expertise in technology education.

An additional challenge is the preparation of technology education teachers in pre-service programs and through professional development. This is a complicated challenge because of the limited curriculum materials and standards for engineering classes. *Project Lead the Way* has developed pre-service and in-service materials for their specialized curriculum, and lessons could be learned from their experiences (see Chapter 9). Refocusing technology teacher education programs and developing effective professional development experiences will have to be addressed. The problem is compounded by perceptions of members of the engineering

community that a calculus background is essential for individuals teaching high school engineering. This perception is not backed by research, but will be hard to argue for, or against, in the near term.

## CONCLUSIONS

Technology education has much to offer high school students through general technological literacy programs and specialized engineering programs. The greatest opportunity for technology education to be valued by the engineering community is to solve the pathway problem by providing engineering experiences that excite female and minority students about the profession of engineering. Solving the pathway problem also improves the nation's ability to compete in the technology-driven global economy of the twenty-first century. The challenges are not insurmountable if a "technology push" model is employed. More key stakeholders in the engineering community have to be convinced of the role of technology education in K–12 engineering education and become champions of the cause. Technology education must conduct rigorous research into how to learn and teach engineering and technology concepts in K–12 schools. Successful engineering programs have to be celebrated and replicated. Finally, a massive communication campaign has to be embraced by all members of the technology education profession to educate the engineering community, parents, school districts, and other important stakeholders on the importance of technology education as the primary provider of the engineering experience for K–12 students.

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## INTRODUCTION

Over the past century, the framework for technology education curriculum has evolved from craft, to industry, to technology. At the turn of the century, the *Technology for All Americans Project* ushered in “technological literacy for all,” an objective wholly consistent with the general education philosophy to which most in technology education have subscribed. Concurrently, technology education had initiated a pedagogical transition from the project method of industrial arts to the “technological [design] method” heralded in *Conceptual Framework for Technology Education* (Savage & Sterry, 1990), published by the International Technology Education Association (ITEA). With the movement toward design pedagogy in the 1990s, technology education found new common ground with engineering educators who were themselves rediscovering design as the essence of engineering.

Technology education’s new technological design pedagogy opened the door to a range of higher-order thinking opportunities that the project method failed to address. This has been evidenced in a series of new instructional activities and curriculum that encouraged the integration of mathematics and science with technology education instruction (e.g., Brusic & Barnes, 1992; Hutchinson, 2002; LaPorte & Sanders, 1996; Satchwell & Loepp, 2002; Scarborough, 1993; Todd, 1999). In aligning design pedagogy with technology, science, and mathematics content, technology education curriculum innovators have moved closer philosophically to K–12 educators who are working closely with engineering in the opening years of the 21st century. Despite new collaboration opportunities created by their shared design-based pedagogy, engineering education and technology education approach K–12 education with different goals in mind. The engineering education community seems primarily interested in recruiting more students, including underrepresented populations, into the engineering profession, while technology education is focused primarily on the

goal of “technological literacy for all.” This creates somewhat of a paradox for technology education, which strives to offer a curriculum for all, but recognizes unprecedented opportunity in the role it perhaps could play in the delivery of engineering education for some. This chapter identifies and describes many of the K–12 engineering-related instructional initiatives that have emerged from both the engineering education and technology education communities over the past two decades; initiatives promoted by professional associations, state and federal funding, the corporate sector, and the engineering community.

## PROFESSIONAL ASSOCIATION INITIATIVES

Professional associations are in the business of promoting new trends and initiatives. They deploy their publications, conference activities, political connections, and employees’ time to promote what the association leadership perceives to be strategic new directions. With the national educational reform agendas actively promoting design pedagogy and the concurrent push for increasing the interest and enrollments in engineering degree programs, it is not surprising that professional associations in engineering education and technology education have provided leadership for K–12 engineering-related curriculum initiatives over the past two decades.

### International Technology Education Association

Since World War II, the International Technology Education Association (ITEA) has championed the study of industry and technology in general education. Warner’s presentation of *A Curriculum to Reflect Technology* at the annual conference of the American Industrial Arts Association in 1947 (Warner, Gary, Gerbracht, Gilbert, Lisack, Kleintjes, & Phillips, 1947/1965) launched six decades of curriculum innovation that began the transformation of the field from its industry and skills emphasis to a focus on technological literacy. These efforts culminated in the publication of *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000). William Wulf, President of the National Academy of Engineering, enthusiastically endorsed the *Standards* as “an essential core of technological knowledge and skills we might wish all K–12 students to acquire” (ITEA, 2000, p. v). In 1998, the ITEA formed a curriculum consortium that developed and promoted new *STL*-based K–12 curriculum materials, which they branded *Engineering by Design*<sup>™</sup>.

## American Society of Engineering Education

Recently, the American Society of Engineering Education (ASEE) established a series of new K–12 engineering education initiatives, making it very clear that engineering education has become an important new focus of the engineering profession. In January 2004, they initiated *Go Engineering*, a monthly online newsletter for K–12 teachers and sponsored ASEE’s first K–12 engineering workshop, which showcased teaching and learning materials. They also established the *Engineering K–12 Center* <http://engineeringk12.org>, a Web portal that “seeks to identify and gather in one place, the most effective engineering education resources available to the K–12 community.” In 2005, after more than a century in operation, the ASEE formally established a new K–12 and Pre-college Engineering Division for the purpose of furthering the study of engineering in grades K–12. That same year, they rolled out *Engineering: Go For It!*, a colorful 64-page booklet that introduces K–12 students to engineering careers. In the first General Session of the ASEE’s 2006 conference, the K–12 engineering education initiative was second on the list of priorities outlined by the president of the Association. At its 2006 annual business meeting, ASEE’s K–12 and Pre-college Engineering Division formally entered into a strategic alliance with the Council on Technology Teacher Education (CTTE), an affiliate of the ITEA, by passing a motion that encourages collaboration between the two organizations to improve K–12 technology education, thus laying the foundation for future collaborative initiatives.

## The Society of Women Engineers

The Society of Women Engineers (SWE), one of the oldest professional associations dedicated to women in engineering, has teamed up with the Exxon corporation to support K–12 engineering initiatives. The SWE’s K–12 initiatives include intra- and extra-curricular activities. At the elementary level, the SWE sponsors contests, clubs, expositions, and community outreach. SWE also sponsors camps, mentoring between professional engineers and classroom teachers, contests, and provides activities for middle and high school teachers and students. (Society of Women Engineers, Retrieved August 11, 2006, from <http://www.swe.org/>).

## **The Institute of Electrical and Electronics Engineers**

The Institute of Electrical and Electronics Engineers (IEEE) has been prominent among engineering associations in implementing K–12 initiatives. Their efforts include the establishment of *TryEngineering.org*, a Website that promotes engineering as a career, hosts interactive “games” for students and an “Ask the Expert” section that enables students and teachers to solicit advice from professional engineers. IEEE also provides professional development for teachers and a clearinghouse of lesson plans and activities in electronic format. (Institute of Electrical and Electronics Engineers, Retrieved August 11, 2006, from <http://www.ieee.org/>).

## **The American Society of Mechanical Engineers**

The American Society of Mechanical Engineers (ASME) provides leadership on several key engineering fronts, including public policy issues and K–12 education. At the K–12 level, ASME provides workshops for teachers, kits for elementary classrooms, activities that focus on science, technology, engineering, and mathematics (STEM), and career guidance. (American Society of Mechanical Engineers, Retrieved August 11, 2006, from <http://www.asme.org/>).

## **American Indian Science and Engineering Society**

The American Indian Science and Engineering Society (AISES), headquartered in Albuquerque, New Mexico, has held regional and national conferences since 2001. The AISES’s mission is to increase the representation of Native Americans and Alaska Natives in the STEM disciplines. To achieve this mission, the AISES has developed K–12 teacher professional development programs, collaborations with higher education institutions, and career services. (American Indian Science and Engineering Society, Retrieved August 11, 2006, from <http://www.aises.org/index.cfm>).

## **STATE INITIATIVES**

In the late 1980s, a relatively small number of technology educators in the United States began developing and implementing technological problem-solving activities. By the early 1990s, state and federal funding became available for projects that developed and promoted integrated technology,

science, and mathematics instruction. These two efforts emerged as states began to develop technology education curricula for secondary education with an engineering focus. The relatively early statewide efforts in Virginia and New York were indicative of the curriculum changes that would continue to occur across the U.S. through the turn of the century.

## Virginia

In 1992, the Virginia Department of Education published two new engineering curriculum guides: *Introduction to Engineering and Advanced Engineering*. These new courses were targeted at grades 11 and 12, and were oriented toward attracting aspiring engineering students. They each encouraged college preparatory mathematics and science courses as prerequisites. The state sanctioned these new courses and offered implementation workshops. Given the field's historical emphasis on "woods, metals, and drafting," the following list of Virginia's technology education courses provides evidence of the significant secondary curriculum revision efforts that occurred over the past two decades.

### *Virginia Middle School Course Titles and Laboratory Initiatives*

In the late 1980s, the Virginia State Department of Education (VSDOE) introduced three new middle school courses: *Introduction to Technology* (Grade 6), *Inventions and Innovations* (Grade 7), and *Technological Systems* (Grade 8). To facilitate the implementation of these new courses, the VSDOE concurrently promoted the transition from traditional general labs to modular technology education middle school labs across the state. The popular Synergistics modular lab distributed by Pitsco, Inc. continues to offer middle school boys and girls the opportunity to engage in hands-on learning modules with the following titles: *Alternative Energy, Applied Physics, Bioengineering, Biotechnology, CAD, CNC Lathe, CNC Manufacturing, CNC Mill, Computer Graphics Animation, Digital Design, Digital Transportation, Digital Video, Electricity, Electronics, Energy, Power, Mechanics, Engineering Bridges, Engineering Towers, Engines, Flight Technology, Graphic Communications, Materials Science, Package Design, Plastics and Polymers, Practical Skills, Research and Design, Robots, Rocket Science, Rocketry and Space, Simple Machines, Video Production, and Webmaster*. Modular labs have become a popular means of delivering technology education instruction, particularly at the middle school level.

In 1992, the VSDOE published a series of three high school curriculum guides under the “Design and Technology” heading: *Technology Assessment*, *Technology Foundations*, and *Technology Transfer*. Since then, they have revised the state curriculum to include the following array of high school courses:

- Pre-Engineering course cluster: *Introduction to Engineering*, *Advanced Engineering*, *Project Lead The Way*;
- Technical Design/Geospatial Systems course cluster: *Technical Drawing and Design*, *Engineering Drawing and Design*, *Geospatial Technology*, *Architectural Drawing and Design*;
- Applied Physics course cluster: *Principles of Technology I*, *Principles of Technology II*;
- Biotechnology course cluster: *Bio-Engineering*, *Biotechnology Foundations*;
- Communication Technology course cluster: *Graphic Communication Systems*, *Communication Systems*, *Digital Visualization*, *Imaging Technology*, *Media and Video Technology*, *Information Technology Fundamentals*;
- Computer Control & Automation course cluster: *Computer Control and Automation*, *Electronics Systems I*, *Electronics Systems II*, *Electronics Systems III*;
- Production Technology course cluster: *Materials and Processes Technology*, *Production Systems*, *Manufacturing Systems*, *Advanced Manufacturing Systems*, *Construction Technology*; and
- Energy & Power Technology course cluster: *Energy and Power*, *Power and Transportation*.

In 1997, the VSDOE began sponsoring a “Children’s Engineering Convention,” which annually showcases best practices in elementary technology education instructional activities and provides professional development for elementary teachers and administrators. It is part of a statewide effort to introduce technology education activities into elementary school practice.

## **New York**

In the early 1990s, the New York State Education Department (NYSED, 1994) developed a new *Curriculum, Instruction, and Assessment Framework*

for *Mathematics, Science, and Technology*. This led to their *Learning Standards for Mathematics, Science, and Technology* (NYSED, 1995a) and a new *Principles of Engineering* curriculum guide (NYSED, 1995b). The course was developed around the teaching and learning of “six major concepts identified as generic to all engineering activity: Engineering Design, Modeling, Systems, Optimization, Technology-Society Interactions, and Engineering Ethics.” (p. 8)

## Massachusetts

In 1995, Massachusetts became the first state to teach and assess technology education with all pre-K–12 students statewide, through the adoption of a new *Science and Technology/Engineering Curriculum Framework* (OPAS Summit, 2005). In grades Pre-K–5, one fourth of the time allotted for science instruction is earmarked for the study of technology/engineering. Under this framework, students enroll in the equivalent of one full year of technology/engineering education coursework between grades 6 and 8, and take another full-year technology/engineering education course in grade 9 or 10. In grades 11 and 12, students may enroll in a semester- or year-long technology/engineering course. The uniqueness of the Massachusetts curriculum framework for science and technology/engineering is their statewide assessment of pre-K–12 technology/engineering content. Not surprisingly, Massachusetts has resurrected one of its technology teacher education programs and has generated a great deal of project activity associated with pre-K–12 engineering-related education.

## Indiana and Utah

Indiana and Utah offer two distinct tracks for students wishing to enroll in a series of courses relating to higher-level technology education and/or pre-engineering courses. Indiana offers two upper-level secondary pre-engineering choices for students. The first consists of five courses either 18 or 36 weeks in length: *Computers in Design and Production Systems*, *Fundamentals of Engineering*, *Technology and Society*, *Technology Enterprise*, and *Technology Systems*. The second option is *Project Lead the Way* (PLTW), described later in this chapter. (Indiana Department of Education, Retrieved August 11, 2006, from <http://www.doe.state.in.us/octe/technologied/welcome.html>).

The State of Utah offers a program similar to Indiana’s, with secondary students having two pre-engineering tracks from which to choose. The first option is titled the Utah Pre-Engineering Program, which offers a series of four courses: *Foundations of Technology*, *Engineering Design*, *Materials and Processing*, and *Pre-engineering Technology*. The second option is the PLTW curriculum. (Utah State Office of Education, Retrieved August 11, 2006, from <http://www.schools.utah.gov/ate/teched/Programs.htm>).

## **International Baccalaureate Organization**

Beginning in 1968, the International Baccalaureate Organization (IBO) began developing and promoting three new K–12 programs: one for students three to twelve years old, another for students eleven to sixteen years old, and an International Baccalaureate (IB) diploma option for students sixteen to nineteen years old. The IB curriculum includes a *Design Technology* course. Nearly 2,000 schools from 124 countries around the world are currently working with one or more of the IBO programs. In the United States, 681 schools currently offer at least one of the IB programs in grades K–12, though very few schools appear to be teaching the *Design Technology* course in the U.S. The intent of these IB curricula is to focus on interdisciplinary projects that challenge the brightest students to engage in higher order thinking such as analysis, synthesis, and evaluation. For this reason, the IB *Design Technology* diploma aligns well with university engineering degree programs. Many colleges and universities throughout the world look favorably upon the IB degrees. (International Baccalaureate Organization, Retrieved January 30, 2007, from <http://www.ibo.org/>).

## **UNIVERSITY TECHNOLOGY TEACHER EDUCATION INITIATIVES IMPACTING K–12 EDUCATION**

Three new teacher education models that are integrated with engineering courses/degrees have recently emerged in the U.S. All three are very different from the traditional undergraduate technology teacher education programs that defined the profession throughout the 20th century. In 2004, Virginia Tech implemented a new fifth-year masters/licensure program for those holding bachelor’s degrees in Engineering, Architecture, Design, or Industrial Technology. Consistent with Virginia licensure regulations, this

option includes 24 hours of graduate technology education coursework: *Introduction to K–12 Technology Education*; *Technical Design Systems*; *Communication Systems*; *Production Systems*; *Energy/Power/Transportation Systems*; and *Technological Systems*. Each of these courses provides students with a mix of both pedagogical and technical content knowledge. In addition, students enroll in 15 graduate hours of professional education courses—including two courses in technology education curriculum and methods of instruction—and a semester of technology education student teaching. The program is designed for cohorts to begin in May and complete the following July, with students earning both a Master’s degree and a Virginia technology education teaching license.

The Colorado State University model is an option within the Engineering Science Degree program—an interdisciplinary major that provides a strong foundation in mathematics, physical sciences, and 54–56 semester hours of “engineering fundamentals.” To be eligible for a technology education teaching license, engineering science majors enroll in the engineering education concentration, which consists of 15 hours of technology education coursework as well as 18 semester hours of general education courses. The technology education courses include *Methods and Materials in Technology Education* (3 hrs.), *Student Teaching* (11 hrs.), and *Professional Seminar* (1 hr.).

A third new engineering-related technology teacher education model was recently introduced at The College of New Jersey (TCNJ). In 2006, the Department of Technological Studies at TCNJ, situated in the School of Engineering, re-conceptualized its undergraduate technology teacher education program. Their revised program blends coursework from three engineering “strands” (Mechanical Engineering, Electrical Engineering, and Designed World) with general education courses (including educational psychology, creative design, general science, calculus, engineering math, and physics) and a sequence of technology education professional courses. Course content aligns with the *Standards for Technological Literacy* and includes laboratory and capstone design experiences. Concurrent with this curriculum revision, they hired two new faculty holding PhDs in engineering to complement the technology education faculty. The program also has a new Master’s degree option intended for engineers or other design professionals who wish to earn technology education certification in New Jersey.

Other technology teacher education programs are beginning to emphasize engineering content by adding engineering, science, and mathematics coursework. Illinois State University, for example, has strengthened its mathematics requirements. It seems likely that new technology teacher education models that incorporate additional engineering content and/or integrate with existing engineering programs will continue to emerge.

## **K–12 DESIGN COMPETITIONS**

Design competitions have long been a part of K–12 technology education. The Technology Student Association (TSA), for example, has been hosting state and national competitions since 1965. In recent years, design competitions have become more prevalent in technology education—sometimes embedded in the curriculum, but more often employed as an extracurricular activity sponsored by the technology education program.

The competitions seem to fall into two tiers: (a) those that promote widespread participation requiring relatively modest individual and school investment; and (b) more expensive/exclusive competitions. The TSA competitions are indicative of the first tier, which are relatively inexpensive for participating schools and individuals, and encourage widespread participation through a “cocurricular” approach. The FIRST Robotics high school competition is emblematic of the second tier. Like many of the more costly competitions, it is sponsored and promoted by the engineering community as a means of attracting students to the engineering professions. It is costly and extracurricular in nature, and attracts a small number of students from the participating schools. Many teams seek corporate sponsors in the community, since FIRST Robotics expenses can run into tens of thousands of dollars in a given year. Many individuals and schools simply do not have the resources to participate in these tier-two competitions, thus limiting participation to a select population of students. The tier-two competitions may be encouraging a small number of students to pursue engineering professions, but this strategy does little to increase the number of underrepresented populations in engineering. Logic suggests the less-visible, but more widely enrolled, elementary and middle school tier-one competitions are more likely to assist with the underrepresented populations “pipeline” challenge.

Following are some of the better known K–12 engineering-related competitions:

## **Dell-Winston Solar Car Challenge**

- Grade Level/Scope: High School/International.
- Sponsoring Organizations: DELL, Inc. and The Winston School are the primary sponsors.
- Overview: The Dell-Winston School Solar Car Challenge, established in 1996, teaches high school students around the world how to build roadworthy solar cars. On even-numbered years, the competition is held as a 4-day closed-track race at the Texas Motor Speedway. On odd-numbered years, the teams drive cross-country to share their projects with millions of people.
- URL: <http://www.winstonsolar.org/challenge/>

## **FIRST Lego League™**

- Grade Level/Scope: Age 9–14/Regional, State, National.
- Sponsoring Organization: FIRST (For Inspiration and Recognition of Science and Technology) is a multinational non-profit organization that aspires to transform culture, making science, math, engineering, and technology as cool for kids as sports are today.
- Overview: With the help of LEGO® MINDSTORMS™ Robotics Invention System technology, young participants are challenged to design and build a robot and compete in a friendly, FIRST-style robotics event specially designed for their age group. Using LEGO bricks and other elements such as sensors, motors, and gears, teams gain hands-on experience in engineering and computer programming principles as they construct and program their unique robot inventions.
- URL: <http://www.usfirst.org/jrobotcs/fllego.htm>

## **FIRST Robotics™**

- Grade Level/Scope: High School; Multi-national.
- Sponsoring Organization: FIRST.
- Overview: The FIRST Robotics competition teams professionals and young people to solve an engineering design problem in an intense

and competitive way. According to FIRST, in 2005 the competition reached close to 25,000 high-school students on close to 1,000 teams in 30 competitions. Teams that year came from Brazil, Canada, Ecuador, Israel, Mexico, the U.K., and almost every U.S. state. The competitions, which draw spectators, involve brainstorming, teamwork, mentoring, project timelines, and deadlines.

- URL: <http://www.usfirst.org/robotics/>

## **Future City Competition**

- Grade Level/Scope: Seventh- and eighth-grade/Regional, State, National.
- Sponsoring Organizations: Bentley Systems, Incorporated and Engineers Week.
- Overview: Seventh- and eighth-grade students work with engineers to develop a future city. The contest stresses teamwork, problem solving, research and presentation skills, mathematical and scientific reasoning, and computer skills.
- URL: <http://www.futurecity.org/>

## **Future Scientists and Engineers of America**

- Grade Level/Scope: K–12/National.
- Sponsoring Organizations: Over 100 small to medium-sized businesses.
- Overview: A focus of this non-profit organization is to infuse technology into the schools and to help establish after-school technology clubs. Students work on real-world problems that simulate how engineers and scientists solve problems. Mentoring or partnerships between engineers, scientists, college students, and parents establishes a team. The most prominent among the many activities that teams may work on is the rocket launch competition.
- URL: <http://www.fsea.org/>

## **International Bridge Building Contest**

- Grade Level/Scope: High School/International.
- Sponsoring Organization: Illinois Institute of Technology.

- Overview: A bridge building contest for high school students. Regional and international competitions are held. The goal is to develop the most efficient bridge constructed from balsa.
- URL: <http://www.iit.edu/~hsbridge/database/search.cgi:/public/index>

## **International High School Space Settlement Design Competition**

- Grade Level/Scope: High School/International.
- Sponsoring Organizations: National Aeronautics and Space Administration (NASA) and Boeing Corporation are among the many co-sponsors.
- Overview: A NASA design competition that simulates the experience of working on an aerospace industry proposal team. Student teams prepare city designs in which at least 10,000 people will reside. Students learn creative skills, as well as technical, teamwork, and management skills. Typically, about twelve proposals are received nationally, with eight being selected as finalists. Students work with engineers during the design competition.
- URL: <http://spaceset.org/>

## **Junior Solar Sprint Competition**

- Grade Level/Scope: Middle School/Regional, National.
- Sponsoring Organization: National Renewable Energy Laboratory.
- Overview: An educational contest designed to improve students' knowledge of STEM and renewable energy. This contest is held at the regional and national levels. Student teams design a solar-powered car from kits provided. In addition to solar energy, new competitions in fuel-cell technology are being developed.
- URL: [http://www.nrel.gov/education/jss\\_hfc.html](http://www.nrel.gov/education/jss_hfc.html)

## **National Engineering Design Challenge (JETS)**

- Grade Level/Scope: High School/State, Regional, National.
- Sponsoring Organizations: Numerous corporate sponsors, professional organizations and university affiliates.

- **Overview:** The JETS competition is a real-world challenge that helps to solve social needs. The competition involves students in learning about STEM, problem solving, research, writing, drafting and design, and presenting their solution in a hands-on fashion. Regional and national contests exist and are judged by a national panel of experts. The national competition is held in Washington, DC, in conjunction with the National Engineers Week.
- **URL:** <http://www.jets.org/programs/nedc.cfm>

## **Odyssey of the Mind**

- **Grade Level/ Scope:** K–College; Regional/State/National/World.
- **Sponsoring Organization:** Odyssey of the Mind (Non-profit organization).
- **Overview:** Odyssey of the Mind, founded by technology teacher educator Sam Micklus, is an international educational program that provides creative problem-solving opportunities for students from kindergarten through college. Students are challenged to solve problems that range from building mechanical devices to presenting their own interpretation of literary classics. They bring their solutions to competitions on the local, state, and world levels. Thousands of teams from throughout the U.S. and about 25 other countries participate in the program.
- **URL:** <http://www.odysseyofthemind.com/>

## **RoboCup**

- **Grade Level/Scope:** K–12/Local, Regional, International.
- **Sponsoring Organizations:** Numerous global partners.
- **Overview:** An international joint project to promote artificial intelligence, robotics, and STEM. The mission of RoboCup is to develop a team of autonomous robots to play soccer against humans by 2050. Since soccer is one of the most significant international sports, the organizers of RoboCup used soccer as the vehicle to study robotics. More recently, RoboCup has initiated new contests involving search and rescue robots to help solve social issues.
- **URL:** <http://www.robocup.org/>

## **Technology Education Collegiate Association (TECA) Competitions**

- Grade Level/Scope: College Technology Teacher Education Majors/TECA members.
- Sponsoring Organization: TECA/ITEA.
- Overview: Live Communication Contest; Live Manufacturing Contest; Problem-Solving Contest; Teaching Lesson Contest; Technology Challenge Contest; Transportation Contest.
- Related Information: Competitions take place in four regional venues. For example, the TECA Eastern Regional Conference, held in late February each year, involves about 250 college students from about 15 universities on the East Coast from Connecticut to Georgia.
- URL: <http://www.tecaeast.org>

## **Technology Student Association Competitions**

- Grade Level/Scope: Middle and High School/Regional, State, National.
- Sponsoring Organizations: Technology Student Association (TSA), numerous corporate and government-related agencies, and professional organizations.
- Overview: More than 60 middle and high school competitions ranging from agriculture and related biotechnologies to video game design are available. National competitions are moved throughout the United States on a rotating basis.
- URL: <http://www.tsaweb.org/>

## **West Point Bridge Design Contest**

- Grade Level/Scope: Age 13 through 12th grade/National.
- Sponsoring Organizations: U.S. Military Academy at West Point and American Society of Civil Engineers.
- Overview: The contest introduces students to engineering in a realistic manner by having them design, model, and optimize steel bridges that are then tested via a computer modeling software program. The software (*West Point Bridge Designer*) is free to download and can be

used on all school computers. There are several rounds of the contest, which lead to a national champion.

- URL: <http://bridgecontest.usma.edu/>

## **FUNDED PROJECTS**

Since the early 1990s, major funding agencies such as the National Science Foundation, NASA, and state departments of education have supported projects that promote engineering-related content in K–12 education. Typically, these projects developed and field-tested integrated technology/science/mathematics and/or engineering design activities and/or developed and implemented professional development programs to enhance K–12 STEM teachers’ abilities to implement STEM and/or engineering-related activities. The projects below represent more than \$30 million invested in these developmental activities, and provide a foundation for future efforts. Some of these projects published activities and materials that are readily available. Others developed materials that were not commercially viable, and thus remain unavailable.

Most of these projects were heavily influenced by the national standards for technology, science, and mathematics education, causing them to emphasize applications and connections among those different content areas. At the approach of the 21st century, engineering educators began to promote a K–12 engineering education agenda, which coincided with the availability of substantive funding from NSF and others for K–12 instructional materials and professional development projects, like many of those that follow. As a result, an increasing number of engineering educators have become involved in K–12 engineering-related instructional development projects. Those projects directed by engineering educators tend to reflect more engineering content and processes than those in the 1990s that were directed by technology educators, who focused more on making connections among technology, science, and mathematics than on creating what many call “pre-engineering” curriculum—courses designed purposefully for the engineering-bound track. The common denominator among all or nearly all of these projects is reliance upon designing instructional activities to interest and motivate K–12 students.

Given the confluence of interest in engineering/design activities and curriculum from the STEM education community, the number and scope of K–12 engineering-related funded projects such as those listed below will likely increase in the years ahead. At issue is the role the various STEM

education disciplines will play as each tries to move the scenario beyond funded projects to the school curriculum.

## **Center for Innovation in Engineering and Science Education**

Established in 1998, the *Center for Innovation in Engineering and Science Education* (CIESE) supports teaching and learning of STEM subjects through Web-based instructional strategies. The CIESE collaborates with K–12 teachers, university educators, researchers, policymakers, and educational organizations to develop instructional materials. The curriculum resources incorporate real-time data and Web-based collaborations, and are mapped to the national science and mathematics standards. In addition, CIESE provides professional development for STEM educators and seeks to improve teacher preparation through Web-based technologies (<http://www.ciese.org/>).

## **City Technology: Stuff That Works!**

*Stuff That Works! A Technology Curriculum for the Elementary Grades* is a series of design and technology curriculum guides for elementary and middle school teachers. The curriculum consists of five units, each sold as a stand-alone book: *Mapping*; *Mechanisms*; *Packaging*; *Designed Environments*; and *Signs, Symbols, and Codes*. The guides include classroom-tested activities that use common inexpensive household materials. Each activity identifies the related math, science, technology education, and English language arts standards. Their accompanying *Guide for Professional Developers* includes guidelines and resources for: a) developing and facilitating hands-on workshops for teachers; and b) using *City Technology's* online forum to prepare and support teachers during the classroom implementation period (<http://citytechnology.ccnycuny.edu/>).

## **Children Designing and Engineering**

The Children Designing and Engineering™(CD&E) units integrate technology, science, and mathematics using a design and problem solving approach to learning in the primary grades. CD&E units challenge students to solve practical problems related to real, work-world settings. Each unit allows students to experience the planning, designing, development, and

operation of their own classroom businesses and services. The twelve teacher guides and accompanying multimedia assist teachers with implementation. Students are challenged to conduct investigations, generate ideas, plan a course of action, make and test solutions, and reflect upon what they have learned. Units begin with the posing of a “Big Challenge”—usually related to product or service development—followed by four to six weeks of related lessons that facilitate student problem-solving. West Ed, a well-known educational research and development company concluded: “Nineteen of the twenty *Standards for Technological Literacy* are addressed in the (CD&E)... A blended approach to topic and subject integration allows students to simultaneously gain new understanding and skills in many content areas” (<http://www.childrendesigning.org/home.html>).

## Design in the Classroom Project

*Design in the Classroom* is a Web-based project that provides extensive information about technological design instruction. The site includes, for example, video clips of science and technology education teachers teaching design and students learning design. Other areas of the project site include video timelines, interactive design processes, and tutorials on key concepts relating to design. Most learning activities have video clips associated with them (<http://ditc.missouri.edu/index.html>).

## IMaST

The *Integrated Mathematics, Science, and Technology* (IMaST) curriculum provides integrated, year-long programs for grades 6, 7, and 8 that promote hands-on learning for students, and teamwork among teachers from different disciplines. IMaST strives to get away from traditional teacher-centered strategies that treat students as passive learners. The “active learning” helps students understand the concepts better and apply them in real-life situations. Problem solving is used as a key instructional technique throughout the IMaST program. Students develop strong critical thinking skills such as predicting, hypothesizing, planning, analyzing, interpreting, and assessing. Problem solving becomes “second nature” to students in the IMaST program. IMaST’s integrated instructional units are grounded in a non-linear process that involves students in defining, assessing, planning, implementing, and communicating (DAPIC).

## National Center for Engineering and Technology Education

The *National Center for Engineering and Technology Education* (NCETE) is one of the National Science Foundation Centers for Learning and Teaching. NCETE consists of four doctoral granting institutions: Utah State University, University of Illinois at Urbana-Champaign, University of Georgia, and the University of Minnesota; and five technology teacher education institutions: Illinois State University, University of Wisconsin-Stout, North Carolina A&T State University, Brigham Young University, and California State University, Los Angeles. The goal of NCETE is to infuse engineering design, problem solving, and analytical skills into K–12 schools through technology education. As part of this goal, NCETE seeks to increase the quality, quantity, and diversity of engineering and technology educators, and strengthen the pathways to engineering and technology professions for K–12 students. To help reach these goals, NCETE has developed a community of 20 Ph.D. students, 50 students seeking Master's degrees, 150 classroom teachers, and 250 pre-service technology education teachers (<http://www.ncete.org>).

## National Center for Technological Literacy

The goal of the National Center for Technological Literacy (NCTL), located at the Boston Museum of Science, is to “integrate engineering as a new discipline in schools nationwide and to inspire the next generation of engineers and innovators.” The NCTL works with state departments of education and teacher organizations to facilitate the re-engineering of K–12 curricula. The Center has a variety of funded projects that develop educational products and professional development programs for pre-K–12 students and teachers in partnership with state departments of education and teacher organizations. Products produced by NCTL include curriculum materials, in-service workshops, and an online resource center for teachers. Specific NCTL-developed curricula include: *Engineering is Elementary*, engineering and technology lessons for the elementary grades; and *Engineering the Future*, a pre-engineering curriculum for high school students (<http://www.mos.org/nctl/>).

## Pre-college Engineering for Teachers Program

*Pre-College Engineering for Teachers* (PCET) is a professional development program for K–12 teachers in Massachusetts. The PCET Project partners are Tufts University, University of Massachusetts in Lowell, and Worcester Polytechnic Institute. The project offers professional development for classroom teachers on engineering design during the school year and through the summer. As part of the project, teachers must develop a unit of instruction that is implemented in their classrooms. The PCET Web site includes a collection of middle and high school projects and assessment tools (<http://130.64.87.22/pcet/default.asp>).

## Project ProBase

*Project ProBase*, funded by the NSF and developed at Illinois State University, is an engineering-related curriculum designed for high school juniors and seniors planning to enroll in technical or engineering programs at two- or four-year colleges/universities. ProBase curriculum development was guided by the *Standards for Technological Literacy*, and “bridge competencies” identified through research. The instructional materials were field-tested throughout the U.S. ProBase courses consist of four nine-week learning units, supported by student and instructor guides. Each of the activities follows a four-phase learning cycle: exploration, reflection, engagement, and expansion. The materials are being distributed by the ITEA/Center to Advance the Teaching of Technology & Science (CATTS) *Engineering by Design* program. *Advanced Design Applications/ProBase* is a 36-week course that includes units in manufacturing, energy and power, construction, and transportation technologies. *Advanced Technological Applications/ProBase* is the other 36-week course, and includes units in information and communication, agriculture and related biotechnologies, medical technologies, and entertainment and recreation technologies (<http://www.iteaconnect.org>).

## Teach Engineering

*Teach Engineering* is a searchable Web-based digital library that hosts teacher-tested, hands-on, engineering-related lessons and activities for K–12 STEM teachers. The project was developed collaboratively at four universities and was funded by the National Science Foundation’s Digital Library initiative. Each lesson is mapped to national education content

standards and some specific state standards and is available to educators free of charge (<http://www.teachengineering.org>).

## **TECH-know Project**

The *TECH-know Project* developed a set of *TECH-know* books for middle and high school teachers and students. These books provide content and instructional materials that complement selected middle and high school Technology Student Association (TSA) competitive events. These materials include technology, science, and mathematics content based upon *Standards for Technological Literacy*, *National Science Education Standards*, and *the Principles and Standards for School Mathematics* (<http://www.ncsu.edu/techknow/index.html>).

## **Technology for All Americans Project**

ITEA launched the *Technology for All Americans Project* (TfAAP) in 1994 with the goal of developing and disseminating national technological literacy standards. That goal was realized with the publication of *Standards for Technological Literacy: Content for the study of technology* (ITEA, 2000), which provided the framework for many of the engineering-related projects funded both during and after its development and publication. In addition, the TfAAP developed *Technology for all Americans: A rationale and structure for the study of technology* (ITEA, 1996) and *Advancing excellence in technological literacy: Student assessment, professional development, and program standards* (ITEA, 2003). The project, funded by the National Science Foundation (NSF) and NASA, concluded its work in 2005.

## **Technology, Science, Mathematics Connection Activities**

The *Technology, Science, Mathematics Connection Activities* are technological design activities intended to be taught by teams of technology education, science, and mathematics teachers working together. Developed primarily for middle school grades, the *TSM Connection Activities* require students to apply principles of technology, science, and mathematics as they design, construct, and evaluate solutions to the technological design problems posed. Each activity includes a “Design Brief” that describes the problem/challenge to students, as well as a separate set of robust

instructional support materials for each of the teachers involved. The *TSM Connection Activity* titles include: “Power Boat,” “Composite Beam,” “Cabin Insulation,” “MagLev Vehicle,” “Plant Plant,” and “Rocket.”

Available: LaPorte, J. & Sanders, M. (1996). *Technology, Science, Mathematics Connection Activities*. Woodland Hills, CA: Glencoe/McGraw-Hill, 400pp. ISBN #0-02-636947-8. These materials are being revised/republished as: LaPorte, J. & Sanders, M. (2008). *Technology: Engineering and Design Applications*. Woodland Hills: Glencoe/McGraw-Hill.

## **Project Lead The Way, Inc.**

Founded in 1997, *Project Lead The Way*, (PLTW) is a not-for-profit corporation that “has established and is supporting a working relationship among school districts, colleges and universities, and the private sector to provide a high school and middle school engineering and technology curricula.” PLTW does this through contracts it signs with school divisions who agree to purchase a set of four PLTW high school courses over four years and/or two or four 10-week middle school instructional units. Contracted school divisions also agree to purchase teacher training and purchase or lease “designated software” and equipment from PLTW-approved vendors. PLTW is not a “project” like those in the previous section; rather it is a corporation that contracts with school divisions to deliver “turnkey” pre-engineering curriculum packages.

PLTW currently offers eight high school course titles: *Principles of Engineering*, *Introduction to Engineering Design*, *Digital Electronics*, *Computer Integrated Manufacturing*, *Civil Engineering and Architecture*, *Biotechnical Engineering*, *Aerospace Technology*, and *Engineering Design and Development*. In addition PLTW offers one middle school course, *Gateway to Technology*, which includes units in “Design and Modeling,” “Magic of Electrons,” “Science of Technology,” and “Automation and Robotics.”

PLTW teachers become certified through a summer program that includes a pre-training assessment, two weeks of “core training” in the summer, and ongoing training offered online after completing the two-week summer training. PLTW also contracts with some technology teacher education programs to certify technology education teacher education majors for PLTW courses while they are completing their technology education degree program. PLTW currently identifies 46 states that have “schools in the PLTW network.” Some university engineering “affiliates”

recognize PLTW courses in the admissions process. (*Project Lead The Way*, Retrieved February 2, 2007, from <http://www.pltw.org/>).

## ENGINEERING CAMPS

Engineering camps, generally offered by universities during the summer months, provide extra-curricular engineering opportunities for K–12 students. Summer engineering camps have been around for decades; Worcester Polytechnic University has been conducting them for 25 consecutive years. The Engineering Education Service Center maintains a fairly extensive listing of these camps (see <http://www.engineeringedu.com/summercamps.html>). Most of the camps offer a general introduction to engineering, though some focus on specific engineering sectors, such as traffic engineering, robotics, civil engineering, computer security, car design, aeronautics, entrepreneurship, and nuclear engineering.

The most common model is the university-sponsored engineering camp for rising high school juniors and seniors that runs for one or two weeks during the summer. Most of these camps have been established by universities to recruit prospective students—including underrepresented populations—into their engineering programs. Other models include: (a) a seven-week engineering camp (University of Florida) in which students spend 25 or more hours per week working in laboratory settings and attend seminars and workshops; (b) a model that offers separate camps for elementary, middle, and high school students (North Carolina State University) or separate camps with different foci (such as the University of Missouri’s unique camps for nuclear energy/nuclear reactors); and (c) a model targeted specifically for female high school students (Cornell University); and (d) another Cornell University model that provides eight hours of university credit for an extended six-week summer engineering camp.

## DISCUSSION

Over the past two decades, a variety of factors promoted widespread interest in infusing engineering content into K–12 education. In technology education, the design-based pedagogy the field began to adopt in the late 1980s created significant common ground with engineering, and in the early 1990s, technology educators began to strongly consider the possibility of using engineering as means of organizing technology education content (Bensen & Bensen, 1993). The *Standards for Technological Literacy* (ITEA, 2000) offered a

set of themes that were sufficiently aligned with engineering education ideals to warrant an endorsement from the engineering community.

While the ITEA was busy developing national standards for technological literacy, *Project Lead The Way* began taking dead aim at the engineering education market. They quickly developed a pre-engineering curriculum that consisted of middle and high school courses, established partnerships with university engineering “affiliates” to deliver course-by-course PLTW certifications, and successfully marketed the whole package to schools across the U.S. PLTW was also successful in convincing some of its engineering affiliates to recognize PLTW coursework in the university admissions process. In Fall 2006, PLTW announced it would be “coordinating and facilitating the development of engineering standards for the pre-college program with invested stakeholders” (Blais, 2006). A draft of those standards was circulated for review in January 2007. In a decade’s time, PLTW created an infrastructure upon which it hopes to build in the years ahead.

Across the same timeline, the engineering community was becoming smitten with the idea of infusing engineering content into K–12 education. NSF funded numerous projects, directed by both technology and engineering educators that developed age-appropriate design-based activities for K–12 students. The National Academy of Engineering endorsed the *STL* as having “distilled an essential core of technological knowledge and skills we might wish all K–12 students to acquire,” and in 2006, after more than a century of operation, the ASEE formally established its K–12 and Pre-College Engineering Division.

The array of K–12 engineering-related initiatives promoted by professional associations, state departments of education, universities, public and private funding agencies, and private corporations illustrates the widespread interest in K–12 engineering-related education. For the field of technology education, this presents an interesting paradox. While the technology education community stands behind its goal of technological literacy for all K–12 students, the engineering community seems most interested in high school “pre-engineering” courses for those pursuing engineering degrees—a relatively small percentage of the school population.

Technology educators are left to weigh their ideal of technological literacy for all against the allure represented by the option of engineering education for the few. The former brings the field closer to the general education arena where science and mathematics education make their home; the latter is more closely aligned with a “vocational paradigm.”

Is there middle ground to be found between the general education and vocational paradigms, with benefits derived from collaborative border crossings? Should technology educators simply continue, as they have throughout the history of the field, to play it both ways? And what is to be made of PLTW in all of this? We should expect to see continued interest in K–12 engineering-related initiatives from all three constituents, and continuing ambivalence throughout the technology education profession with respect to the paradox at hand.

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The relationship between engineering and technology education takes on a variety of characteristics depending on the “lens” through which it is being viewed. This chapter is comprised of a series of eight essays written by individuals representing a variety of perspectives, with differing educational backgrounds as well as unique personal and professional cultures. These include a professional engineer, an informal science educator, a classroom teacher, engineering educators, technology educators, and a state supervisor. In addition to a variety of lenses, we made a deliberate attempt to include discussion of several key issues and initiatives with regards to K–12 engineering such as gender involvement and *Project Lead the Way*.

It is important to note that the authors were selected because they have something worthwhile and interesting to say, not because we thought they would necessarily be representative of their discipline or position type. The authors were encouraged to speak from their own personal experience and to share their unique perspectives. In some cases the ideas will be mainstream and conventional while other views may be controversial and even disturbing. This is by design. It is our hope that these voices will stimulate thought and discussion among students and professional educators as they attempt to think through important curricular and policy issues related to engineering and technology education. In order to facilitate this type of discourse, each of the essays concludes with a set of recommendations. The authors were encouraged to take a position or positions and even to be controversial. We hope that, through this chapter, we have been able to capture a snapshot of the types of conversations that are occurring within and beyond the field.

# Technology Meets Engineering: Notes from the Ground

Gary Benenson

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Engineering Professional Perspective

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*Feeble as the monarchy had become, surrounded by its great vassals and vegetating in their shadow, it none the less harbored within it the principle of its future power.*

—Henri Pirenne, *A History of Europe, describing 12th Century France*

As with the French crown, there is a principle of great power lurking within a collaboration between technology and engineering education. Each discipline has a great deal to offer the other. However, the facts on the ground tell a different story.

The problem for me is the word “alliance.” While there may be some fusion of ideas, I do not see much of an alliance between *people*, certainly not at the classroom level. In Greg Pearson’s words, “Neither profession seems seriously interested in reaching out to the other” (Pearson, 2003, p. 8). The vast majority of engineering educators have probably never even heard of technology education, let alone sought involvement in it. Conversely, many (if not most) technology educators have little or no contact with engineers or engineering educators, nor awareness of any proposed alliance. Even in Massachusetts, there is considerable resistance among technology teachers toward adopting the new curriculum approach (M. Cyr, personal communication, February 18, 2005).

Some of my difficulty is resolved by Ted Lewis’ distinction between the “regular” and “movement” versions of pre-engineering (Lewis, 2004). His regular version of pre-engineering—which I would call technological literacy—attempts to integrate engineering concepts, processes, and attitudes into K–12 education for all students, as advocated by national standards (AAAS, 1993, pp. 41–57; NRC, 1996, pp. 135–8, pp. 161–6, pp. 190–3; ITEA, 2000). People involved in this effort include mathematics, science, engineering, and technology educators, and cognitive scientists. As an engineer deeply involved in K–12 education, it has been my own primary project over the past ten years.

Lewis' "movement version of pre-engineering"—which I would simply call pre-engineering—attempts to translate undergraduate engineering education content and pedagogy to the middle or high school level. The effort, under the leadership primarily of engineering educators, is targeted at high-performing students, and is designed to recruit students into STEM careers (Gomez, 2001; PLTW, 2006).

So, where do we find the alliance between engineering and technology education? Technological literacy efforts—Lewis' regular version—are being pursued by some technology educators (but few engineers) in addition to others, such as elementary teachers, math and science teachers, and informal science educators. My own collaborations have rarely involved technology teachers. The latter are hard to find in elementary schools and in low-income districts generally, where most of my work has taken place. Pre-engineering programs—Lewis' movement version—do involve engineering educators and former engineers-turned-teachers, but not necessarily technology teachers. These programs are difficult to justify from a diversity or equity viewpoint, because the target audience tends to be very selective for both economic and academic reasons.

The elusive quality of the "alliance" is not surprising, given the structural barriers to collaboration. Some of these are listed by Pearson (2003, pp. 4–6). Engineering education is still largely based on didactic models that persist in spite of strong evidence for their ineffectiveness (Smith, et al, 2005). The role of design, the core process in technology according to the ITEA Content Standards (2000), is still contested within engineering education (Dym, et al, 2005; Lewis, 2005). Also, the reward structure in most of higher education is still weighted heavily towards research in engineering. Education even of *undergraduates* (let alone K–12 students) takes a seat at the back of the bus when tenure and promotion decisions are made. I am unaware of *any* mutual efforts that draw on *both* sets of perspectives in order to develop better approaches for both engineering and technology education. Now that's what I would call an *alliance!*

What then is the "principle of its future power" harbored within the linkage between technology and engineering education? The advantages to the technology education side include more than technological literacy, as outlined in Pearson and Young (2002). As I have suggested elsewhere, engineering design offers a systematic approach to a whole range of problems, from mathematical problem solving to writing process to resolving classroom issues to making life choices (Benenson, 2001; Benenson &

Neujahr, 2002). K–12 engineering education can also play a significant role in addressing the academic achievement gap (Benenson, in press). Incorporating design education in technology can provide a framework for education, which focuses less on getting the right answer, and more on how to get from existing situations to desired ones. At the same time, technology education can contribute project-based, experiential pedagogies that are largely missing from engineering education. Achieving these outcomes will be a massive design problem in itself!

## Recommendations

- Engineering and technology educators need to meet, talk, explore problems, and learn from one another. Each group has something to offer the other. Engineering educators are typically more familiar with engineering analysis and design, while technology educators typically know more about engaging students, and certainly about the culture of schools and classrooms.
- There is an urgent need for research into how students learn technology. At two AAAS technology education research conferences, nearly all of the significant papers came from the UK, Canada, or Australia (AAAS, 2006). The same problem is revealed by the annotation “No relevant research available” next to the AAAS concept maps for technology education (AAAS, 2001, pp. 31–37).
- Engineering and technology educators ought to think “outside the box” about how disadvantaged populations could be served and social problems could be addressed by pedagogically responsive technology or engineering education. My own preliminary thoughts on this subject are outlined in Benenson (in press).

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# Technology and Engineering in Museums

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Informal Science/Engineering Perspective

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To date, science centers and museums have educated the public about engineering and technology in only very limited ways. However, the innovations occurring in some museums present alternatives that could change the role that informal educational centers, such as museums, play in familiarizing visitors with engineering and technology.

## A Bit of History

Many science museums began as collections of artifacts—they displayed collections of specimens from the natural world or scientific and technological inventions, such as locomotives or airplanes, for the public to view. For decades, the predominant paradigm of a science museum was as a center that preserved artifacts and products of the natural, scientific, and technological world for the public to view.

In the 1980s, thinking about the core purposes of museums changed. Museum professionals in general exhibited a heightened focus on education, and science museum professionals more specifically began to explore ways to educate the public about *how* scientific knowledge came to be. Communicating “Science as a Process” became a new focus of many museums—exhibits and programs tried to develop scientific thinking skills by engaging people in scientific activities and processes. Concurrently, perhaps by necessity, science museums also became more “hands-on.” Instead of viewing artifacts through glass, newer exhibits invited visitors to interact with and manipulate materials and objects. For example, an exhibit might ask visitors to think about, predict, and then test on which angle of a ramp a golf ball would most rapidly descend.

## What About Technology?

Designing and creating museum exhibits and programs that reinforced visitors’ scientific thinking skills grounded many museums for more than two decades. But while the processes underlying science were being illuminated for visitors, any mention of technology in science

museums remained as a product—computers, equipment, or inventions. In fact, the vast majority of science museum technology was either largely ignored, not conveyed as any different than science, or portrayed solely as information technology and computers.

Late in the 20th century, some exhibits that highlighted engineering and technology were created. Many of these, for example *Tech City* or *Engineer It!*, were temporary, traveling exhibits. These exhibits exposed visitors to what engineering was and engaged them in engineering activities and processes. Today, most science centers treat engineering as one of many fields that they educate visitors about; as such, their floors may contain one exhibit that focuses on engineering and technology.

## Some Models for Engineering and Technology Museums

There are two notable examples of science museums in which engineering and technology have assumed a much more prominent, and balanced, role. The Tech Museum of Innovation in San Jose, California was created to help people explore the technologies in their lives and inspire innovation. From its creation in 1978, it has attended to both technology/engineering and science. The Museum of Science in Boston began in 1830 as a natural history museum. About five years ago, it launched an initiative to include technology and engineering in its exhibits and programming and to treat these fields as equal partners to science. These two institutions have asked: How can museums best help visitors to understand the fields of engineering and technology, their role in our society, and their concepts and processes?

Three major categories of technology exhibits and programs have emerged:

1. *Those that showcase new technologies.* Weekly, new technologies are introduced into society. The public is interested in what they are, how they work, and how they came to be. By showcasing such new inventions on museum floors, visitors get a sense of cutting-edge technological innovations;
2. *Those that invite visitors to innovate and engage in the processes of engineering.* Innovation is central to engineering and a few museums have developed programs to foster innovation among visitors. Additionally, just as science has a set of processes that guide the creation of scientific knowledge, so engineering has distinct processes

and ways of thinking that underlie the creation of new technologies. Museums have invited visitors to think like engineers by engaging them, for example, with engineering design challenges; and

3. *Those that ask the visitor to consider the relationships between technology and society.* Technology affects society and society affects technology. Cultural, economic, and environmental values shape decisions about technology. Museums are just beginning to explore how to create places for visitors to conduct dialogue and deliberation about how we make decisions about technology.

While engineering and technology are accepted as fields that may be included in a science center or museum, it is not currently the case that developing technological literacy is a goal of most science museums. Perhaps, over the next couple decades, the field will increasingly rise to the challenge of educating our citizenry about engineering and technology as well as science. In the meantime, a few museums will continue to experiment with programs to better understand how to design informal museum experiences about technology and engineering.

## **Recommendations**

- As our society increasingly depends on engineering and technology, and the national concern for fostering citizens' technological literacy grows, science centers and museums should critically reassess their role in promoting understanding of these disciplines and question whether their current exhibitions and programs are sufficient to meet this challenge.
- Museums offer unique environments that can provide life-long learning. Many adults, particularly older adults, are concerned that they do not understand many of the new, sometimes common, technologies that are emerging. Often they express a desire to have educational experiences that would make technologies understandable and accessible. Museums can, and should, play a leading role in fostering technological understanding among adults.
- How do and should technology and society interact? Society and the public should have a role in determining how new technologies might be used or implemented. Museums should play a major role in helping people to understand the new technologies and encouraging them to discuss the societal, environmental, political, and cultural consequences of them.

# With or Without Us

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Classroom Teacher Perspective

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K–12 engineering education is not “on the horizon.” It is here. One major engineering curriculum project lists thousands of participating schools, with hundreds of thousands of students. Publishers advertise dozens of K–12 engineering textbooks. The century-old American Society of Engineering Education (ASEE) has staff and resources devoted entirely to K–12 education, and the National Science Foundation (NSF) is writing six- and seven-figure checks for K–12 engineering initiatives.

It would seem that the technology education classroom would be the perfect home for these engineering initiatives. Traditionally, technology programs have had the faculty, the industry contacts, and the facilities for hands-on courses like engineering. Yet the engineering/technology education linkage is not necessarily as strong as it seems. It is significant that most engineering programs for the secondary school are designed to be taught by mathematics, science, or technology teachers with an emphasis on the “or.” Other academic disciplines will soon be expanding the boundaries of secondary engineering education, and perhaps shifting the center as well. In the meantime, the obvious strengths of technology education programs are matched by some equally important, but less obvious, shortcomings. The future of engineering in the technology education classroom depends on whether these shortcomings can be adequately addressed.

## Mathematics

One of the most glaring disparities in the technology education/engineering linkage is in the mathematical skills required of professionals in each field. Most technology education programs include courses in algebra and trigonometry, or a general mathematics course that teaches similar concepts. In contrast, a typical four-year engineering program essentially requires a minor in mathematics—calculus in multiple forms, differential equations, matrix theory, and perhaps some computer programming. The rigorous mathematics requirement in the engineering program is there for a purpose: engineering concepts depend heavily on a mathematical foundation. It is not unusual to find engineering textbooks that explain key concepts solely in terms of equations, not words.

The disparity in mathematical education between engineers and technology teachers suggests that technology teachers will be at a serious disadvantage in teaching mathematics-based engineering concepts to their students. Granted, much of the higher-level mathematics concepts are only used at the university level. However, teachers of engineering at the secondary level will need to be qualified to distill these concepts into a form that is usable by their students. To do so, technology teachers will need to have some of the same mathematical foundation as engineers.

## **Diversity**

One area in which technology education and engineering are alike is in their demographics. Both fields are underrepresented by women and ethnic minorities. Laudably, both fields are also taking steps to address this problem. As a practical matter, though, neither field is currently able to help the other with the problem. Technology education programs are not able to send a diverse group of students on to engineering programs, and engineers are not able to provide many diverse role models for prospective students.

This issue is critical because a primary goal of many federal grants and engineering outreach programs is to increase the number of women and ethnic minorities in engineering degree programs. To do so, they will need to look outside the traditional technical-track envelope to recruit students from underrepresented groups. This means more engineering presence in mathematics, science, and other classrooms—or even in extracurricular events. The ASEE, for example, recently sponsored a major engineering outreach through regional Girl Scout councils in the United States.

Technology education programs are still a strong source of students for technical degree programs. After all, these students have already shown interest in the field. But technology education programs will need to be aggressive in addressing their own demographic imbalances if they want to be the primary recipients of engineering outreach efforts.

## **Standardization**

Technology programs vary widely in their scope and content. Technology teachers seem to value their ability to teach a customized curriculum based on their skill set and local student needs. This curricular perspective has its strengths, but also creates problems for any large-scale engineering initia-

tive. Technology curriculum writers at any level cannot make very many assumptions about prior technical knowledge of students. They also have a hard time knowing what facilities and equipment are available for courses, or the level of student proficiency with that equipment. In contrast, most math and science programs have clearer targets for students at each grade, but they lack much of the hands-on skill base of technology programs.

Engineering initiatives must land in this curricular pile somewhere. One current solution is the “all or nothing” approach, where an engineering program is adopted as a complete package—four-year curriculum, equipment, materials, and teacher training included. This approach has shown very promising results. Yet it is also being resisted by some educators because it supplants existing curriculum wholesale, rather than building off of it. A less comprehensive solution, the *Standards for Technological Literacy* (ITEA, 2000), is also a step towards a coherent curriculum, but even this document will only be successful to the extent it is seen as a complete model, not merely a menu of curriculum options to choose from. Technology educators will need to address this growing pressure to standardize curriculum, especially if they wish to maintain a strong linkage with engineering.

## **With or Without Us**

Many indicators point to engineering education having a promising future in the K–12 environment. However, it is dangerous to assume that technology education programs must naturally be a part of that future. The challenges addressed above are likely to seriously hinder the linkage between engineering and technology education unless they are addressed on a nationwide scale. Professionals in the field of technology education will need to act decisively and soon to capitalize on current momentum.

## **Recommendations**

- Increase the mathematics requirements in technology teacher preparation programs, including coursework in the concepts of calculus.
- Initiate state and national program renewal projects specifically designed to attract underrepresented groups with updated programs, curricula, and facilities.

- Expand or supplant the *Standards for Technological Literacy* with a condensed set of minimum core content requirements for technology programs.

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# Engineering and Technology Education

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Teacher Educator Perspective

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The advancement of technology on a global basis has heightened the expectations many hold for public education. With the advent of high-stakes testing, a focus on reading, writing, and arithmetic are no longer sufficient to satisfy most with the offerings of the local secondary school (Daugherty, 2006). The public demands a more savvy citizenry—graduates with the skills required to solve complex technological problems, competence with computers, an ability to manage and make sense of large amounts of data and information, and an ability to work in diverse settings to solve increasingly complex problems. Since these are skills that are typically associated with the practice of engineering, there is an increasing level of interest in introducing engineering to students at the secondary level (McKenna & Agogino, 1998).

Subsequently, engineering courses and programs are starting to emerge in secondary schools in almost every part of the United States, particularly where state initiatives have placed a high emphasis on technology or on boosting the number of qualified engineers (McVearry, 2003). This emergence seems to be driven by advocates both internal and external to the engineering community. There appears to be increased optimism within the engineering community in the United States that secondary-level engineering programs offer a powerful way to affect the number and quality of students entering post-secondary engineering programs (Camp 1997; Johnson & Sheppard, 2002; Kimmel & Cano, 2001). External to the engineering community, leaders in the field of technology education have placed an increased emphasis on engineering-related standards, content, and instructional methodology in secondary technology education classrooms as well as in teacher preparation programs. With the publication of the *Standards for Technological Literacy* (ITEA, 2000), many leaders in technology education have reexamined their curricular offerings and the purpose of their programs, initiating efforts to deliver content more closely related to engineering. Similarly, technology teacher educators have crafted new accreditation standards that mirror the *Standards for Technological Literacy* and also include an increased emphasis on engineering and engi-

neering design (ITEA/CTTE/NCATE, 2003). This restructuring of technology teacher education has involved an examination of both the academic and instructional content needed as well as the unique engineering-related experiences chosen for integration into preparation programs.

While technology education is beginning to explore ways to teach engineering design and related concepts at the secondary and pre-service levels, the challenge lies in delivering core engineering concepts while remaining true to a focus on technological literacy and the historically high value placed on hands-on learning (Dearing & Daugherty, 2004). Unfortunately, with a few notable exceptions, technology education and technology teacher education programs in the U.S. appear not to have substantially altered their curricular offerings and educational experiences to include increased levels of mathematics, science, and engineering experiences. Rather, they have largely adapted to the trend toward additional engineering content by renaming technological problem solving activities, calling them engineering design activities. Clearly, the technological problem solving activities, common in technology education classrooms for decades, have some relationship to engineering but they are almost always missing the mathematics and science content needed to make the transition.

Findings from cognitive science research and the curriculum design community offer suggestions for the creation of more effective technology education and technology teacher education curriculum materials and learning experiences (Bransford, Brown, & Cocking, 1999; Wiggins & McTighe, 2005). Frankly, if technology education is to forge a lasting relationship with the engineering community, it must: (a) identify core engineering content that is to be delivered in technology education and build learning experiences and assessments around these; (b) increase the level of mathematics and science included in the curriculum and in the engineering design problems used; (c) conduct, disseminate, and implement the findings of research on learning and teaching engineering in technology education; (d) develop and deliver a sustained series of teacher professional development programs that prepare practicing teachers to deliver high-quality engineering experiences in their classrooms; and (e) raise both the floor and the ceiling of the technology education experience and increase the number of students entering secondary programs and ultimately transitioning to undergraduate engineering programs.

## Recommendations

- Leaders in technology education should promote engineering and engineering design as a vital component of a standards-based technology education program.
- Although adding engineering content to technology education courses and programs may well prepare students to enter post-secondary engineering degree programs upon graduation, leaders in the field should remain steadfast in the belief that the primary purpose of the discipline is “technological literacy for all.”
- Organizational leaders in technology education (e.g., ITEA, CTTE, TED, NSF, etc.) must promote the fact that technology education is an appropriate discipline for delivering engineering content at the secondary level, but must also reject the notion that technology education is simply a feeder program for university engineering degree programs.
- Technology education leaders and curriculum developers must take steps to include a greater emphasis on advanced mathematical (e.g., trigonometry, calculus, etc.) concepts and applications in textbooks, design activities, and other curriculum materials.
- Technology education leaders and curriculum developers should work with members of the science and engineering communities to identify appropriate content and instructional methodologies for including heightened levels of engineering content in technology education courses and programs.

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# Engineering and Technology Educators Working Together to Promote Interest in Engineering and Technology Disciplines in K–12 Students

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Engineering Educator Perspective

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Thomas Friedman in *The World is Flat* wrote, “The National Science Board (NSB) report found that the number of American eighteen- to twenty-four-year-olds who receive science degrees has fallen to seventeenth in the world, compared with our ranking of third three decades ago...universities in Asian countries now produce eight times as many engineering bachelor’s degrees as the United States” (Friedman, 2006, pp. 330–331). The decrease in science, engineering, and technology degrees from United States universities may result in a crisis in the near future regarding our leadership in innovation and technology development. A major reason for this degree decrease is a declining interest in engineering and technology at the K–12 level. Engineering educators need to collaborate with technology education teachers to address this declining interest by improving technological literacy in the United States.

The Gallup Organization conducted two surveys for the International Technology Education Association (ITEA) on the American public’s perceptions regarding technological literacy (ITEA, 2001; ITEA 2004). The following three conclusions were drawn from these surveys:

1. The public understands the importance of technology in our everyday lives and understands and supports the need for maximizing technological literacy;
2. There is a definitional difference: the public thinks first of computers when technology is mentioned, while experts in the field assign the word a meaning that encompasses almost everything we do in our everyday lives; and
3. The public wants and expects the development of technological literacy to be a priority for K–12 schools.

Organizations such as the National Science Foundation (NSF), ITEA, the American Association for the Advancement of Science (AAAS), and the National Academy of Engineering (NAE) have been attempting to raise the awareness of technological literacy since the 1980s (AAAS, 1990; Bloch, 1986; ITEA, 2000; Pearson & Young, 2002). The ITEA's *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000) was a monumental work that was designed to establish a framework and a set of technological standards for K–12 education.

The NAE has also produced two reports from its *Engineer of 2020* initiative. These reports, *The Engineer of 2020: Visions of Engineering in the New Century* (NAE, 2004) and *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* (NAE, 2005), both advocate the need for the engineering community to be involved in technological literacy. A major recommendation from the second report is that “the engineering education establishment should participate in efforts to improve public understanding of engineering and the technological literacy of the public and efforts to improve math, science, and engineering education at the K–12 level” (NAE, 2005, p. 3).

State school systems appear to have a choice of two general approaches to teaching technological literacy. Administrators can incorporate technology standards within the existing mathematics and science curriculum, or they can attempt to address the technology standards in a set of technology and/or engineering courses. This second approach would involve a separate curriculum that would be mostly directed to high school students. While both approaches are needed, there are two significant advantages in pursuing the first approach: (a) teachers can begin to address the issue of technological literacy at a much earlier age and begin to positively influence students to pursue engineering and technological careers; and (b) teachers would affect all K–12 students while, in the second approach, only a limited number of students would be reached.

While in the past, collaboration between engineering educators and technology teacher educators has been minimal, that collaboration is growing as noted by the creation of several engineering and technology education departments at universities. Engineering educators are beginning to see the positive influence that technology education can have on K–12 students. Working together, these educators could do much to address the concerns noted above.

## Recommendations

Engineering educators and technology educators should collaborate in the following ways to help bring about technological literacy:

- Teach post-secondary students who are preparing to be technology education teachers. Engineering educators could help infuse engineering content in technology education programs that are graduating students who require certification to teach engineering content and programs in middle and high schools, such as *Project Lead the Way* (PLTW, 2007).
- Conduct research on the assessment of technological literacy in K–16 students and the general public. In *Tech Tally: Approaches to Assessing Technological Literacy*, the writers state the following: “the starting point for improving technological literacy must be to determine the current level of technological understanding and capability . . . the committee defined technological literacy as having three major components, or dimensions: knowledge, capabilities, and critical thinking and decision making” (NAE, 2006, p. 2).
- Work with college admission personnel to develop admission requirements that include technological understanding and capability.
- Conduct research on the teaching and learning of technology in K–16 students. The emphasis here should be on how students learn technological concepts.
- Teach post-secondary students who are preparing to be K–12 teachers. Engineering and technology educators could teach a seminar/class for education majors on the engineering design process and how it can be used to help develop problem-defining and problem-solving skills in K–12 students.
- Teach general education courses to post-secondary students of all disciplines. Universities need to rethink general education programs to include technological literacy for all university students.
- Provide professional development for K–12 teachers.

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# A State Supervisor's Perspective of the Future

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Technology Supervisor Perspective

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One of the most pressing questions confronting technology education state supervisors today is the role and significance of engineering content and courses in state instructional programs. For the purpose of this essay, the following assumptions are made—technology education is defined explicitly and implicitly by the *Standards for Technological Literacy* (STL) (ITEA, 2000). While some engineering concepts, principles, and skills are shared and found within these standards, technology education is not the same as engineering (or pre-engineering) education in design or purpose. Technology education's primary purpose is one of general literacy, and as with other literacy programs (e.g., reading, writing, mathematics, and science), it is designed to serve all students. In contrast, pre-engineering programs are vocational in the sense of preparing students for a specific occupation or cluster of related occupations. Furthermore it is assumed that some of the prerequisite understandings required of technology education and engineering differ, with the study of engineering requiring a deeper understanding of mathematics and science. Finally, it is also assumed that while technology education serves well students who have the desire and ability to become engineers, pre-engineering programs such as *Project Lead the Way* (PLTW) are more focused, generally more rigorous, and better reflect university engineering programs, and the educational pathway to such programs.

As a state supervisor I am confronted with the following questions:

- Should the purpose of technology education change to become exclusively that of pre-engineering?
- Alternatively, should only a portion of state and local funds be redirected to pre-engineering programs?
- Is there any evidence of the efficacy of pre-engineering programs increasing the number of students enrolled in university engineering programs and increased success of these students once enrolled?
- Assuming pre-engineering programs are demanding and require prerequisite understandings of advanced high school mathematics

and science, should funds be redirected to pre-engineering programs to serve students who are already successful (by definition those students capable of advanced mathematics and science)?

- Given finite state and local resources, would students served in non-pre-engineering technology education programs suffer from the redirecting of resources?
- Would serving at-risk students\*\* through technology education programs be a better use of finite resources?
- Rather than using redirected funds, can additional resources be found to support pre-engineering programs to avoid reducing the number of existing technology education programs?
- Would the inclusion of pre-engineering programs such as PLTW into a state or local technology education instructional program enhance the overall program through the rigor and prestige inherent in engineering?

Addressing these questions, beginning with the last, it is felt that the inclusion of pre-engineering programs into our traditional technology education program would enhance and strengthen our state's program (Note: In 2002 PLTW became part of the North Carolina scope & sequence). State leadership (including the state superintendent) believed that of all Career and Technical program areas, technology education was best positioned to oversee and direct middle and high school pre-engineering programs. However, regarding the displacement of resources, most of the resources (teachers, facilities, and funds) applied to the new North Carolina pre-engineering programs displaced existing programs; veteran teachers were trained and existing facilities were updated as needed.

The question of the best use of finite resources is difficult to answer. There is strong evidence that most at-risk, academically struggling students come from economically disadvantaged settings. One could argue that more students would attend schools of engineering through programs designed for the economically disadvantaged and at-risk students than pre-engineering programs that end up serving students who would likely end up becoming engineers regardless of intervention. A curious, if not confounding, statistic regarding our PLTW programs is that more

\*\* North Carolina currently has a high school dropout rate (9th graders graduating with their class) of approximately 33%, slightly higher than the national average which is estimated at 30%.

than half of the students served in the North Carolina programs have been identified as at-risk. What is not known at this point is if they were struggling academically going into the pre-engineering programs and what their success rates are as measured by their instructional outcomes.

In an attempt to address these questions, a strategic planning team comprised of business and industry, technology education teacher educators, technology teachers, and department of education consultants, developed a new technology education scope and sequence (S&S) for North Carolina, which may be informative at the national level. The new program is comprised of three primary goals:

1. developing technological literacy for all students (a role analogous to mathematics and science education);
2. providing quality pre-engineering programs for students interested in pursuing occupations within the fields of engineering; and
3. supporting the study and understanding of mathematics and science through the use of technology tools and processes (This last goal is addressed primarily through a visualization and modeling curriculum which will play an increasingly significant role in serving at-risk students).

While keenly aware of the need for additional research as well as the need for a clearer and deeper understanding regarding the role and relationship of engineering to and within technology education, I respectfully offer technology education leaders and administrators the following suggestions.

## Recommendations

- Do not lose the focus of the *Standards for Technological Literacy* and what the standards imply. While one should support the addition of pre-engineering programs into the schools, general literacy programs should not be displaced. More is to be gained through programs designed to promote general technological literacy than one more narrowly defined such as that of pre-engineering. Imagine a proposal to replace a K–12 science literacy program with a “pre-scientist” program designed for a select few interested in becoming scientists. Most would find such a strategy absurd.

- Do not sacrifice those students needing the most help by diverting funds to serving students who have already proved themselves capable and college ready.
- Remember that the vast majority of our citizens will not (and need not) become engineers. However, if we are to thrive as a nation, the vast majority of our citizens must be technologically literate.

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# Project Lead The Way: The Technology Education-Engineering Linkage for the 21st Century

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While engineering made an entrance into the K–12 technology education standards with the publication of the *Standards for Technological Literacy: Rationale for the Study of Technology* (STL) in 2000 (International Technology Education Association), it was not until the exponential growth of *Project Lead The Way* (PLTW) in the 21st century that engineering content actually entered the nation’s high school classrooms. The PLTW curriculum is a four-year sequence of technology education courses that, when combined with college preparatory mathematics and science courses, introduces students to the scope, rigor, and discipline of engineering and engineering technology. In 2006, PLTW courses were being offered to 175,000 students in 1,300 schools in 49 states, and these efforts were being supported by 21 universities.

The strength of the PLTW curriculum is twofold. First, it is standards-based, utilizing the STL (2000) as its foundation, augmented with national science, mathematics, and language arts standards. Second, PLTW involves engineering professors in the curriculum development process for each of its courses. Involvement of the engineering profession from the curriculum’s inception adds credibility to the PLTW courses. Nationally, PLTW has received numerous recognitions for its problem-based curriculum. Both the National Academy of Sciences and the National Academy of Engineering recommend the PLTW instructional model that fosters high-quality teaching with world-class curricula. In short, PLTW is the national linkage between technology education and engineering.

A few states, like New York and Indiana, have been at the leading edge of adopting PLTW as a component in the state technology education curriculum. Indiana technology education teachers have embraced PLTW and its infusion into the school curriculum (Rogers, 2005). These teachers perceive the PLTW curriculum as being very effective in developing pre-engineering competencies in their students.

The results of an Indiana study indicated that high school principals have very strong positive perceptions of PLTW and its effects on their schools, teachers, and students. The principals noted a strong positive effect on students' motivation and enthusiasm as a result of PLTW. They also noted a positive residual effect on technology education teachers. The principals also indicated that the students' critical thinking skills and problem-solving skills were improved by the PLTW pre-engineering curriculum. Parents of students from PLTW programs also noted the positive benefits of PLTW.

The costs for a high school to add PLTW to its existing technology education program are minimal, especially when weighed against the benefits to students. For example, to convert a traditional computer-aided drafting course to PLTW's *Introduction to Engineering Design* would require an annual investment of \$4,000 to lease the Inventor software. This lease includes all the required software for every PLTW course. For a high school to add PLTW's *Principles of Engineering* course would require an investment in equipment of approximately \$16,000. Again, technology education programs often have some of the required equipment in existing labs, so the costs will vary.

PLTW can be effectively infused in high schools of varying sizes. In Indiana, for example, a small rural high school with a 9–12 enrollment of approximately 300 students has established an exemplary program with its one technology education teacher. Many large urban high schools offer an excellent array of technology education courses, including all eight of the PLTW courses.

The technology education profession should utilize PLTW as its linkage to engineering. The engineering profession is seeking ways to enter the K–12 environment, and technology education has already established itself in the secondary school curriculum. PLTW provides a vital link between engineering and secondary schools, whose principals and teachers have already indicated acceptance of PLTW and its positive effects. The technology education profession should capitalize on the success of PLTW. Otherwise, as has happened at some universities, engineering will embark on its own K–12 engineering curriculum, a curriculum that does not include technology education.

Where technology education programs have embraced PLTW, the programs are growing stronger, adding technology education teachers, increasing course offerings, expanding laboratories, and strengthening

community support. For these programs, the future is very bright. The same is true for universities that have incorporated PLTW into their technology teacher education programs. In states that have embraced PLTW, school administrators are contacting university teacher education programs seeking PLTW teachers. Across the spectrum, the technology education programs that have embraced PLTW as their linkage to engineering are “leading the way.” Technology education programs that do not build a strong linkage with PLTW will become non-existent in the 21st Century.

## Recommendations

- The technology education field, including state departments of education, should embrace secondary pre-engineering curricula, including PLTW, and insure that engineering is a component of technology education.
- The technology education field must not view PLTW as a separate discipline. PLTW should be viewed as a “trade name” for the pre-engineering curricular content offered to students through secondary technology education.

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# Important Opportunities for All

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It is my personal belief that it is critical for the technology education experience to include pre-engineering concepts and be mandatory for *all* students in school. Taking the step of including engineering will build logically upon the evolution of technology education. In the transition from industrial arts to technology education, the content expanded from the appropriate use of tools and a focus on industry to also include design and societal impact. Incorporating an engineering component will bring technology education to a new level, and at the same time benefit student learning. At the higher education level, engineering can be viewed broadly as the use of science concepts (e.g., heat transfer, dynamics, materials, etc.) that are applied to solve problems (e.g., increasing efficiency from a power plant).

Often tools such as CAD and thermal analysis software, or construction of small models are used for the design and analysis of these problems. In a technology class, including the engineering component expands the use of a design process to also apply science-based knowledge to develop solutions to problems, providing an applied learning experience. What we end up knowing is what we can learn how to use. We learn by doing. In his recent article, Lehrer (2006) connects modern neuroscience findings to the process of learning through hands-on experiences. What better opportunity exists than to provide students with experiences through technology/engineering that will be lessons learned for life no matter what career aspirations they have? Research in the sciences about the student learning and retention of concepts is addressed by both the National Research Council (2005) and White (1998). While technology is different than science, it is reasonable to infer that the hands on nature that accompanies the doing and learning in a technology class would match that of science. Many technology teachers already incorporate science concepts into their classes, but it is not the typical kind of teaching done in technology.

I can personally attest to the advantages of combined learning experiences, not through classes, but based upon my childhood experiences. I had wonderful learning opportunities as a child because my parents continually involved all of us in lots of meaningful, hands-on projects, indiscriminate of our age or gender. One of the projects I recall is installing the charged wire fence around an enclosure for a pony we kept in our backyard. I learned more about electricity from that experience than from anything in secondary school. The knowledge that came from driving the metal fence poles into the ground, adding insulators to fasten the wire so that it wouldn't short out, and learning that the electric pulse came at regular intervals is something that remains with me to this day. And while there were many smaller construction projects over the years, another memorable project the family took on was the building of a log cabin at a campsite in Maine, a location without electricity or running water. We helped to read the blueprint plans, obtained the right parts in order, and did much of the assembly and construction. Each time we worked on a project, we knew what the goal was and learned about all the principles and tools that were needed for successful completion. In addition, we learned to make modifications and problem solve as the project progressed.

Every student, no matter what opportunities are provided at home, will benefit from having an in-school opportunity to experience the hands-on work of solving real challenges and problems. Ideally any stereotypical roles and conceptions of ability based upon gender or ethnicity that tends to be induced by society will be dissuaded by the teacher. As a result, students will not only learn the concepts but they will discover areas where they have strengths that might not be apparent in traditional classrooms. One of the best ways to do this is by merging the grade-level appropriate science knowledge into technology education classes, making it much like engineering. Not only does it create a motivational environment for learning, but as Lehrer (2006) and White (1998) report, it also results in long-term learning and knowledge. With direct experiences like this, students will become more literate in how technology impacts them, and will also develop a confidence that allows them to analyze and assess potential solutions. Including engineering in technology classes will provide a rich environment that introduces students to many career options, provides a strong foundational knowledge in science and applications, and gives them the ability to perform in problem solving environments.

## Recommendations

- Technology education will provide a richer experience for students if it should include the application of science concepts. One of the most effective ways to do this is to train technology teachers not to shy away from the use of science and mathematics as they work with their students in the approach and solutions to technical designs. If technology education continues to work in a silo, as the other disciplines do, the strength of real-world applications in technology will not be as robust as it has the potential to be.
- It is a common goal to increase the diversity of students who take technology education classes. This will only happen when stereotypical roles and abilities are removed from the experiences that students have in their classes. Since the majority of technology teachers are white males, they are not engrained with the knowledge about what the reactions and motivators are for female and minority students. Technology education teachers should find ways to actively work and communicate with educators from the underrepresented populations to avoid a self-replicating model that will not diversify.

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## **CHANGING CONTEXT IN ENGINEERING AND TECHNOLOGY EDUCATION**

We are living in very challenging times, as globalization brings a changing landscape of expertise in scientific and technological leadership. The National Science Board has indicated that the U.S. science and engineering workforce is imperiled due to global competition and a shortage of scientific and technologically competent graduates entering the workforce (NSB, 2003). This shortage has resulted in the need to improve the educational structure and capabilities of K–16 students and faculty. In response to this need, the Accreditation Board for Engineering and Technology (ABET) developed “Criterion 3: Program Outcomes and Assessment” within *Engineering Criteria 2000*, and the International Technology Education Association published the *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000). Both initiatives were designed to help guide the development of engineering and/or technology education. In particular, these initiatives are “committed to producing engineering and secondary school graduates, respectively, with a higher level of technological competency and literacy and with the motivation, capability, and knowledge-base for life-long learning” (Gorham, Newberry, & Bickart, 2003, p. 95).

Engineering education has emerged as a separate discipline with the National Academy of Engineering’s criteria for election reflecting the value of educational contributions and the development of degree-granting engineering education departments at Purdue University and Virginia Tech University (Lohmann, 2005). The engineering education community is also more actively involved with K–12 education than at any other

time in recent history, from searching for ways to infuse engineering into existing curricula, to developing stand-alone educational experiences for students (DeGrazia, Sullivan, Carlson, & Carlson, 2001; Poole, DeGrazia, & Sullivan, 2001). There is a growing awareness that engineering and technology education are close relatives; a question being sorted out is whether they are cousins or siblings.

Spurred by these and other initiatives, the engineering and technology education fields have begun to broaden their research agendas to better prepare the next generation of technological thinkers. For example, technology education researchers have begun to explore the integration of engineering concepts within the K–12 classrooms as an avenue to developing technological literacy (Dearing & Daugherty, 2004; Lewis, 2005; Wicklein, 2006). There are also the beginnings of research regarding the embedding of mathematics and science in technology education lessons (Akins & Burghardt, 2006; Stone, 2005). These beginning efforts indicate that it is challenging to meaningfully imbed math into technology education. Furthermore, while there has been extensive research that examines student learning using scientific inquiry, analogous research related to design is in its infancy. The issue of the design processes used by engineers and technology educators is being examined for similarities and differences. One key difference is the use of analytic predictive tools by engineers versus building on prior practice by technologists. Salinger (2005) indicates that “the study of engineering is not vocational; it is a way of thinking” (p. 2). Not only is research needed regarding student learning using design, but also about the compatibility of the engineering view and the way of thinking, with technology education practice. These are examples of the directions that specific research efforts in engineering and technology education may take. However, what is unclear is the future of the broader research agenda in engineering and technology education.

## **THE ROLE OF A RESEARCH AGENDA FOR ADVANCING A DISCIPLINE**

Scientific inquiry is a continual process of rigorous investigation to answer the critical questions of a discipline. Advances in scientific knowledge are achieved through long-term scholarly efforts of the scientific community by creating new understanding in the form of models or theories that can be empirically tested (Shavelson & Towne, 2002). Accumulation

of scientific knowledge over time is nonlinear and indirect. It often involves highly contested or controversial results that undergo professional scrutiny, skepticism, and criticism. Through this process, research results are questioned, studies are replicated, and results confirmed or rejected. In only the rare case does a single study produce an indisputable result; hence, multiple studies using numerous methods in varying contexts are needed to establish a verifiable base of understanding.

To be ethically conducted and produce valid results, scientific efforts must be guided by fundamental principles that are agreed upon by the community of researchers within a discipline. The guiding principles that underlie all scientific inquiry, including educational research consist of:

- posing significant questions that can be investigated empirically;
- linking research to relevant theory;
- using methods that permit direct investigation of the question;
- providing a coherent and explicit chain of reasoning;
- replicating and generalizing across studies; and
- disclosing research to encourage professional scrutiny and critique (Shavelson & Towne, 2002, p. 52).

A research agenda is the framework that determines the boundaries for scientific inquiry that addresses the fundamental questions of a discipline. It provides the means of grounding theory with practice. Ideally, practitioners uncover and communicate the problems to be investigated to the researchers who find ways to explore the problems within the research agenda of the discipline. If the problems do not fit within the research agenda, the agenda is questioned and modified. It is through this synergistic and iterative process that the research agenda evolves. An effective research agenda is one that stands the test of time as researchers and practitioners exchange problems and research results to move the discipline forward (Liles, Johnson, Meade, & Underdown, 1995).

According to Liles and colleagues, an active research agenda is also complex and substantial enough to be divided into themes. These themes are then used to formulate multiple sub-questions that guide the research necessary to contribute to the body of knowledge needed to answer the fundamental questions of the discipline. Whatever the structure of an educational research agenda, it must have built-in flexibility to reinvent itself as needed to more effectively meet the evolving challenges of the field.

## **PERSPECTIVES ON A RESEARCH AGENDA FOR ENGINEERING AND TECHNOLOGY EDUCATION**

The question of critical research areas in engineering and technology education has been the focus of discussion for several government councils and professional association committees in recent years. Several special initiatives have been charged with the task of identifying the current status of research in these areas and determining the critical questions that need to be answered. The following section is a description of the current efforts to examine the state of research in engineering and technology education, as well as a critique of the conclusions that have been raised. These efforts include the work of the Committee on Research in Mathematics, Science, and Technology Education (National Research Council), the Center for the Advancement of Scholarship on Engineering Education (National Academy of Engineering), the National Science Foundation (Engineering Education Research Colloquies), and Project 2061 (the American Association for the Advancement of Science).

### **Committee on Research in Mathematics, Science, and Technology Education**

In 1985, the National Research Council's Committee on Research in Mathematics, Science, and Technology Education (CRMSTE) submitted a report to the National Institute of Education that reflected its judgment of the current status and recommended future directions for research in mathematics, science, and technology education. The committee stated that educational research has a long tradition of maintaining "a relatively loose structure, multiple sponsors, and multiple agendas" (p. 52). Without rejecting that basic strategy, the committee recommended that a more focused research agenda be developed that enhances our knowledge and experience base in mathematical, scientific, and technological learning in the United States. The ultimate goal of this effort was to improve pre-college education in mathematics, science, and technology.

It is suggested in the report that additional investments in research and development will contribute to our understanding of the causes of our present deficiencies in education for mathematics, science, and technology, and will highlight ways to resolve the problems. The committee further rec-

commended that future research in this area be focused on understanding the development of reasoning and ways to increase the amount of quality learning time through better instruction, better settings for learning, and the development of new learning systems (CRMSTE, 1985). The goal of this committee was to suggest a strategy for research and development that would provide better answers to practical questions such as “How should new courses be designed and taught to ensure student achievement? What makes an effective teacher? Or a good school? How can modern information technology contribute? How can parents and the public assess the extent to which educational goals are being reached?” (CRMSTE, 1985, pp. ii–viii)

Two years later, the Committee on Research in Mathematics, Science, and Technology Education completed a follow-up report for the National Science Foundation that focused on the need for more interdisciplinary research in mathematics, science, and technology education (CRMSTE, 1987). Their basic premise was that interdisciplinary research in mathematics, science, and technology education is both necessary and feasible. As defined in the report, interdisciplinary research refers to all types of research/practice collaborations including collaboration among different specialties; among disciplines; among basic and applied research and development; and among researchers, practitioners, and policy makers.

Related to the call for a more interdisciplinary research agenda is Fortenberry’s desire for larger-scale research in engineering education (Fortenberry, 2006). He commented that, while a significant amount of research is being conducted, in order to have the greatest benefit, careful thought must be given to the manner in which the overall research is being pursued. He argues that the researchable problems in engineering education are too large to be tackled by individual researchers. Using the biomedical community as an example of a successful large-scale research agenda, Fortenberry suggests that engineering education research focus more on broad goals as opposed to the specific goals of most small-scale research projects. Priorities for future research need to emphasize high-leverage research opportunities that will increase the return on investment from research funding. He also makes a case for more problem-directed research with clearly defined deliverables and specific endpoints. Finally, large-scale research needs to be committed to employing multiple investigators, while at the same time staying focused on the multi-institutional and interdisciplinary approach.

## **Center for the Advancement of Scholarship on Engineering Education**

In January 2002, the National Academy of Engineering (NAE) hosted a retreat to discuss the importance of engineering education research as a way to change how engineering is taught and practiced. Twenty-eight leaders from academia, industry, and government agreed on the need to establish a center for research on engineering education within the NAE.

With the establishment of the Center for the Advancement of Scholarship on Engineering Education (CASEE), the NAE is able to promote scholarship and innovation in engineering education. The goal of CASEE is to close the gap between the knowledge, skills, abilities, and attitudes of engineering graduates and those attributes desired by academia, industry, and government. The way to close this gap is to build capacity for the conduct of high-quality research on engineering education and integrate engineering education research and practice by connecting the most promising engineering education research findings into classroom and laboratory practice.

In order to meet its goals, CASEE has articulated its core strategies, research thrusts, and specific research areas for investigation. The three core strategies that underlie all activities of CASEE include: (a) building capacity for the conduct of high-quality research on engineering education; (b) integrating engineering education research and practice; and (c) leveraging the efforts and interests of relevant stakeholders. The four “research thrusts” focus on:

1. identifying bodies of knowledge required for professional practice in engineering fields;
2. developing, validating, and implementing institutional, instructional, and curricular strategies that value diversity;
3. developing, validating, and implementing innovative, cost-effective and time-efficient instructional and curricular strategies and technologies for improving student learning, and enhancing the instructional effectiveness of current and future faculty; and
4. developing, validating, and implementing assessments of student learning and instructional effectiveness.

To help accomplish significant research in these “thrust” areas, CASEE offers six additional research areas, as well as specific research ideas within

each area. CASEE suggests that the following areas serve as an initial taxonomy of the “research landscape”:

1. Research on teaching, learning, and assessment processes;
2. Research on teacher and learner behaviors and interactions;
3. Research on courses, laboratories, curricula, instructional materials, and learning technologies;
4. Research on educational management and goal systems;
5. Research on political, economic, and social influences on engineering education; and
6. Research on diffusion of educational innovations.

By working within these research areas CASEE seeks to “promote and to facilitate rigorous quantitative and qualitative approaches to education research, to disseminate education research results and to aid their transition into practical use.” By supporting scholarly interaction between educational researchers, practitioners, and consumers, CASEE plans to continue developing and prioritizing these researchable issues as well as synthesizing what is learned and what is still necessary to know.

## **Engineering Education Research Colloquies**

The Engineering Education Research Colloquies (EERC) is an initiative sponsored by the National Science Foundation. The goal of this initiative is to develop a systematic framework for engineering education research and increase the nation’s capacity for engineering education research. This goal is to be accomplished through a series of colloquies that will involve a collaboration of over 70 engineering education leaders and researchers, STEM education researchers, learning scientists, and representatives from industry, working together to meet these needs.

The first colloquy, held in September 2005, resulted in the identification of 16 research themes from an original set of 48 topics that represented the desired outcomes from educational programs in engineering. The second colloquy, held in October 2005, resulted in an additional two themes to the set of 16, along with in-depth descriptions of critical engineering education research areas. Then, in February 2006, the 18 themes were synthesized into five research cluster areas that cover research on: (a) what constitutes engineering now and into the future; (b) how diverse human talents contribute to the social and global relevance of the profession; (c) developing

learners' engineering knowledge and expertise; (d) the instructional culture and epistemology of engineering educators; and (e) the development of assessment methods, instruments, and metrics to enhance engineering education. Another colloquy is planned that will focus on building capacity in research, faculty development, curriculum, and infrastructure.

## Project 2061

The main effort to create a research agenda for technology education was organized through *Project 2061* of the American Association for the Advancement of Science (AAAS). *Project 2061* hosted two technology education research conferences that brought together leading scholars in science education, technology education, and cognitive science. During the first conference, 35 participants discussed the role of research in technology education around four themes: (a) research areas; (b) how children learn technological ideas; (c) research methods; and (d) assessment. After the conference, each of the participants was asked to share their thoughts through a reflection paper (Project 2061, n.d.).

Cajas (2000) synthesized the participants' reflections and highlighted several issues that need to be addressed in future research in technology education. First, although there is extensive research in science and mathematics education that can serve as a model for technology education research, the participants recognized that the issues in technology education are different. Second, the participants identified several areas of needed research in technology education that would fit within a productive research agenda focused on student learning of key technological ideas and skills that are needed for technological literacy (AAAS, 1993; ITEA, 2000). These included: research on how well curriculum materials and classroom instruction actually help students to learn specific technological concepts and skills; research on how teachers come to understand technology, and; research to determine the most efficient and cost effective ways to conduct professional development of technology educators. Third, there is a need to prioritize what to study, how to study it, and where and when to conduct the research. Cajas noted that several of the reflections offered ideas for research topics, but failed to provide a rationale for why one area should be prioritized over another. According to Cajas, we "not only have to clarify the areas of research, but also need to provide an argument for which area is most urgent. This is a difficult task, but setting priorities should be a priority itself" (Cajas, 2000, pp. 78–79).

Cajas offered the following list as a prioritized framework and rationale for research in technology education:

1. Specific goals for knowledge and skills students will learn;
2. How students learn those ideas and skills;
3. Shaping instruction to promote student learning; and
4. Enabling teachers to use this new instruction effectively.

Prioritizing the framework, according to Cajas, has a clear rationale because “until we learn more about what we want students to learn, what students know, and how they learn it, we are not prepared to study instructional methods. And until we learn more about what kinds of instruction are effective, we are not prepared to teach teachers how to do it” (p. 79).

## **CRITIQUE OF RESEARCH IN ENGINEERING AND TECHNOLOGY EDUCATION**

Several studies have been done in the past that examined the focus, methods, and overall quality of research in engineering and technology education. For example, Wankat (2004) conducted a meta-analysis of the first 10 years (1993 to 2002) of the *Journal of Engineering Education* (JEE). Based on his analysis, he concluded that the JEE was becoming a high-quality archival research journal. However, Wankat did identify weaknesses such as the lack of use of educational theories and learning styles and the publication of opinion pieces that contained little to no data or references. Similarly, Whitin and Sheppard (2004) conducted a six-year survey of papers published in *JEE* as part of the Carnegie Foundation’s *Taking Stock* study, to determine the primary topics that have been the focus of engineering education researchers. Noting the increase in the number of articles published in *JEE*, Whitin and Sheppard found that the majority of papers focused on engineering courses and programs.

Within technology education, concerns about the quality and focus of research have been raised for years (Foster, 1992; Johnson, 1993; McCrory, 1987; Passmore, 1987; Sanders, 1987). More recently, Zuga (1997) examined research that was published in the main technology education journals and dissertation abstracts from 1987 through 1993. Zuga found that half of the 220 studies she reviewed were primarily descriptive and focused on curriculum. Zuga outlined four areas missing from technology education research: (a) constructivism; (b) integration; (c) inclusion

of all students; and (d) cognition. Constructivist problem-based instruction, according to Zuga, is fundamental to technology education, along with the integration of other subjects, especially science and mathematics. However, she found that few of the published studies explored either of these components. What Zuga found to be most disturbing about technology education research was the lack of research on students. In particular, specific groups of students such as females, ethnic minorities, or physically and mentally challenged students were not the topic of much research. Lastly, few research studies explored cognition within a technology education context. In conclusion, Zuga stated that the focus of technology education research “on descriptions of status and curriculum development points to researchers who are narrow, inwardly focused, and oblivious to the goals of their own field” (p. 213).

Petrina (1998) conducted a similar meta-study of research published in the *Journal of Technology Education* (JTE) from 1989 to 1997. Utilizing meta-ethnography and both quantitative and qualitative analysis, Petrina performed a content and critical discourse analysis of the studies in JTE. In terms of research, Petrina concluded that of the 96 articles, 62% of the research methods used in the studies were either conceptual or descriptive and only 35% of these involved human subjects. In his examination of “analytical units of substance” he found that few studies explored issues such as appropriate technology, class, ecology, gender, labor, race, and sexuality. Petrina concluded that the lack of this type of research indicated an insubstantial “understanding of the way inequities play out in technology and the trades” (p. 38). Citing a study by Foster (1992) and studies by Zuga (1994, 1995, 1997), he stated that those examining research in the field have concluded it to be a “malfunctioning practice” (p. 28). Petrina’s final analysis of the “state” of technology education research was that “conservative voices are favored and critical voices the exception” (p. 51). He recommended that for research to be relevant, it needs to have “a distinct theoretical component and be cast within particular areas of research practice” (p. 48).

## **Analysis of Current Research in Engineering and Technology Education**

With the alignment of engineering and technology education comes the need to examine the collective state of educational research in these

related fields. The following describes an effort to examine the top engineering education and technology education journals to provide a critique of the current status of the published research. Understanding where we are in terms of research focus, method, and overall quality is a necessary step in developing a research agenda for the future.

This study involved the identification of the key journals in engineering and technology education. Input was solicited from key leaders in the field to identify these journals. A total of six technology and engineering education journals were identified. These include the *Journal of Technology Education (JTE)*, the *Journal of Engineering Education (JEE)*, the *Journal of Technology Studies (JTS)*, the *Journal of Industrial Teacher Education (JITE)*, the *International Journal of Technology and Design Education (IJTDE)*, and the *Journal of STEM Education (STEM)*. All of the articles that were published in these six journals within the past 10 years were obtained and reviewed for inclusion in the analysis. Articles were selected for further analysis if they explored some issue related to either engineering or technology education and were based on empirical data that was collected through either quantitative or qualitative methods. A guiding rule was that the studies to be reviewed needed to involve the collection and analysis of data. Therefore, synthesis pieces, commentaries, and opinion pieces were not included in the analysis. Also, only selected years of the certain journals were available for review, which included nine years for the *JTS* and seven years for the *STEM* (see Table 1).

Table 1. Number of Empirical Articles Examined in Each Journal.

<b>Name of Journal</b>	<b>Years Reviewed</b>	<b>Empirical Studies</b>
<i>International Journal of Technology and Design Education</i>	1997–2006	57
<i>Journal of Industrial Teacher Education</i>	Foundations of Technology 1996–2005	48
<i>Journal of Technology Studies</i>	1996–2004	28
<i>Journal of Technology Education</i>	1996–2006	56
<i>Journal of STEM Education</i>	2000–2006	13
<i>Journal of Engineering Education</i>	1997–2006	151
Total Number of Articles Reviewed		353

The studies that met the criteria were then reviewed and coded according to type of research, research method, data source, data type, and key variables. The initial codes for research type and method were generated from the classification provided in a typical educational research textbook (Gall, Gall, & Borg, 2007). The articles were screened carefully and thoroughly because some of the studies did not explicitly state the method that was used, while for others it was questionable whether the study held true to the method that was stated. For example, many of the studies referred to as experimental were actually quasi-experimental because there was no random selection from the population.

Codes for data source, data type, and variables were developed by reviewing the content of each article. The intent of the codes was to provide a general, yet descriptive term that could be used for generating frequency counts across all of the articles. The codes used to classify the research focus of each article were adapted from the coding scheme used in Wankat (2004) in his analysis of *JEE* articles. Modifications to Wankat's coding scheme included combining his Computer and Internet/Web codes into an Educational Technology code, expanding his Gender/Women code to Gender-Race, and adding Opinions-Attitudes and Problem Solving as new codes.

A second coder served as a reliability check by first examining and verifying the accuracy all of the codes that were assigned for the *JTE* studies and then checking the questioned codes by the first coder from all of the other journals. This resulted in 38% of the codes being examined by another person. When coding disagreement occurred, the coders discussed and resolved the disparity. For those codes that could not be resolved, a third coder was used to independently assign a final code. After this thorough examination of the coding scheme, the codes were agreed upon and deemed reliable.

## RESULTS

### Types of Research in Engineering and Technology Education

As shown in Table 2, the majority of the studies were classified as quantitative research, with fewer qualitative studies and a very limited

number of studies involving mixed methods. It should be noted, however, that the low number of mixed methods studies is a conservative figure. Several of the articles mentioned that they utilized mixed methods. However, most of the time only one research method was described in the published study and therefore the research was coded accordingly. The predominance of quantitative studies was more dominant in Zuga (1997) and Petrina's (1998) analyses. Petrina concluded that technology educators had yet to adopt more of the interpretive methods used by researchers in other "practical" fields, reinforcing the lack of qualitative studies in technology education research. As revealed in the current analysis, qualitative research has increased within technology education. When looking at the articles within the fields of technology education and engineering education together, the technology education journals published over twice as much qualitative research as the engineering education journals. Perhaps spurred by Hoepfl's (1997) qualitative methods "primer," technology education researchers appear to be rising to the challenge of pursuing research questions through a sustained, in-depth analysis.

Table 2. Type of Research.

Type of Research	Technology Ed.		Engineering Ed.	
	<i>n</i>	%	<i>n</i>	%
Quantitative	108	57.1%	139	84.8%
Qualitative	73	38.6%	24	14.6%
Mixed Methods	8	4.2%	1	.6%
TOTAL	184	100%	164	100%

Regarding the research method used, the majority of the studies in both technology and engineering education research were primarily descriptive in nature, as shown in Table 3. Technology education research, however, tends to rely heavily on descriptive surveys or the case study method, while the engineering education research relies more on quantitative research methods. This is similar to Zuga's finding that 65% of the 220 studies she classified were descriptive. Petrina reported that 25% of the studies published in *JTE* were descriptive in nature. Zuga noted that the descriptive research in her review relied heavily on the Delphi technique and mailed surveys. Similarly, Foster (1992) found that the majority of the graduate research in technology education relied on surveys that were designed to collect descriptive data.

Besides descriptive studies that involved the administration of questionnaires, the most commonly used quantitative methods in the studies analyzed were quasi-experimental, correlation, and causal comparative. Although no experiments involved true randomization, this is not atypical for social science research where random selection and assignment of students is impractical. The use of quasi-experimental, correlation, and causal comparative methods differs dramatically from the analysis reported by Zuga and Petrina, who both found few of these types of studies in their analyses. In regards to qualitative methods, interpretive research and case study were the most frequently used. Few studies relied on naturalistic methods such as protocol analysis and ethnography, perhaps indicating an area of need.

Table 3. Primary Research Method Used.

Type of Research	Technology Ed.		Engineering Ed.	
	<i>n</i>	%	<i>n</i>	%
Descriptive	80	42.1%	47	28.8%
Quasi-Experimental	26	13.7%	37	22.7%
Correlation	17	8.9%	38	23.3%
Causal Comparative	7	3.7%	20	12.3%
Interpretive	23	12.1%	12	7.4%
Case Study	25	13.2%	5	3.1%
Delphi	6	3.2%	1	0.6%
Protocol Analysis	6	3.2%	0	0.0%
Evaluation	0	0.0%	2	1.2%
Ethnography	0	0.0%	1	0.6%
TOTAL	190	100%	163	100%

## Types of Data in Engineering and Technology Education Research

The population groups that were sampled from in the reviewed studies predominantly included students or teachers (see Table 4). The focus on students ranged from preschool to college and adult. This is a vast improvement from Zuga's findings (1997) from a decade earlier and Petrina's more recent findings in 2004. Petrina had concluded that "relatively little time

has been spent investigating the practice of technology at the local, school-based level” (p. 35). This, however, no longer seems to be the case. College students were the most sampled population of students in the engineering education studies ( $n=99$ , 89.2%) while, as expected, the majority of the technology education studies sampled from secondary education populations ( $n=51$ , 47.2%). The next most common population group for the technology education studies was college students ( $n=33$ , 30.6%) followed by elementary students ( $n=18$ , 16.7%).

There was a wide disparity between engineering and technology education research in terms of their reliance on data from teachers. Only three of the engineering education research studies analyzed data collected from teachers, while almost one-fourth of the technology education studies involved teachers ( $n=49$ , 24.3%). Most of the teachers in the technology education studies taught at the secondary level ( $n=24$ , 68.6%), with the remainder teaching at the preschool ( $n=5$ , 14.3%), elementary ( $n=4$ , 11.4%), or primary school ( $n=2$ , 5.7%) level.

Zuga noted that most technology education studies seemed to rely on a “closed circle of people” (p. 209) that was comprised of technology educators and industrialists. This narrow scope appears to be widening somewhat within technology education research. The increase in the number of studies focused on students and the inclusion of administrators, parents, and the general public as population groups (although a small percentage of the total), may indicate a discipline that is beginning to extend its research base and perhaps its influence. Within engineering education, however, population groups that included administrators, parents, and the general public were not sampled. The focus of engineering education research has been primarily at the collegiate level. Although students comprised a large percentage (66.9%) of the population groups sampled in the engineering education research, Whitin and Sheppard (2004) were alarmed by the apparent lack of attention to students in the articles they analyzed. Attributing part of this conclusion to their coding scheme that used only one code per study, they stated that, if true, this lack of attention on students is an alarming trend “since engineering education reform is trying to maintain focus on students and student learning” (p. 10). The current study addressed this concern by separately coding multiple population groups within individual studies.

Table 4. Population Groups Represented in Research.

Data Source	Technology Ed.		Engineering Ed.	
	<i>n</i>	%	<i>n</i>	%
Students	107	53.0%	109	66.9%
Teachers	49	24.3%	3	1.8%
College Faculty	12	5.9%	15	8.8%
Professionals	9	4.5%	9	5.3%
Mixed Group	8	4.0%	9	5.5%
Administrators	5	2.5%	0	0.0%
Graduates	3	1.5%	10	5.8%
Parents	3	1.5%	0	0.0%
Documents	5	2.5%	8	4.9%
General Public	1	0.5%	0	0.0%
TOTAL	202	100%	163	100%

### Focus of Research in Engineering and Technology Education

As noted by both Zuga (1997) and Petrina (1998), technology education research tends to rely heavily on perceptions and self-reports rather than observable or verifiable data. As shown in Table 5, this continues to be the case with the majority of the technology education studies relying on perception (29.6%) and self-report data (26.5%). Only 11.7% of the studies relied on observable behavior and involved analysis of test scores. Very little technology education research has relied on data obtained from existing documents (5.1%), observable behaviors (11.7%), verbal protocols (2.6%), and archival data (.5%). Although the engineering education research also relies heavily on perceptions (27.9%) and self-report data (25.5%), there is greater reliance on test scores (26.7%).

Table 5. Type of Data Collected.

Data Type	Technology Ed.		Engineering Ed.	
	n	%	n	%
Perceptions	58	29.6%	46	27.9%
Self Report	52	26.5%	42	25.5%
Documents	10	5.1%	15	9.1%
Observable Behaviors	23	11.7%	3	1.8%
Test Score	23	11.7%	44	26.7%
Mixed Method	4	12.2%	4	2.4%
Verbal Protocol	5	2.6%	0	0.0%
Archival Data	1	.5%	11	6.7%
TOTAL	196	100%	165	100%

Regarding the focus of the research in engineering and technology education, most studies have addressed issues related to teaching and curriculum. This is consistent with Zuga's finding that 50% of the technology education research she reviewed dealt with curriculum from the perspective of assessing the beliefs of state supervisors and teacher educators. Foster (1992) also noted that the majority of the graduate research in technology education focused on pedagogy, curriculum, and program evaluation. In spite of Cajas' (2000) call for greater emphasis on studies of student learning, only 16.7% of the technology education research addressed this critical area.

The pattern of research focus is similar in engineering education, with the majority of the research focused on questions related to teaching and curriculum, and even less emphasis on student learning (8.4%). Engineering education research also tended to explore issues related to educational technology (12.6%) assessment and evaluation (11.4%), and gender (9%). This differs slightly from Wankat's review of *JEE*, which yielded teaching, computers, and design as the top three keywords that emerged in the engineering education studies. It is also interesting to note there has been very little empirical research on problem solving and design, especially when considering that these two cognitive issues are central to the curriculum and practices of both fields.

Table 6. Primary Focus of Research Studies.

Research Focus	Technology Ed.		Engineering Ed.	
	n	%	n	%
Teaching	51	26.2%	31	18.6%
Curriculum	48	24.6%	35	21.0%
Learning	33	16.9%	14	8.4%
Opinions-Attitudes	14	7.2%	9	5.4%
Gender-Race	10	5.1%	15	9.0%
Assessment-Evaluation	8	4.1%	19	11.4%
Problem Solving	8	4.1%	4	2.4%
Design	8	4.1%	1	0.6%
Educational Technology	8	4.1%	21	12.6%
Career-Professional Development	5	2.6%	7	4.2%
Completion-Retention	2	1.0%	8	4.8%
Communication-Writing	0	0.0%	3	1.8%
TOTAL	195	100%	167	100%

## CONNECTING THE RESEARCH PRIORITIES FOR A COMMON AGENDA

A few distinct commonalities emerge in the research priorities of engineering education and technology education (such as educational technology and assessment). Perhaps the greatest commonalities between the two are problem solving and design. As indicated in the above analysis, and also in Petrina’s and Wankat’s studies, design is emerging as a focused area of study within engineering education and technology education research. For example, the issue of the design processes used by engineers and technology educators has been examined for similarities and differences (Dugger, 1994). Also, different studies have emerged that explore

design thinking, in particular expert/novice design behavior (Christianns & Venselaar, 2005; Welch & Lim, 2000). Salinger (2005), for example, concluded that “the study of engineering is not vocational; it is a way of thinking” (p. 2). Besides research on design problem solving, what other key concepts are being and should be explored in engineering and technology education research? What are some areas of need in the research?

Based on the above analysis of research priorities in engineering and technology education, Table 7 provides an initial framework for setting the boundaries for future efforts of engineering and technology education researchers. The following research framework seeks to examine commonalities, such as design problem solving, as well as to delve further into what is actually being taught and learned in engineering/technology education courses. The framework also requires a focus on student performance and accountability, which is consistent with the national agenda for education set by the No Child Left Behind Act of 2001.

It is important to note that research on the practice of technology and engineering at the school-based level appears to be occurring with the large number of studies sampling students as their populations. However, with the predominance of descriptive methods and perception studies, this focus on students appears to be a superficial analysis. In order to better understand learning and the learner, the methods used in studies that examine student learning need to be broader and more in-depth. For example, protocol analysis is a method that a few engineering and technology education researchers have used to examine the thought processes of subjects while they complete a task or solve a problem (Atman & Bursic, 1998; Johnson & Chung, 1999). Verbal protocol analysis requires subjects to say aloud everything they think to themselves while performing a task or solving a problem. The researcher’s task is to take the incomplete record provided by the protocol and infer the underlying psychological processes by which the subject performed the task (Ericsson & Simon, 1984). It is also possible to use films of students and analyze their conversations and actions (Crismond, 1997). The Vermont Mathematics MSP (2005) has also developed a set of observation protocols for examining teacher and student behaviors in constructivist classrooms.

Table 7. Engineering/Technology Education Research Framework.

Research Issue	Key Questions
Teaching and Learning in Engineering and Technology Education	<p>How do high school students learn engineering concepts and skills?</p> <p>What are the most appropriate pedagogical strategies for engineering/technology educators?</p> <p>What pedagogical content knowledge is needed to incorporate engineering concepts into K–12 technology education?</p> <p>What engineering-related professional development techniques and strategies are effective in promoting teacher change?</p> <p>What issues, opportunities, and constraints do teachers confront as they infuse engineering concepts into technology education?</p>
Design in the Classroom	<p>What are the effective methods for developing core understandings of design (e.g., optimization)?</p> <p>How does design problem-solving skill improve student knowledge in other content areas (e.g., math, science, language arts)?</p> <p>How do students develop the ability to construct predictive models prior to constructing prototype designs?</p> <p>How do design activities support inclusion students?</p>
Technology Education Content	<p>What is the content currently being delivered in K–12 technology education classes? How does this align with the <i>Standards for Technological Literacy</i>?</p> <p>What are the content differences between engineering and technology education courses at the high school level?</p> <p>How do high school student attitudes toward engineering, technology, and STEM careers change after participating in an engineering-oriented curriculum?</p>

Research Issue	Key Questions
Engineering Education and Technology Education Collaboration	<p>What are the similarities and differences between NCATE and ABET accreditation requirements and implementation at the collegiate level?</p> <p>Do high school courses in engineering and technology change student career perceptions of engineering?</p> <p>What content/practice in high school technology education courses supports college level engineering education?</p>
Under-represented Populations	<p>What are the course dynamics (e.g., curriculum, teaming) that foster interest in engineering and technology education?</p> <p>What are appropriate initiatives to attract and involve more under-represented populations?</p>

Although this research framework is not comprehensive, it does reflect the important issues confronting the practice and development of engineering/technology education. It can be viewed as a starting point for the critical examination of teaching and learning in the field. Besides the priorities listed in the framework, there are other issues that merit consideration, such as:

- How should cognitive research on learning influence the engineering education process?
- How do teachers nurture critical thinking, innovation, and ingenuity?
- What roles do experiential learning practices, such as service learning, play in developing critical skills for a productive professional career?
- What is the nature of problem identification, formulation, and solution?
- What distinctive skills lead to successful open-ended problem solving?

However, it is very important at this point in the evolution of engineering and technology education to examine the interface between the disciplines, the areas of commonality, the areas of difference, and the connections to other academic disciplines. Recognizing their similarities can strengthen the engineering and technology education communities and yet their differences can distinguish the importance of both disciplines. It is a time to build on the similarities and benefit from the distinctions with positive changes based on research data, rather than anecdotes.

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# Engineering and Technology Education—Key Challenges for the Future

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Chapter

12

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## INTRODUCTION

Throughout this book the authors have addressed issues associated with the relationships between engineering and technology education. The conceptual and historical roots are clearly intertwined in both interesting and perplexing ways. Yet, aspects of the two academic and professional cultures are distinctly different and disconnected.

We begin this final chapter with a conceptual model designed to frame this relationship, largely from an occupational point of view. While this approach may initially appear to be somewhat incongruent with technology education's historical emphasis on general education, we encourage the reader to "hear us out." We are confident that the framework will address the pertinent issues involved in the relationship.

The model is designed to reframe the discussion away from a conceptually simplistic dichotomy that either (a) aligns technology education with engineering, or (b) highlights the ways in which they stand in contrast with one another. The first approach emphasizes their compatibility, pointing to a similar conceptual base and shared historical roots. The second approach focuses on distinctiveness, including the cultural, academic, and professional differences. The model is designed to serve as a context within which to frame key issues integral to an engineering/technology education alliance.

## FRAMING THE ISSUE

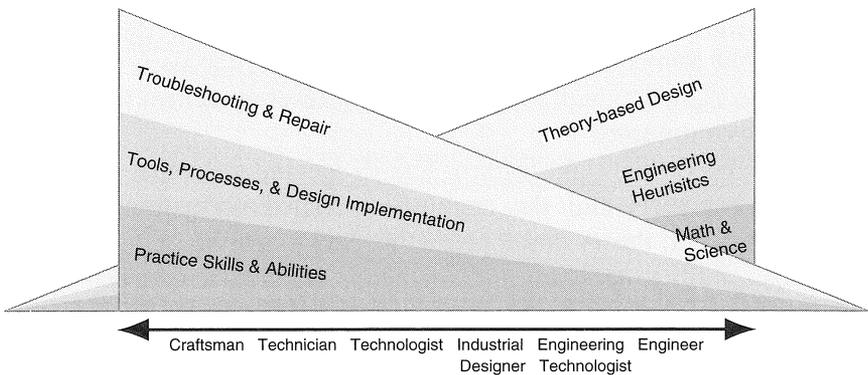
One important commonality between technology education and engineering is the involvement and interest of both in design. This similarity is clearly evidenced in the *Standards for Technological Literacy* (ITEA, 2000) where engineering design is a key element. This common foundation has led to an examination of ways in which the design characteristics and procedures of engineers and technology educators are similar and different. Similarities tend generally to focus on things like design loops, planning, prototyping, evaluating, and redesign. Discussions of contrast focus on the engineers' use of analytical tools in the optimization of design solutions to address selected constraints compared with technology educators' preference for trial and error.

This approach, however, suffers from an important logical flaw. While the "compare and contrast" approach makes sense at one level (i.e., engineers and technology educators both engage in design activities), it falls apart when viewed occupationally. Rather than beginning with the question, "How do engineers and technology educators design differently/similarly?" ...what if the point of departure were instead, "What is it that engineers DO?" and "What is it that technology educators DO?" The answers are clearly different. Engineers "do" design while technology educators "do" education about a range of topics including technology, social and ethical issues, how things work, the interaction between science and technology, problem solving, innovation, design, and much more. The primary role of engineers is broadly to produce designs that will solve problems and improve the quality of life. The goal of technology educators is to provide students with a range of knowledge and experiences necessary to function successfully in a complex technological world. Framed in this manner, it should be clear that the primary purpose of engineering and technology education are actually fundamentally different. The discussion that follows will show how these two very different purposes can be incorporated into a single model that informs the engineering-technology education relationship in a more conceptually appropriate manner.

## ENGINEERING AND TECHNOLOGY EDUCATION MODEL

Forming the foundation of the engineering and technology education model is an occupational continuum comprised of technology-related career titles (see Figure 1). On one end of the spectrum are highly skilled craftspeople with specialized training and expertise in specific trades. At this extreme are the individuals, typically with many years of experience and expert knowledge. This level of technology knowledge (i.e., tacit knowledge), as described by Frey (1991), “resists all attempts at verbalization. Such knowledge develops during deep and sustained experience” (p. 8). Not all technicians are able to achieve this level of finely honed skill.

Figure 1. Engineering and Technology Education Conceptual Model



At the other end of the continuum are engineers, whose work is typically grounded in mathematics and science-based analytical procedures. Koen (2003), in his seminal work on the engineering method, employs the term “heuristics” to describe this type of highly specialized knowledge.

Between these two extremes are a range of occupations that are involved, in various ways, with the central purpose of technology (e.g., the design, refinement, and production of artifacts and systems to meet the needs and

wants of individuals and societies). People employed in these occupations all engage in technological problem solving, which includes troubleshooting, innovation, invention, planning, and design (Custer, 1995).

The second feature of the Engineering and Technology Education model are “wedges” depicting the types and levels of technological knowledge and skills. The wedge on the left is comprised of a set of knowledge and skills common to highly skilled tradespersons. For example, automotive technicians are able to diagnose, repair, and replace components of automobiles, which consist in part of integrated and complex, computer-based feedback systems. Problem-solving research indicates that successful troubleshooting of technological systems depends on a specialized base of knowledge about specific systems and how they behave under various conditions and applications. This end of the spectrum includes the ability to select and use tools, implement designs, interpret drawings, and employ an enormous variety of practical skills and abilities. According to the model, the elements represented by this wedge decline along the occupational spectrum and tend to be substantially less represented within the engineering community.

The wedge on the right features knowledge and skills that are more typical of engineers and the engineering-related occupations. These include heuristics, theory-based predictive design analysis, and a knowledge of and ability to apply complex mathematical and scientific principles in the process of completing designs. The National Center for Engineering and Technology Education (NCETE) has identified a set of core concepts central to engineering design, which have been termed COPA. These include constraints, optimization, and predictive analysis (Merrill, Custer, Daugherty, Westrick, & Yong, 2007). Similar to the specialized technical wedge, the engineering-related knowledge and skill set is depicted as being less represented at the skilled trades end of the spectrum.

At this juncture, two observations are in order. First, it is important to note that neither end of the spectrum is devoid of the elements represented

in either of the wedges. Clearly, individual engineers and technicians possess unique and specialized sets of knowledge and skills. Rather, the model is intended to depict the nature of the relative strengths and deficiencies that are generally present along the technological occupations spectrum. The second, and perhaps more important, observation is that technology education is not yet, at this point, represented within the model. This is because the intent of the model is to describe the knowledge and skills of individuals who design and develop technological designs to address people's needs and wants. The role of technology education is distinctly different; that is, the role of technology education is not to produce designs. It is to educate.

So, where does technology education fit within the model? Figure 2 presents four depictions of technology education's placement in the model. Each of the four graphics includes two vectors that are designed to indicate a range of perspective or scope for technology education. For example, graphic (a) entitled "Historically (Industrial Arts)" indicates that the historical scope of the field has tended to concentrate on the crafts/technician/technologist end of the spectrum. It should be noted that in all four graphics, technology education is depicted as both "separate from" and "engaged with" the occupational spectrum. Technology education is *separate* because it is not formally part of the occupational spectrum. Technology educators are not in the business of vocational education... preparing individuals for specific jobs in these technologically-related occupations. However, they are appropriately quite *engaged* in the sense that they are providing students with an overview of the knowledge, skills, and career opportunities involved in technologically-related occupations as well as some perspective on how a range of technologies interact for good and ill with society, cultures, and the environment. In this sense, technology education is intensively engaged with the technological occupations spectrum; although in a much broader sense.

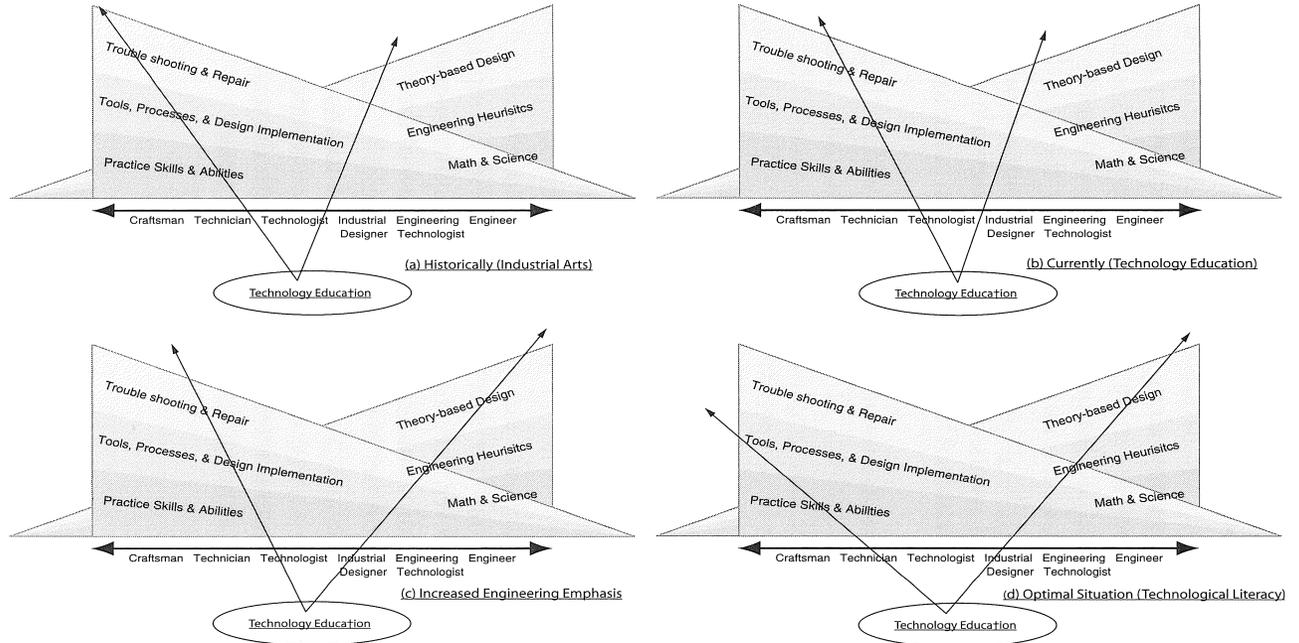


Figure 2. Technology Education's Role

According to graphic (b), the scope of the field shifted (narrowed) away from the crafts end of the continuum with the move from industrial arts to technology education over the past three decades. It should also be noted that, while the scope of occupational emphasis narrowed somewhat, the field was concurrently becoming more broadly conceived in terms of technological literacy with its emphasis on what all citizens need to know and be able to do to function successfully in an intensive technological world. The shift away from the crafts end of the spectrum also represented a deliberate attempt by the field to draw a more clear distinction between career/vocational education (industrial arts) and general education (technological literacy).

Current thinking has shifted the emphasis toward engineering (see graphic (c)). The *Standards for Technological Literacy* (STL, 2000), the funding of the National Center for Engineering and Technology Education (NCETE), the emergence of *Project Lead the Way*, the CATTS consortium's curricular focus on engineering, and a number of other engineering-oriented initiatives all serve as indicators that the scope of technology education is undergoing a significant shift toward the engineering end of the continuum. Again, as noted by William Wulf's opening comments in this book, this shift is not occupational (i.e., to prepare engineers or to become pre-engineering at the K–12 level). Preparing engineers is the job of departments of engineering in colleges and universities around the world. Rather, the role of technology education is “to create a public with enough understanding of engineering and technology to be responsible citizens in a technologically sophisticated democracy” (Wulf, 2008).

The final graphic (d) depicts what we would argue to be the ideal scope for technology education, where the content base consists of the full range of technological knowledge, capabilities, and interests across the entire spectrum. From this broad scope, students would be exposed to and develop an appreciation for the wide array of knowledge and skills involved in designing, developing, and evaluating a range of technologies that will affect them throughout their lives. This includes an understanding and appreciation of the role of engineers, repair technicians, technology management professionals, and much more. All of this is contained within the broader context that includes an understanding of how technological systems interact with and are impacted by social, cultural, political, and environmental priorities.

To summarize, the discussion and presentation of the model began with the observation that the relationship between engineering and technology education is too often presented in conceptually simplistic ways. This too frequently leads to direct comparisons of how engineers and technology educators engage in design, which we argue is both inappropriate and inaccurate. The more accurate view is that a familiarity with engineering is important and essential if technology educators are going to introduce students to the full spectrum of content knowledge, abilities, and perspectives of those who engage in technological activities.

## **IMPLICATIONS AND RECOMMENDATIONS**

The model provides a useful structure for some concluding thoughts on the implications of an increased alignment of technology education with engineering. These include implications for interdisciplinary collaboration, curriculum and standards, teacher pre-service and professional development, and student recruitment. Given that the focus of this book is on the relationships between engineering and technology education, much of this discussion will focus on the engineering end of the continuum. Considerable additional effort could be devoted to a similar discussion of the entire spectrum presented in the model. We hope this will occur and strongly encourage this type of more extensive and far-reaching discussion in technology education classes. For the purposes of this text, we will restrict our discussion to engineering.

## **INTERDISCIPLINARY COLLABORATION**

Benenson, in his essay in Chapter 10, focused on the relationship between engineering and technology education, providing a sobering perspective. “The vast majority of engineering educators have probably never even heard of technology education, let alone sought involvement in it. Conversely, many (if not most) technology educators have little or no contact with engineers or engineering educators, nor awareness of any proposed alliance” (p. 204).

Benenson’s point is well taken. If the scope of technology education is to embrace and include a significant component of engineering, alliances must be forged that currently do not exist at levels sufficient to fuel change. Establishing these relationships will involve significant cultural,

conceptual, and academic issues. Within academia, the focus of engineering is almost exclusively at the post-secondary level and is concentrated into well-defined engineering disciplines, whereas in technology education, the focus is at the K–12 level with a much broader conceptual scope (i.e., technological literacy). Engineering remains grounded in analytical and theoretical pursuits in contrast to technology education's emphasis on activities, often disconnected from a clearly focused conceptual base and learning goals. In spite of a growing concern about engineering pipeline issues, the vast majority of engineering educators continue to target students with strong mathematics and science backgrounds, remaining largely unaware and unappreciative of the potential contribution of technology education. Clearly, there is a gap that must be addressed if meaningful collaboration is to occur.

Positive indicators have been noted throughout this book. Among these are the budding relationship between the CTTE and the K–12 Division of the American Society for Engineering Education (ASEE), degree program collaborative efforts at several universities around the country (e.g., Virginia Tech, Colorado State University, Utah State University, and Purdue), the National Academy of Engineering's endorsement of the *Standards for Technological Literacy* and substantial work with technological literacy (e.g., *Technically Speaking* and *Tech Tally*), and the rapid growth of *Project Lead the Way*. But a gap remains that must be addressed.

Another major need is for technology educators to redouble their efforts to collaborate with the science and mathematics areas. As with engineering, significant progress has occurred over the past several decades including substantial involvement with the National Science Foundation (e.g., two decades of technology education program officer representation and a number of NSF-funded projects), the inclusion of technology concepts in the two sets of science standards (NAS and AAAS), state- and national-level policy activity with STEM, and funded interdisciplinary projects (e.g., IMAST, TSM).

As with engineering, much work remains to be done. Some within the larger STEM community have advocated a merger between science and technology at the K–12 level, which could enhance the authenticity and applied aspects of science while moving technology education into the mainstream of required coursework. Many technology educators worry that this type of alignment would lead to the demise of the field. The shift

toward the engineering end of the spectrum has, in many respects, served to force the mathematics-science collaboration issue given the importance of their analytical tools for engineering. The future health and viability of the field could well hinge on our willingness to become genuinely engaged with our mathematics and science colleagues in creative and potentially threatening ways.

## Curriculum And Standards

A second major area of discussion triggered by the Engineering and Technology Education model has to do with standards and curriculum development. These types of decisions fundamentally are grounded in two key issues. The first issue is directly connected to decisions about the scope of technology education (depicted in Figure 2). Each of the four scenarios has direct implications on the scope of content and curriculum for the field. It should be clear that the current shift in scope toward engineering is triggering a need for standards and curriculum materials that will address engineering content and concepts. This shift toward engineering is apparent in the *STL* (ITEA, 2000) as well as a number of curriculum efforts around the nation.

The second issue is more philosophical and relates directly to the engineering end of the continuum. Specifically, curricular decisions must be made about whether engineering at the K–12 level should be primarily oriented toward general education or pre-engineering. Proponents of the general education approach argue that a basic knowledge of how engineers design is a key aspect of technological literacy and that this type of knowledge is appropriate and even necessary for all citizens (Lewis' regular version of pre-engineering, 2005). The alternative argument is that engineering, particularly at the secondary level, should concentrate on identifying, encouraging, and preparing students for university-level engineering studies (Lewis' movement version of pre-engineering, 2005). As with the other STEM areas, both approaches are evident along the K–12 spectrum, generally with more emphasis on general education at the lower grades and a more in-depth, college preparatory focus at the secondary level. This represents a critical philosophical issue that must be addressed before curriculum conceptualization and development can appropriately begin.

The discussion will now turn to some specific engineering-related curriculum issues. Among the benefits of standards is that they serve to

identify and structure the core concepts for a field of study as a base for curriculum development. This has been particularly important in technology education where curriculum has frequently been driven by activities rather than concepts. As noted previously, the *STL* (ITEA, 2000) contains a significant emphasis on engineering and engineering design. However, much of this lacks the level of detail needed to adequately inform curriculum development.

One example of an effort to specify core concepts has been the work of the NSF-funded National Center for Engineering and Technology Education (NCETE). NCETE has identified a set of core engineering concepts appropriate for secondary-level technology education. The concepts, conceptualized under the broad umbrella of engineering design, include Constraints, Optimization, and Predictive Analysis (COPA). While these were developed as a base for teacher professional development, they are also being recommended for use in curriculum development. In fact, the Center has developed activities specifically designed to deliver COPA for research and professional development purposes. Another example is the ITEA/CATTS consortium's *Engineering by Design* initiative, which focuses on a set of broad organizing principles closely aligned with the *STL* (ITEA, 2000). Examples of these include "Engineering through design improves life," "Technology drives invention and innovation and is a thinking and doing process," and "Technology impacts society and must be assessed to determine if it is good or bad" (<http://www.iteaconnect.org/EbD/ebd.htm>).

This concept-based approach represents a significant cultural change for technology education in several important respects. First, as noted previously, technology education curriculum has too often been driven by and organized around projects and activities rather than focused on delivering concepts. As indicated by the work of curriculum theorists such as Wiggins and McTighe (2001), this process should be reversed to begin with concepts and assessment which, in turn, inform the selection and development of appropriate activities.

Ironically, a second challenge associated with the shift to concepts is to retain the rich activity orientation of the technology education curriculum. As seen in other disciplines, a focus on concepts can degenerate into excessive and passive "seat time" and "book work" with students surfing the Web for definitions and teachers lecturing to students. The challenge for curriculum developers is to retain the field's engaging activity emphasis, while crafting activities designed to deliver and reinforce concepts.

A final aspect of this cultural shift is to involve engineers in the process. This is much more difficult than it appears on the surface. The technology education community lacks an in-depth understanding of how engineers think and conduct their work. In the absence of this type of understanding, curriculum and activities typically lack the “engineering touch” with its analytical orientation and scientific approach. Conversely, the educational experiences of engineering educators consist primarily of theoretical, analytically based courses in a narrow engineering discipline and are largely devoid of experiences designed to prepare them for curriculum development and pedagogy. These factors represent difficult cultural differences that must be overcome if engineers and technology educators are to collaborate successfully in curriculum development.

### **Teacher Pre-service And Professional Development**

A third area of discussion related to the Engineering and Technology Education model focuses on technology teacher pre-service and professional development. As with the discussion of implications for curriculum, the focus and configuration of technology teacher preparation and professional development hinges on the decisions about the scope of the field (i.e., which of the scenarios in Figure 2 are selected). The comments in this section will address the implications of the shift toward the engineering end of the spectrum. Several key deficiencies and needs will be identified and discussed.

One of the most important issues that must be addressed if technology educators are to be prepared to incorporate engineering concepts into their teaching is a significant deficiency in mathematics and science. Indeed, this may well represent *the* most serious issue for pre-service and professional development. As Culbertson asserts in his essay (in Chapter 10), “The disparity in mathematical education between engineers and technology teachers suggests that technology teachers will be at a serious disadvantage in teaching mathematics-based engineering concepts to their students” (p. 212). As noted by McAlister, Hacker, and Tiala (in Chapter 5), most technology teacher education programs require only one course in mathematics, typically college algebra. Given the strong analytical emphasis in engineering design, we simply must address this issue and, on a national scale, make reasonable adjustments to the mathematics requirements of our teacher preparation programs. The same point applies to the

level of physical science requirements in our programs. This represents a critical and difficult decision for university-level faculty, many of whom share the same deficiencies as their students. The concerns about student capability and the potentially negative impact on student enrollment are painful and real. But, the fact remains. If technology education is to shift its focus to include engineering in a manner that will be perceived as legitimate by the engineering community, difficult decisions must be made about the level of academic rigor.

Also regarding pre-service, close attention should be paid to new programmatic models and degree configurations that are beginning to emerge around the nation involving engineering, mathematics, and science. Among the current efforts of note are programs at Virginia Tech, Colorado State University, Purdue, Utah State, and Ohio State University. These models are interesting and should continue to be monitored to inform practice across the profession.

Substantial work needs to be done with professional development to retool technology teachers to deliver engineering design concepts. Historically, professional development has played a major role in curriculum and programmatic reform in technology education. In his *Innovative Programs in Industrial Education*, Les Cochran (1970) describes a series of twenty-four curriculum and programmatic initiatives that occurred in the 1960s and early 1970s. One of the important threads running throughout Cochran's work was the critical importance of professional development. Professional development is even more important, and perhaps more difficult, today as we work to align with engineering.

Prior to launching into large-scale professional development as a field, it is important that we explore successful models from related disciplines. In other words, we have much to learn from the wealth of experience of others, particularly in mathematics and science. Several key resources and initiatives are worthy of note. One major resource is a model developed by Loucks-Horsely, Love, Stiles, Mundry, and Hewson (2003) based on many years of experience with mathematics and science professional development. The core of the model consists of four basic process components, including (a) setting goals, (b) planning, (c) doing, and (d) reflecting. In addition to these primary process components, the model also includes four critical input elements that impact and influence the implementation of the process components, including (a) context, (b) critical issues, (c) knowledge and beliefs, and (d) strategies.

Another resource is a symposium that was funded by the National Science Foundation and supported by the National Center for Engineering and Technology Education on professional development for engineering and technology education. The event was held in Dallas, Texas in February 2007, and focused on three major areas including core engineering concepts, engineering pedagogical content knowledge, and effective professional development models and practices. Proceedings of the meeting are being developed for distribution, and copies of the papers are located at <http://www.conferences.ilstu.edu/NSA/home.html>.

The National Center for Engineering and Technology Education is also working on other aspects of professional development. For the past three years, the Center has conducted professional development workshops for teachers designed to help them better understand the mechanisms involved in engineering-oriented professional development. Through this base of experience, the Center is in the process of developing and testing a professional development model. Concurrently, the Center is conducting a landscape case study designed to identify and examine in some depth best practices in engineering-oriented professional development. The collective results of these efforts will be disseminated broadly throughout the U.S. over the next several years.

One additional point is worthy of note at this juncture specific to professional development: Lee Shulman (President of the Carnegie Foundation for the Advancement of Teaching) and a team of researchers at Michigan State University have developed an extensive body of work concentrated on pedagogical content knowledge. The insights obtained from their work are worth noting in technology education and could serve as a framework for better understanding teacher knowledge. Quoting Shulman (1986), “The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students” (p. 15). This is particularly important for technology educators at this juncture, since we are in the process of breaking new ground on at least two of Shulman’s fronts. Specifically, we are expanding our base of content knowledge into engineering while also learning new lessons about the pedagogy required to teach engineering concepts. This represents a rich and important area of future inquiry for the field.

We need to involve engineers in the design, development, and delivery of professional development. This seems obvious! If we are to prepare technology teachers to deliver engineering concepts and activities, does it not make sense to include those who are involved on a daily basis with engineering? As with curriculum development, the challenges associated with identifying engineers and engineering educators with the interest in K–12 education and appropriate educational background can represent a daunting challenge. The benefits for technology education are clear; engineering involvement with professional development will also serve to enhance the critically needed flow of communication between engineering and technology education.

Finally, activity-based materials need to be developed for professional development. As technology education moves toward engineering, which in many cases tends to be somewhat more theoretical and abstract than what has traditionally been delivered in technology education courses, it is very important that exemplary activities be developed to serve as practical and applied examples. The old adage, “we teach how we were taught” remains intact. Technology teachers need to experience, first hand, professional development designed to model best practices using top quality materials and activities focused on core engineering concepts. The current availability of such materials is quite limited. If the technology education field is to be successful with professional development, it will be very important to pursue funding through state and federal agencies and foundations to support this work.

## **Student Recruitment**

As noted earlier in this chapter, the move toward the engineering end of the spectrum is causing technology educators to rethink (and worry about) student recruitment. In the broad view, a number of factors, including the need for increased academic rigor, additional mathematics and science, and an ability to solve complex technological and engineering problems, signal a need for a better quality of student. The underrepresentation of female and minority students across the STEM areas also represents a serious problem that must be addressed. In the extreme, the shift toward engineering could lead to a restriction in the type of student who will be attracted into technology education (i.e., high ability, predominantly male, college-bound students with strong aptitudes in mathematics

and science). This would not be good for technology education.

On closer view, it might well be possible to successfully appeal to a broad range of student interests and abilities. As indicated earlier, two approaches to engineering at the K–12 level include general literacy and pre-engineering. Both have merit and can be implemented. The general literacy approach (engineering literacy) is very closely aligned with technological literacy, which is framed in the *STL* (ITEA, 2000) and which has been the focus of substantial activity over the past several decades. William Wulf, in this book’s introduction, asserts that importance of equipping “the public with enough understanding of engineering and technology to be responsible citizens in a technologically sophisticated democracy.” The leadership that Dr. Wulf provided to issues related to technological literacy during his tenure as President of the National Academy of Engineering (including his involvement with the development and review of the *STL*) signals a strong relationship between engineering/technological literacy. This relationship is, in fact, quite clear in the *STL*.

Again, as the Engineering and Technology Education model indicates, the choice is not between engineering and technology. Rather, engineering represents one important and natural aspect of a much broader spectrum of activity directed toward designing and creating the human-made world. Thus, a commitment to technological literacy for all, logically includes aspects of engineering literacy (e.g., what it is that engineering contributes to the broad technological enterprise). In this sense, ideas and aspects from the engineering end of the continuum can and should be woven very naturally into the K–12 educational experiences of all students. At this level, the focus should be on such things as social and environmental constraints and impacts and an overview of engineering design procedures rather than on the more technical and analytical aspects of engineering.

The more rigorous and focused pre-engineering approach is also appropriate. This is quite similar to mathematics and science where the general literacy focus of the early grades (for all students) gives way to more specialized, selective, and rigorous courses at the upper grades (for a subset of students). One of the serious challenges for technology education for many years has been to conceptualize advanced-level coursework

(i.e., 11th and 12th grades) designed to build appropriately on the technological literacy foundation achieved in the earlier grades. Frankly, we have not always done this very well. Classes have consisted of a murky mixture of everything from secondary-level career preparation to experiences designed to prepare students for college. For example, it is not always clear to students (and sometimes teachers as well) why courses such as CAD and electronics are being delivered. Are they to prepare students for work, for advanced technical education, or for professional careers (e.g., engineering, architecture, technology education, etc.)? Obviously, a number of purposes can appropriately be pursued. The key point is that upper-level technology education courses can, and should, include the development of a foundation of engineering knowledge designed to prepare students for the rigors of post-secondary engineering education. Student recruitment at this level will be more selective, and that is okay. The technology education field would be well served if our best and most creative minds could link with our engineering colleagues to craft models for advanced-level courses focused on engineering at the secondary level. While the primary thrust of the *STL* is on literacy, the general framework is still sufficient to inform a more specialized emphasis on engineering.

## **CONCLUDING COMMENTS**

It is our sincere hope that you will find this book to be informative and useful. We have made every attempt to present a variety of perspectives, views, and ideas. We know that some of these are familiar and broadly accepted by the field. Other points are more controversial. We hope so. This has been by design. The book will have been successful if it stimulates dialogue and debate, which will hopefully lead to new program configurations, curriculum, and professional development. It is our sense that we stand at a critical juncture as a field of study. The decisions that we will be making over the next several years could well have a major impact on the ongoing viability and even survival of the field. Our view is that a carefully conceived and implemented alignment with engineering and, more broadly, the STEM disciplines, will be critically important to our future.

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