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K–12 ENGINEERING EDUCATION

The BRIDGE

LINKING ENGINEERING AND SOCIETY

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LINKING ENGINEERING AND SOCIETY

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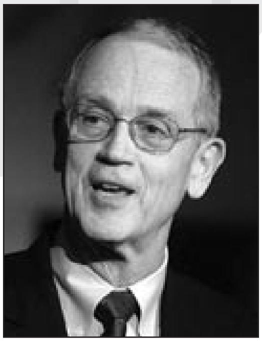
Editor's Note



Charles M. Vest

Putting the "E" in STEM Education

Recently I participated in a White House-sponsored workshop that brought together leading K–12 teachers and administrators to discuss how STEM education can be improved. Toward the end of the day, Steve Robinson, Special Advisor to the U.S. Secretary of Education, asked, "Where is the E in STEM? Doesn't engineering have a role?" That is a good question and one that NAE has been examining in some detail through the work of the Committee on K–12 Engineering Education.

Continuing concerns about the nation's innovation capacity, particularly in light of the current economic crisis and evidence of climate change, have brought renewed attention to the importance of student engagement with STEM subjects—science, technology, mathematics *and* engineering. We simply must provide girls and boys in elementary school, the drivers of the economic engine of tomorrow, opportunities to develop interest and skills in these subjects. If we do not, we may not be able to sustain our quality of life or address the grand challenges of our times.

The teaching of engineering in K–12 schools raises many questions. The most fundamental questions are what "engineering" means in the K–12 context, how it differs from technology, and how it relates to science and mathematics curricula. The first article in this issue addresses this question. Authored by NAE member **Linda Katehi** and two National Academies staff members, the article provides a summary of *Engineering in K–12 Education: Understanding the Status and Improving the Prospects*, a recently released report that surveys the landscape of K–12 engineering in the United States (NAE and NRC, 2009). The study committee came to several important conclusions, one of which is that the dominant STEM subjects—science and mathematics—tend to be taught in "silos," that is, as separate, independent subjects. Engineering, the committee suggests, may provide a catalyst for integrating STEM education and making it more relevant to students' everyday experiences.

The next two articles are by experts working on curriculum development and teacher professional development. Christine Cunningham of the Boston Museum of Science shares her experiences as part of a team that developed Engineering is Elementary™ (EiE), a series of units for teaching basic engineering concepts and skills to elementary school students. Each EiE unit combines an engineering design project with basic science, math, and reading skills. EiE also provides training for teachers and other support resources. Rodney Custer and Jenny Daugherty, of Illinois State University, report on their research related to teacher professional development and the factors that can influence classroom outcomes.

To get a sense of how engineering education plays out in the real world, we invited Jacob Foster, Massachusetts Department of Education, to recount how his state has fared in incorporating engineering ideas into its K–12 learning standards. Massachusetts is the first state to have taken this step.

Christian Schunn from the University of Pittsburgh then discusses what cognitive researchers have learned about how and at what age children appear able to learn engineering concepts and skills. As he points out, this topic has not been well researched, but there are indications that even the youngest students can grasp many engineering concepts, such as systems, optimization, and trade-offs.

The last article, by Suzanne Jenniches of Northrop Grumman and Catherine Didion, head of the NAE Diversity Program, describes the history and impact of NAE's *EngineerGirl!* website, which is designed to interest middle school and high school girls in engineering studies. The site is one example of the many informal, out-of-classroom initiatives that have been developed to introduce engineering to K–12 students. As the authors show, there are some encouraging signs that this informal route is bearing fruit.

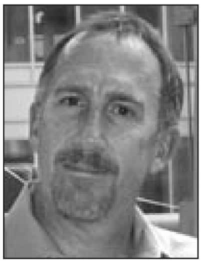
Taken together, these six articles provide a snapshot of the still-developing shape of engineering's footprint in K–12 schools. Considerably more effort on multiple fronts will be necessary to improve and expand the fairly isolated pockets of current K–12 engineering education. Given the issues we face as a nation, it is critical that we understand how best to develop young people's passion and ability to change the world through engineering.

K–12 engineering education has significant implications for the future of STEM education.

The Status and Nature of K–12 Engineering Education in the United States[1]

Linda Katehi, Greg Pearson, and Michael Feder

Linda Katehi



Greg Pearson

Michael Feder

K–12 engineering education has slowly been making its way into U.S. K–12 classrooms. Today several dozen different engineering programs and curricula are offered in schools around the country. In the past 15 years, several million K–12 students have received some formal engineering education, and tens of thousands of teachers have attended professional development sessions to learn how to teach engineering-related coursework.

The presence of engineering in K–12 classrooms is an important phenomenon, not because of the number of students impacted, which is still

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[1] This article is adapted from the executive summary of *Engineering in K–12 Education: Understanding the Status and Improving the Prospects* (NAE and NRC, 2009).

small compared to other school subjects, but because of the implications of engineering education for the future of science, technology, engineering, and mathematics (STEM) education.

In recent years, educators and policy makers have reached a consensus that the teaching of STEM subjects in U.S. schools must be improved. The focus on STEM topics is closely related to concerns about U.S. competitiveness in the global economy and about the development of a workforce with the knowledge and skills to address technical and technological issues (e.g., CCNY, 2009; NAS et al., 2007; NSB, 2007). To date, most efforts to improve STEM education have been concentrated on mathematics and science, but an increasing number of states and school districts have been adding technology education to the mix, and a smaller but significant number have added engineering.

U.S. global competitiveness is directly related to the quality of STEM education.

In contrast to science, mathematics, and even technology education, all of which have established learning standards and a long history in the K–12 curriculum, the teaching of engineering in elementary and secondary schools is still very much a work in progress, and a number of basic questions remain unanswered. How should engineering be taught in grades K–12? What types of instructional materials and curricula are being used? How does engineering education "interact" with other STEM subjects? In particular, how does K–12 engineering instruction incorporate science, technology, and mathematics concepts, and how are these subjects used to provide a context for exploring engineering concepts? Conversely, how has engineering been used as a context for exploring science, technology, and mathematics concepts? And what impact have various initiatives had? Have they, for instance, improved student achievement in science or mathematics? Have they generated interest among students in pursuing careers in engineering?

In 2006 the National Academy of Engineering (NAE) and National Research Council Center for Education established the Committee on K–12 Engineering Education to begin to address these and other questions. Over a period of two years, the committee held five face-to-face meetings, two of which accompanied information-gathering workshops. The committee also commissioned an analysis of many existing K–12 engineering curricula; conducted reviews of the literature on areas of conceptual learning related to engineering, the development of engineering skills, and the impact of K–12 engineering education initiatives; and collected preliminary information about a few pre-college engineering education programs in other countries. This article summarizes some of the committee's findings and presents selected recommendations from the committee's report.

General Principles

The way engineering is taught varies from school district to school district, and what takes place in classrooms in the name of engineering education does not always align with generally accepted ideas about the discipline and practice of engineering. To provide a vision of what K–12 engineering might look like, the committee set forth three general principles. These principles, particularly Principle 3, which relates to engineering "habits of mind," are aspirational rather than a reflection of current K–12 engineering education, or even post-secondary engineering education.

Principle 1. K–12 engineering education should emphasize engineering design. The design process, the engineering approach to identifying and solving problems, is (1) highly iterative, (2) open-ended, in that a problem may have many possible solutions, (3) a meaningful context for learning scientific, mathematical, and technological concepts, and (4) a stimulus to systems thinking, modeling, and analysis. In all of these ways, engineering design is a potentially useful pedagogical strategy.

Principle 2. K–12 engineering education should incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills. Some science concepts, and some methods of scientific inquiry, can support engineering design activities. Some mathematical concepts and computational methods can also support engineering design, especially in the areas of analysis and modeling. Technology and technology concepts can illustrate the outcomes of engineering design, provide opportunities for "reverse engineering," and encourage the consideration of social, environmental, and other impacts of engineering design decisions. The following concepts and methods should be used, as appropriate, to support engineering design, particularly at the high-school level: testing and measurement technologies, such as thermometers and oscilloscopes; software for data acquisition and management; computational and visualization tools, such as graphing calculators and CAD/CAM (computer-aided design and manufacturing) programs; and the Internet.

Principle 3. K–12 engineering education should promote engineering "habits of mind." Engineering habits of mind[2] are aligned with what many believe are essential skills for citizens in the 21st century.[3] These include (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) ethical considerations. Systems thinking equips students to recognize essential interconnections in the technological world and to appreciate that systems may have unexpected effects that cannot be predicted from the behavior of individual subsystems. Creativity is inherent in the engineering design process. Optimism reflects a world view in which possibilities and opportunities can be found in every challenge and every technology can be improved. Engineering is a "team sport"; collaboration leverages the perspectives, knowledge, and capabilities of team members to address design challenges. Communication is essential to effective collaboration, to understanding the particular wants and needs of a "customer," and to explaining and justifying the final design solution. Ethical considerations draw attention to the impacts of engineering on people and the environment, including possible unintended consequences of a technology, the potential disproportionate advantages or disadvantages for certain groups or individuals, and other issues.

No reliable data are available on the precise number of U.S. K–12 students who have been exposed to engineering-related coursework. With a few notable exceptions,[4] the first formal K–12 engineering curriculum programs in the United States emerged in the early 1990s. Since that time, fewer than 5 million students are estimated to have had some kind of formal engineering education. By comparison, the projected enrollment for grades pre-K–12 for U.S. public and private schools in 2008 was nearly 56 million (DOEd, 2008).

No reliable data are available on the number of teachers involved in K–12 engineering education. At most, 18,000 teachers have received pre- or in-service professional development training to teach engineering-related coursework. The relatively small number of curricular and teacher professional development initiatives for K–12 engineering education were developed independently, often have different goals, and vary in how they treat engineering concepts, engineering design, and relationships among engineering and the other STEM subjects.

Claims for the benefits of teaching engineering to K–12 students range from improved performance in related subjects, such as science and mathematics, and increased technological literacy to improvements in school attendance and retention, a better understanding of what engineers do, and an increase in the number of students who pursue careers in engineering.

The most intriguing possible benefit of K–12 engineering education is improved student learning and achievement in mathematics and science. For example, students who took courses developed by "Project Lead the Way," currently the largest K–12 engineering program in the United States, scored significantly higher on science and mathematics in the federally administered National Assessment of Educational Progress than students in a random, stratified comparison group (Bottoms and Anthony, 2005; Bottoms and Uhn, 2007).

K–12 engineering education may improve student learning in mathematics and science.

Overall, however, the small number, uneven quality, and small size of these studies cannot provide unqualified support for any of these claims. For engineering to become a mainstream component of K–12 education, there will have to be much more, and much higher quality outcomes-based data to guide its development.

To address this challenge, the committee recommends that foundations and federal agencies with an interest in K–12 engineering education support long-term research to confirm and refine the findings of earlier studies of

[2] The term "habits of mind," as used by the American Association for the Advancement of Science in *Science for All Americans* (1990), refers to the values, attitudes, and thinking skills associated with engineering.

[3] See, for example, The Partnership for 21st Century Skills, online at *www.21stcenturyskills.org*.

[4] See, for example, *The Man-Made World* (ECCP, 1971).

the impacts of engineering education on student learning in STEM subjects, student engagement and retention, understanding of engineering, career aspirations, and technological literacy.

Curricula

The committee identified more than 30 K–12 engineering education curricula, more than half of which were reviewed in detail.[5] The curriculum analyses revealed that engineering design, the central activity of engineering, is predominant in most curricula (and professional development programs). The treatment of key ideas in engineering, such as constraints, optimization, and analysis, is much more uneven and, in some cases, suggests a lack of understanding on the part of curriculum developers. These shortcomings may be the result, at least in part, of the absence of a clear description of the most important engineering knowledge, skills, and habits of mind, how they relate to and build on one another, and how and when (i.e., at what age) they should be introduced to students. Unlike the other three STEM subjects, no content standards for K–12 engineering education have been established. The topic of state-level standards for K–12 engineering is addressed by Foster (p. 25) in this issue.

Unlike the other STEM subjects, no content standards have been established for K–12 engineering.

Although there are a number of natural connections between engineering and the other STEM subjects, existing curricula in K–12 engineering education do not fully explore them. For example, scientific investigation and engineering design are closely related activities that can be mutually reinforcing. Although most curricula include some instances in which this connection is exploited (e.g., using scientific inquiry to generate data to inform engineering design decisions or using engineering design to provide contextualized opportunities for science learning), the connection is not systematically emphasized to improve learning in both domains. Similarly, mathematical analysis and modeling are essential to engineering design, but very few curricula or professional development initiatives use mathematics in ways that support modeling and analysis.

To help address these shortcomings, the committee recommends that the National Science Foundation and U.S. Department of Education fund research to determine how science inquiry and mathematical reasoning can be integrated with engineering design in K–12 curricula and teacher professional development.

The review of curricula revealed that technology in K–12 engineering education has primarily been used to illustrate the products of engineering and to provide a context for thinking about engineering design. In only a few cases were examples of engineering used to elucidate ideas related to other aspects of technological literacy, such as the nature and history of technology or the cultural, social, economic, and political dimensions of technology development.

Teacher Professional Development

Compared with professional development for teaching science, technology, and mathematics, professional development programs for teaching engineering are few and far between. Nearly all in-service initiatives are associated with a few existing curricula, and many do not provide ongoing in-classroom or online support following formal training or other follow-up steps that have been proven to promote teacher learning. The issue of professional development is discussed at length by Custer and Daugherty (p. 18) and Cunningham (p. 11) in this issue.

There are no pre-service initiatives that are likely to contribute significantly to the supply of qualified engineering teachers in the near future. Indeed, the "qualifications" for engineering educators at the K–12 level have not even been described. Graduates from a handful of teacher preparation programs have strong backgrounds in STEM subjects, including engineering, but few if any of them teach engineering classes in K–12 schools.

To address this major gap, the committee suggests that the American Society of Engineering Education (ASEE), through its Division of K–12 and Pre-College Education, begin a national dialogue on preparing K–12 engineering teachers to address the very different needs and circumstances of elementary and secondary

[5] The review was overseen by Prof. Ken Welty, University of Wisconsin, Stout, a consultant to the project.

teachers and the pros and cons of establishing a formal credentialing process.

Diversity

The lack of diversity in post-secondary engineering education and the engineering workforce in the United States is well documented (e.g., NACME, 2008). Based on evaluation data, analyses of curriculum materials, anecdotal reports, and personal observation, the committee concluded that the lack of diversity is probably an issue for K–12 engineering education as well. This problem is manifested in two ways. First, the number of girls and underrepresented minorities who participate in K–12 engineering education initiatives is well below their numbers in the general population. Second, with a few exceptions, curricular materials do not portray engineering in ways that seem likely to excite the interest of students from a variety of ethnic and cultural backgrounds. For K–12 engineering education to yield the many benefits its supporters claim, access and participation will have to be expanded considerably.

To begin to address this problem, the committee recommends that K–12 engineering curricula be developed with special attention to features that appeal to students from underrepresented groups (see Cunningham (p. 11) this issue). In addition, programs that promote K–12 engineering education should be strategic in their outreach to these populations. Both curriculum developers and outreach organizations should take advantage of recent market research that suggests effective ways of communicating about engineering to the public (NAE, 2008).

Policy and Program Issues

Although many questions about K–12 engineering education remain unanswered, engineering is being taught in K–12 schools around the country, and it appears that the trend is upward. Thus it is imperative that we begin thinking about ways to guide and support engineering education in the future. An underlying question for policy makers is how engineering concepts, skills, and habits of mind should be introduced into the school curriculum. There are at least three options—ad hoc infusion, stand-alone courses, and integrated STEM education. These options vary in terms of ease of implementation:

- Ad hoc infusion, or introduction, of engineering ideas and activities (i.e., design projects) into existing science, mathematics, and technology curricula is the most direct and least complicated option, because implementation requires no significant changes in school structure. The main requirements would be (1) willingness on the part of teachers and (2) access to instructional materials. Ideally, teachers would also have a modicum of engineering pedagogical content knowledge to deliver the new material effectively. The ad hoc option is probably most useful for providing an introductory exposure to engineering ideas rather than a deep understanding of engineering principles and skills.

The "siloed" teaching of STEM subjects inhibits the development of technological and scientific literacy.

- Stand-alone courses for engineering, which are required for implementing many of the curricula reviewed for this project, presents considerably more challenges for teachers and schools. In high schools, the new material could be offered as an elective. If that is not possible, it would either have to replace existing classes or content, perhaps a science or technology course, or the school day would have to be reconfigured, perhaps lengthened, to accommodate a new course(s). Stand-alone courses would also require teacher professional development and approval of the program at various levels. This option has the potential advantage of providing a more in-depth exposure to engineering.
- Fully integrated STEM education, that is, using engineering concepts and skills to leverage the natural connections between STEM subjects, would almost certainly require changes in school structures and practices. Research would be necessary to develop and test curricula, assessments, and approaches to teacher professional development. New interconnected STEM programs or "pilot schools" might be established to test changes before they are widely adopted.

These three options, as well as others that are not described here, are not mutually exclusive. Indeed, no single approach is likely to be acceptable or feasible for every district or school.

The need for qualified teachers to teach engineering in K–12 classrooms also raises a number of policy and program issues. The current ad hoc approach of mostly in-service training may not be adequate to train enough teachers if K–12 engineering education continues to grow. A variety of traditional and alternative mechanisms should be evaluated as part of the suggested ASEE-led initiative described above ("Teacher Professional Development").

Moving toward STEM Literacy

The "siloed" teaching of STEM subjects has impeded efforts to generate student interest and improve performance in science and mathematics. It also inhibits the development of technological and scientific literacy, which are essential to informed citizens in the 21st century. Thus increasing the visibility of technology and, especially engineering, in STEM education in ways that address the interconnections in STEM teaching and learning could be extremely important.

In an ideal future for K–12 STEM education in the United States, all students who graduate high school would have a level of STEM literacy sufficient to (1) ensure their successful employment, post-secondary education, or both, and (2) prepare them to be competent, capable citizens in our technology-dependent, democratic society. Because of the natural connections between engineering education and science, mathematics, and technology, engineering might serve as a catalyst for achieving this vision.

A worthwhile subject for future study would be to determine the qualities that characterize a STEM-literate person. To this end, the committee suggested that the National Science Foundation and the U.S. Department of Education support research to characterize, or define, "STEM literacy." Researchers should consider not only core knowledge and skills in science, technology, engineering, and mathematics, but also the "big ideas" that link the four subject areas.

Pursuing the goal of STEM literacy in K–12 schools will require a paradigm shift for students, teachers, administrators, textbook publishers, and policy makers, as well as the many scientists, technologists, engineers, and mathematicians involved in K–12 education. As a result of that shift, students would be better prepared for life in the 21st century and would have the tools they need to make informed career decisions or pursue post-secondary education.

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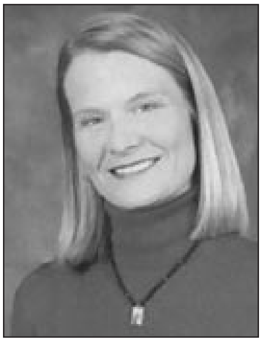
Engineering activities tap into the natural curiosity and creativity of all children.

Engineering Is Elementary

Christine M. Cunningham



Christine M. Cunningham is founder and director of Engineering is Elementary and a vice president at the Museum of Science, Boston.

As our society becomes increasingly dependent on engineering and technology, it is more important than ever that everyone be aware of what engineers do and understand the uses and implications of the technologies they create. Yet few American citizens are technologically literate, largely because technology and engineering have not been taught in our schools (Pearson, 2004).

Children (and many adults) know shockingly little about technology and engineering. In fact, the vast majority believe the term "technology" refers only to electronics and computers and that engineering and science are basically the same (Lachapelle and Cunningham, 2007; Pearson and Young, 2002). To understand the human-made world in which we live, it is vital that we increase engineering and technological literacy among all people, even young children!

Children are born engineers—they are fascinated with designing their own creations, with taking things apart, and with figuring out how things work. In 2003, the Engineering is Elementary (EiE, *www.mos.org/eie*) project was initiated to take advantage of the natural curiosity of *all* children to cultivate their understanding and problem-solving in engineering and technology.

The EiE project staff worked closely with teachers and engineers to develop a research-based, standards-driven, classroom-tested curriculum that integrates engineering and technology concepts and skills and elementary science topics and mathematics learning, as well as literacy and social studies. In addition, EiE provides professional development workshops and resources to improve teachers' understanding of engineering concepts and to develop pedagogical methods for teaching engineering material.

EiE has four main goals:

1. Increase children's technological literacy.
2. Improve elementary educators' ability to teach engineering and technology.
3. Increase the number of schools in the United States that include engineering in their curricula.
4. Conduct research and assessments to further the first three goals and to develop a knowledge base on the teaching and learning of engineering at the elementary school level.

To accomplish these goals, EiE has developed curricular materials and resources, professional development workshops and resources for teachers and teacher educators, a system of national partnerships, and a research and assessment program.

Over the past six years, based on experience, observation, research, and collaboration, the EiE team has learned a great deal about teaching and "doing" engineering at the elementary level. This article presents some of the principles of the project and describes what we have learned so far. However, we know we still have much to learn! The EiE team continues to modify and improve existing materials and workshops, to experiment with new offerings, and to expand our knowledge, programs, and resources.

EiE has designed materials to engage students from marginalized and "at-risk" groups.

Design of the Curriculum: Criteria, Constraints, and Commitments

At its core, the purpose of EiE is to help children understand the human-made world around them. Initially the EiE team defined essential concepts and skills that are central to technological literacy at the elementary school level:

Knowledge (Know about/that):

- what engineering and technology are and what engineers do
- various fields of engineering
- nearly everything in the human world has been touched by engineering
- engineering problems have multiple solutions
- how society influences and is influenced by engineering
- how technology affects the world (both positively and negatively)
- engineers are from all races, ethnicities, and sexes and have various abilities/disabilities

Skills/Experience (Be able to do):

- engage in the engineering design process
- apply science and mathematics to engineering problems
- use creativity and careful thinking to solve problems
- envision one's own abilities as an engineer
- troubleshoot and learn from failure
- understand the central role of materials and their properties in engineering solutions

EiE's foundational principle is a deep commitment to engaging and interesting *all* children in engineering and science, particularly children in groups that have traditionally been underrepresented and underserved. From the beginning, EiE has designed materials to engage marginalized and "at risk" populations, such as girls, minorities, youngsters with disabilities, and children from low socioeconomic backgrounds.

In addition to outlining essential skills and concepts, the EiE team set forth a number of core criteria and constraints to guide product development and ensure that the materials and the engineering they portray are accessible and attractive to a wide variety of students. Thus EiE units and activities reflect the following considerations:

- Engineering design challenges must demonstrate how engineers help people, animals, or society.

- Projects must be set in a large, real-world context to show where and how engineering information and tasks might be relevant.
- Engineering role models must be of both sexes, from a variety of races and ethnicities, and have different abilities/disabilities and a wide range of hobbies and interests.
- Design challenges must be truly open-ended with more than one correct answer.
- Challenges must be amenable to evaluation by both qualitative and quantitative measures.
- Failure must be treated as a necessary and inherent part of engineering that invites subsequent improvements in designs.
- Steps in the process should be explicitly organized to build student skills progressively, without making the process formulaic.
- No previous familiarity with materials or terminology should be assumed.
- Addressing design challenges must require very low-cost, readily available materials.
- Activities must encourage a culture of collaboration and teamwork.
- Situations must create an atmosphere in which all students' ideas can be heard and considered.
- Activities must require that students engage in active, hands-on engineering.
- Materials must be easily scalable, up or down, to meet the needs of different kinds of learners.
- The overall focus must be on developing problem-solving skills.

The EiE team attempted to design materials that would mentor students as they "engineer." Our goal is to develop problems and contexts that are interesting and then invite students to have fun and envision themselves as engineers as they use their knowledge of science and engineering to design, create, and improve solutions.

Structure of the Curriculum

Engineering is a new subject for most elementary school teachers, and so far, only a few states (e.g., Massachusetts and Minnesota) have developed educational learning standards that include engineering at the elementary level. To facilitate the introduction of this new discipline in elementary classes, the EiE team adopted an integrated approach and selected science as the subject most closely connected to engineering. Based on a review of curricula and standards from across the nation, EiE staff identified 20 of the most commonly taught elementary school science topics. We then designed EiE units that build upon and reinforce these concepts through application. Each unit also connects to language arts, mathematics, and social studies skills and topics.

Each EiE engineering unit is based on a science topic (e.g., astronomy), revolves around a field of engineering (e.g., aerospace engineering), and highlights a technology from that field (e.g., parachutes). Projects are also set in different countries.[1] EiE projects are designed so teachers only use the units connected to the science topics they teach (Table 1).

EiE units reinforce science concepts through application.

Structure of Each Unit

All EiE units have a common structure consisting of a preparatory lesson designed to prompt students to think about engineering, technology, and the engineering design process and four unit lessons. The EiE unit guide provides teacher lesson plans, student duplication masters (worksheets), background resources for teachers, and assessment items. By design, the program requires that children DO engineering; there is no student textbook.

Lesson 1. Engineering Story. To provide a context for the unit, to introduce engineering to teachers through a comfortable medium (language arts), and to piggyback on the abundant time available for reading in elementary school classes, EiE units begin with an illustrated storybook. The stories, which are set in cultures and countries around the world, feature a child protagonist who confronts a real-world problem. An adult engineer in the child's life introduces the engineering design process and invites the child character

[1] For a table with information about all 20 units, see *http://www.mos.org/eie/20_unit.php*.

TABLE 1 A Sampling of EiE Units

EiE Unit Title	Science Topic	Engineering Field	Storybook (Setting)
Catching the Wind: Designing Windmills	Wind and Weather	Mechanical	Leif Catches the Wind (Denmark)
Water, Water Everywhere: Designing Water Filters	Water	Environmental	Saving Salila's Turtle (India)
Sounds Like Fun: Seeing Animal Sounds	Sound	Acoustical	Kwame's Sound (Ghana)
The Best of Bugs: Designing Hand Pollinators	Insects/Plants	Agricultural	Mariana Becomes a Butterfly (Dominican Republic)
An Alarming Idea: Designing Alarm Circuits	Electricity	Electrical	A Reminder for Emily (Australia)
Marvelous Machines: Making Work Easier	Simple Machines	Industrial	Aisha Makes Work Easier (USA)

to apply it to develop a solution to the problem. In the classroom, students are then challenged to solve a similar problem.

Lesson 2. A Broad View of an Engineering Field. The second lesson helps students develop a broad perspective on the engineering field of focus. Through hands-on activities, students learn about the kind of work done by engineers in that field and the technologies they produce.

Lesson 3. Scientific Data to Inform Engineering Design. The third lesson is designed to help students improve their understanding of underlying science concepts, explore available materials, and determine which properties of these materials are relevant to the challenge at hand. These lessons also help children recognize linkages between science, mathematics, and engineering. In this lesson, children collect and analyze scientific data they can refer to in Lesson 4 to inform their designs.

Lesson 4. Engineering Design Challenge. The unit culminates with an engineering design challenge. Following the five steps of the EiE engineering design process, students ask, imagine, plan, create, and improve solutions to an engineering problem (Figure 1).

The Unit Development Process

The design of the EiE curriculum is based on Wiggins and McTighe's (1998) "backward design" process, and the essential concepts and skills are closely linked with curricular development. The final curriculum design is shaped by the interplay of the EiE team's commitments, copious feedback from classroom teachers, and results from quantitative and qualitative assessments collected from students and teachers (Figure 2).

The curriculum development process for an EiE unit is intensive, cyclical, and structured to make use of qualitative and quantitative data from students and teachers to inform numerous revisions. Classroom testing is a hallmark of the EiE program; all lessons undergo at least two types of classroom testing—pilot testing and field testing—before they are finalized. Teachers for pilot and field tests are chosen to represent a wide range of schools with many different types of students.

The development process begins with a science topic. EiE staff review science curricula and standards to determine what elementary children will learn about this topic. Then, keeping in mind the science concepts, the field of engineering, and the cultural setting, curriculum developers experiment to generate a design challenge that meets project criteria. Once a viable option has been found, 15 regional pilot teachers review the initial

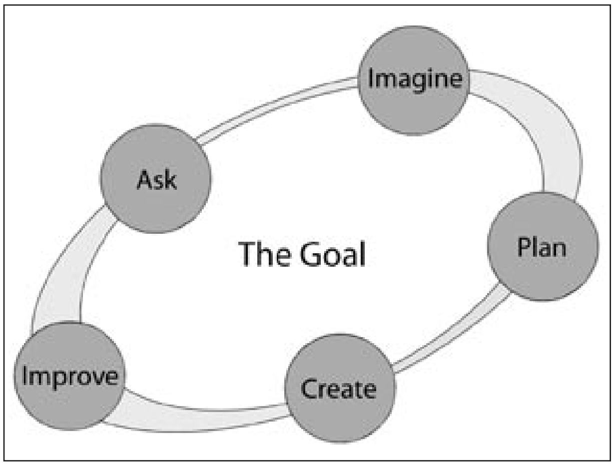


FIGURE 1 The EiE engineering design process.

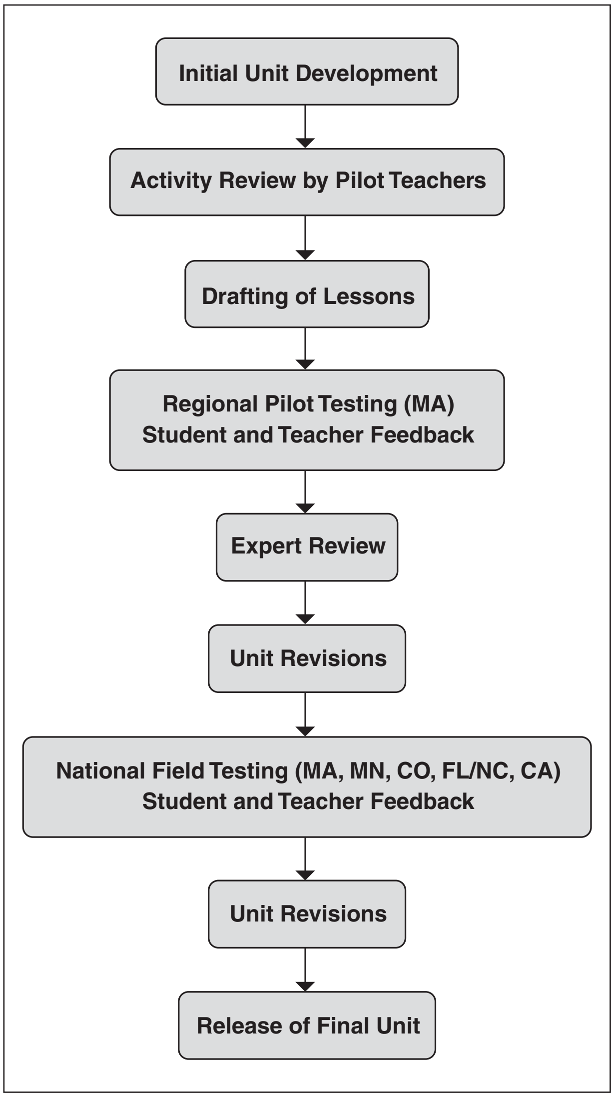


FIGURE 2 The EiE curriculum development process.

ideas and drafts of materials and provide feedback. The lessons are then rewritten based on their comments.

Next the pilot teachers who teach that science topic try teaching the fledgling unit to a class. EiE developers observe every new lesson in at least two different classes with students of different ages and take copious notes about what works and what doesn't. Students then complete pre- and post-class assessments, and pilot teachers complete a detailed feedback form about the lessons in the unit. Reviews of the materials are also solicited from experts in the particular field of engineering and cultural consultants.

The unit is then revised based on observations of pilot tests, feedback, reviews, and assessments. Next the unit is field tested nationally in five states (Massachusetts, California, Colorado, Florida/North Carolina, and Minnesota) by about 60 teachers. Again students and teachers provide feedback, and lessons are observed in Massachusetts classes. These data inform the final revision of the unit.

This development process is extremely time and labor intensive! It takes more than 3,000 hours of EiE staff time and more than two-and-a-half years to develop each unit (a unit generally takes about 6 to 8 hours of classroom time to implement). But, as the final curricular materials and evaluations have shown, those efforts pay off. When EiE materials are finally released, they can help almost any elementary educator teach engineering in a way that generates a contagious excitement among students.

Lessons Learned

In the years we have spent developing materials and observing activities, EiE has learned a number of lessons, some of which are listed below:

- Testing EiE units and specific lessons in classrooms is critical to their success. Even after five years of development experience, EiE lessons are significantly improved by repeated classroom testing. Nothing can replace real-world trials of a lesson and unit in diverse classrooms.

- Children, even young children, are capable of much more complex engineering thinking than we originally anticipated. They can balance multiple constraints and criteria, compare the merits of designs, and represent their designs from different points of view.

- Contextualized design challenges appeal to children. Many students, particularly children who may not show an initial interest or talent for science and mathematics, have been drawn into an EiE engineering challenge through the language arts or social studies hook. They may relate to or be fascinated by the country in which the unit is set, a storybook character, or the story line.

- Engineering has the potential to reach ALL students. Teachers regularly report that struggling, unremarkable, or withdrawn students blossom during EiE lessons. These students contribute, stay on task, and often voluntarily continue the engineering challenges in their out-of-school time.

- National, controlled evaluation studies have shown that student perceptions of engineering and technology, their understanding of engineering, and their understanding of relevant science are greatly improved by participation in EiE activities. Early results also suggest that using EiE materials can narrow, or even close, the achievement gap between children from high and low socioeconomic backgrounds.

Teacher Professional Development

Helping children develop knowledge and skills requires that teachers understand, feel comfortable with, and can teach the relevant subject matter. Because engineering has barely been taught at all at the elementary level, the vast majority of elementary teachers have had very little education about or experience with this subject. Therefore, the EiE project also focuses on helping elementary educators learn to teach engineering by providing resources and professional development workshops for teachers. Professional development workshops vary in length from two hours to several weeks.

> *Workshops give teachers an opportunity to model engineering education based on engaged, open-ended problem solving.*

Through EiE workshops, we can demystify engineering and defuse elementary teachers' feelings of ineptitude, at the same time reinforcing their comfort level and confidence in their grasp of engineering materials. During workshop sessions, participants engage with EiE materials, engage in design challenges, and think about how this new subject matter can be integrated into the other subjects they teach.

After running more than 300 workshops, the EiE team has developed a common structure that encompasses many elements essential to high-quality professional development. During an EiE workshop, teachers working in small groups engage in a series of activities. The first one leads them to develop a definition of technology aligned with the definition adopted by EiE. Next they are presented with a challenge to solve; in discussions afterward they discover that they naturally used an engineering design process to do so. At this point, EiE's five-step Engineering Design Process is introduced.

Once teachers understand the philosophy and structure of the EiE project, they work through all four lessons of a unit. As they become more familiar with the program and with what elementary school level engineering involves, they become more confident in their own abilities.

Mentor-teachers (who often co-lead the sessions) answer participants' questions and offer advice and perspectives about the program. During small group breakout sessions, participants discuss next steps for classroom implementation. Web-based EiE Educator Resources provide continuing support for teachers when they return to their schools.

Lessons Learned

- Perhaps the biggest hurdle to getting engineering into classrooms is teachers' initial fears of the word "engineering," which they perceive as a discipline that can be done, and taught, only by "super-smart" students and teachers.

- Workshops provide an opportunity for them to model engineering instruction. Because of teachers' lack of exposure, experience, and education about engineering, we are presented with a unique situation—teachers do not have ingrained habits of teaching or competing instructional philosophies or paradigms that have to be modified. Therefore, we can model from scratch what we think engineering instruction should be—models that are consistent with engaged, open-ended problem solving.

- In workshop sessions, teachers do what they will do in their classrooms. We have learned that an activity, innovation, or pedagogical strategy is much more likely to be implemented in the classroom if teachers have engaged with it themselves first. In EiE workshops, teachers always work through a unit by doing the lessons. Becoming familiar with the materials and the student handouts helps them visualize how they will use them in their classes. It also helps them understand which aspects of the lessons are most likely to cause students difficulty or to require overcoming misconceptions.

- Follow-up workshops are valuable. Because of teachers' lack of classroom experience with engineering (either as teachers or students), metacognitive or experience-based discussions that enrich professional development programs may be limited in the initial workshop. We encourage teachers to return for a follow-up workshop after they have begun teaching engineering. The follow-up session usually results in a much richer discussion based on classroom experience and the challenges that arose.

- Engineering can change the way teachers teach. Teachers report that their engineering professional development experiences, the first time many encountered a truly open-ended problem with no single "correct" answer, have fundamentally changed the way they teach science and other subjects. They report introducing open-ended inquiry in their lessons. In fact, this change has been one of the most unexpected and most powerful results of our engineering professional development program.

National Dissemination through Hub Sites

In response to early interest in EiE from schools and organizations across the country engaged in engineering outreach, EiE developed models for national dissemination. To reach teachers and students on a national scale, the project involves partnering with complementary organizations interested or engaged in teacher or student science or engineering education to leverage their talent, resources, and professional networks as an EiE Hub Site—an organization or institution that already offers professional development and is interested in leading EiE efforts in its area.

Initially, potential partners attend an EiE Teacher Educator Institute, a two-and-a-half-day workshop that introduces teacher educators to EiE, engages them in engineering challenges, and exposes them to various structures, models, and resources for offering professional development programs. Based on teacher educators' requests, the EiE team has produced unit-specific EiE Professional Development Guides to support workshops offered by other providers of professional development.

Participants then return to their home state or region, where they are familiar with the educational standards, have established networks of local teachers to work with, and are aware of possible funding opportunities. The EiE goal is to provide a solid structure and set of materials for teaching elementary engineering and then encourage, promote, and celebrate creative ideas in sites around the country that pass on this vision. Teacher educators in at least 17 states now offer EiE workshops. With their help, the EiE program has reached more than 15,000 teachers and one million children in all 50 states—so far!

Contributions from Practicing Engineers

From the beginning, engineers have been closely involved in the creation of the EiE curriculum; in bringing EiE to teachers, schools, and districts; and in advocating for including engineering in the elementary school curriculum. Developers of each EiE unit are advised by engineers in the field of focus (e.g., acoustical engineers), who answer questions as they arise and review drafts of the unit binder and storybook to ensure that the content, although simplified, is still accurate.

Engineers have helped raise awareness in schools by introducing EiE curricular materials and have advocated with teachers and administrators that engineering be included in grade school education. Engineers have also volunteered to help teachers in classrooms implement EiE lessons. They provide an extra set of hands to assist in preparing and managing materials and guidance on open-ended projects. In some classes, teachers ask engineers to answer students' questions or talk about their work.

Engineering companies have "adopted" classrooms, schools, and districts to encourage them to adopt and use EiE. Some provide funding for the purchase of EiE materials and/or opt to provide volunteers to support teachers in implementing the materials.

Conclusion

Educating a generation that understands what engineering and technology are and their importance to our society and our world will require the energies, creativity, and talents of teacher educators, teachers, engineers, parents, and children. By developing high-quality, accessible, heavily tested curricular materials, professional development programs, and partnerships, the EiE project is developing resources that can guide and promote elementary engineering education nationwide.

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Very few K–12 teachers are prepared to teach engineering.

Professional Development for Teachers of Engineering

Research and Related Activities

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In the past decade, engineering has emerged as an important new content area on the K–12 scene. The growing interest in engineering has been triggered by several factors. Among these are opportunities for embedding academic content into authentic design situations, thus generating student interest in mathematics and science. The push for introducing youngsters to engineering is also a response to serious concerns about the declining number of students entering the engineering pipeline; a particular concern is attracting more women and minorities to engineering careers. On a more general level, advocates for teaching engineering at the K–12 level argue that all students will benefit from understanding how the technological world is designed and built.

Despite this growing interest, significant challenges will have to be addressed before engineering is accepted as an integral part of the K–12 curriculum. The primary challenges are: to identify a slot in the curriculum to house engineering; to identify a body of content; to convince policy makers, school administrators, and parents of the importance of engineering education; and to prepare teachers to effectively convey engineering content and concepts. All of these issues must be addressed before the

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promise of teaching engineering at the K–12 level can be realized.

The challenge addressed in this article is the need for engineering-related professional development (ongoing educational experience) for K–12 teachers, many of whom do not have the background or knowledge to integrate engineering into their classroom teaching. Some are educated as science or mathematics teachers. Others are technology educators, who emphasize design, technological literacy, and the impact of technology on society. But relatively few are prepared to teach engineering. Thus the existing teacher workforce will have to be retooled, and teacher professional development will be a critical aspect of that retooling.

Background

Over the past several years, through curriculum development, funded projects, and research, the authors have spent countless hours obtaining a better understanding of how engineering is, and can be, taught in schools. In this article we briefly describe the results of our work, with a focus on teacher professional development. Although our efforts were concentrated on the secondary school level, we believe that our results have important implications for the entire K–12 spectrum.

The complex issues we address, both academic and political, are similar in many respects to the issues facing teachers in general and teachers of mathematics, science, and technology in particular. For many of them, a shift toward engineering will represent a substantial change in both content and approach. For some, it will mean learning more mathematics and science. For others, it will involve learning how to interact with colleagues in other disciplines to ultimately rethink and repackage traditional content to focus on engineering and design. For still others, it will involve rethinking teaching methods and learning to facilitate hands-on, open-ended design experiences in which students and teachers work together to solve real-world problems.

Some projects and initiatives have been undertaken to assist teachers in teaching engineering-related curricula, but relatively little research has been conducted to determine what works. For example, little is known about best practices, teaching techniques, or design principles for the professional development of engineering teachers.

Although there is a general consensus in the literature on principles for effective teacher professional development (e.g., Garet et al., 2001; Loucks-Horsley et al., 2003), little is known about how these translate to an engineering context. In addition, several complex issues have emerged that affect the implementation of engineering at the K–12 level and have a direct effect on teacher professional development.

Engineering-related initiatives have generally been clustered at the secondary level. These include funded curriculum projects and initiatives,[1] reports from the National Academy of Engineering (2002, 2006), and standards initiatives for teachers of mathematics, science, and technology education. Thus secondary-level engineering professional development is a combination of existing initiatives for high school teachers.

For most teachers, a shift toward engineering will require a substantial change in content and approach.

The National Science Foundation (NSF) has funded a number of Centers for Learning and Teaching, but with few exceptions, they focus on building capacity for mathematics and science education. Only one NSF center, the National Center for Engineering and Technology Education (NCETE),[2] focuses on teaching engineering at the secondary level. NCETE is an initiative by nine universities from around the United States that have joined forces to engage teachers in professional development, conduct research, and prepare a cadre of leaders for teaching engineering at the pre-college level. Most of our work on engineering professional development has been done in this context.

In this article, we synthesize the outcomes of four major activities: (1) Professional Development for Engineering and Technology: A National Symposium, held in February 2007 in Dallas, Texas; (2) a research project consisting of five case studies of engineering professional development projects (Daugherty, 2008); (3) Symposium on Professional Development for Engineering and Technology Education: An Action Agenda, held June 2009 in Atlanta, Georgia; and (4) a research

[1] See Project Lead the Way (*http://www.pltw.org/*), The Infinity Project (*www.infinity-project.org*), and A World in Motion (*http://www.awim.org/*).

[2] See National Center for Engineering and Technology Education (*http://www.ncete.org/flash/index.php.*)

study on the conceptual basis of secondary-level engineering education. Based on these experiences, we have attempted to develop recommendations for K–12 engineering, as well as for teacher professional development. These four projects are briefly described below.[3]

The absence of a well defined conceptual base for teaching K–12 engineering has created serious problems.

Professional Development for Engineering and Technology: A National Symposium

In February 2007, a group of 55 educators gathered in Dallas, Texas, to share ideas and formulate recommendations for secondary-level engineering professional development. The participants included curriculum developers, state supervisors, professional development providers, pre-service teachers, content experts, and teachers who had completed professional development programs. The goal of this NSF-funded national symposium was to explore issues specific to engineering and technology education professional development. The event featured nine refereed papers organized around three major themes: (1) core engineering concepts; (2) knowledge specific to teaching engineering; and (3) effective models of professional development.

Following the symposium, a number of activities were conducted to refine and synthesize the findings, which yielded ideas and recommendations, among which were the need for better research, curriculum development, and collaboration among STEM disciplines. More specific to engineering, participants noted the need for models of professional development, clarification of unique aspects of engineering pedagogy, and advocacy for K–12 engineering education (Custer et al., 2007).

Engineering-Oriented Professional Development for Secondary Level Teachers: An Analysis of Five Case Studies

The second activity was a formal study of five professional development programs designed to prepare secondary teachers to teach engineering (Daugherty, 2008). The cases included in the study were Engineering the Future™, Project Lead the Way™, Mathematics across the Middle School MST Curriculum, The Infinity Project, and INSPIRES. The focus was on understanding (1) how each professional development program was designed, (2) fundamental content knowledge, (3) essential pedagogies, (4) unique challenges, and (5) effective practices. The study involved interviewing leaders, instructors, and participating teachers; observing workshops; administering a survey to teachers; and analyzing documentation.

Our analysis revealed a number of interesting patterns, including divergent purposes of the five projects (e.g., focus on career vs. general literacy); a general grounding in curriculum; the absence of a well defined, well articulated body of engineering content; diverse pedagogical approaches; divergent backgrounds and needs of teachers; and a strong preference for hands-on activities with relatively little emphasis on learning per se.

Symposium on Professional Development for Engineering and Technology Education: An Action Agenda

Based on a synthesis of the findings from the two major projects described above, a second symposium was held to develop and refine agendas for research and practice. The 25 participants who attended the second symposium includ ed representatives of all STEM disciplines, individuals with established expertise in professional development for teachers in mathematics and science, director-level leaders of three national professional STEM centers, and developers of engineering-oriented curricula.

Through discussions of three case studies and based on their wide range of experience with professional development and research, the meeting participants developed a framework and ideas for research and recommendations for practice. Research ideas were grouped into categories (context, inputs, process, content, and outcomes). Practice recommendations were clustered around policy, access, diversity, curriculum, pedagogy, pre-service, and school reform.

Formulating the Conceptual Base for Secondary Level Engineering Education: A Review and Synthesis[4]

One key concern that emerged from our conversations with curriculum and professional developers, as

[3] This material is based on work supported by the National Science Foundation under Grants No. ESI-0426421 and ESI-0533572.

[4] We wish to acknowledge our co-collaborator, Joseph P. Meyer, an NCETE doctoral fellow at the University of Illinois, Urbana-Champaign, for his work on this project.

well as with teachers, was the absence of a well defined conceptual base for engineering at the K–12 level. The tendency was to concentrate on design activities crafted to engage teachers and students, with the implicit understanding that essential elements of engineering design were being used and, therefore, understood. This approach, although it is an effective strategy for engaging students, is troubling in the current atmosphere with its emphasis on standards in all academic areas and the high value placed on the delivery of content in the professional development of mathematics and science teachers.

To address this concern, we obtained funding for a study to articulate a conceptual basis for teaching engineering at the secondary level. The project involved extensive reviews of philosophical materials, curricular materials, standards documents from STEM disciplines, and previous research. We also conducted a series of focus groups with engineering educators and practicing engineers using criteria designed to identify core concepts of engineering at the secondary level. In addition, we attempted to identify issues and problems directly related to the definition of a conceptual base (e.g., the shape and purpose of engineering at the pre-college level and how to include the ethical and social dimensions of engineering).

Research on Professional Development for STEM Teachers

Before we present the findings and observations from our work with professional development, we first provide a broad summary of what research has shown about professional development for STEM teachers. The literature is fairly consistent about what constitutes effective professional development, although, of course, there is no "paint by numbers kit" (Loucks-Horsley et al., 2003). From a broad perspective, professional designers must consider a range of factors, including the extensive knowledge base that can inform their work, unique contextual features for each subject, a wide range of professional development strategies, and critical issues in education reform.

Contextual issues that surround teachers' work and development are especially important. Teachers do not learn in a vacuum; rather, their learning is interwoven with school culture, instructional mission, and organization, as well as the teacher's knowledge and the learning and achievement of his or her students. This complexity makes "it difficult, if not impossible, for researchers to come up with universal truths" (Guskey, 1995).

Nevertheless, some consistent elements have emerged in the literature on professional development for STEM teachers (Darling-Hammond and McLaughlin, 1995; Desimone et al., 2002; Garet et al., 2001; Loucks-Horsley et al., 2003). Effective professional development designs have the following characteristics:

- They are reform-oriented (grounded in inquiry, reflection, problem solving, and experimentation).
- They engage students, teachers, parents, school officials, and even the wider community in collective and collaborative participation.
- They involve the participants in active, in-depth learning activities.
- They are based on a well defined image of effective classroom learning and teaching.
- They focus on improving both content and teaching techniques.
- They include mechanisms for continuous improvement and evaluation.
- They are embedded in the larger school culture and context.

STEM professional development can provide a framework for engineering-oriented professional development.

These design elements are not completely aligned with our own observations of the teaching of engineering at the secondary level. Strong points of alignment include the emphasis on active engagement, problem-solving, and experimentation, as well as clear ideas of what constitutes effective learning and teaching. The emphasis on content, reflection, and sensitivity to reform and to school culture are less in line with our findings. For the most part, however, the literature on STEM professional development is instructive and provides a broad framework for thinking about engineering-oriented professional development.

General Issues and Recommendations for K–12 Engineering

Based on our work with secondary level, engineering-oriented professional development, we derived several general observations about engineering education at the pre-college level. These observations involve broad systemic issues that go beyond professional development and, in many cases, across the K–12 spectrum.

Purpose of Teaching Engineering

One of the most serious issues confronting K–12 engineering education is establishing its purpose in the schools. On the one hand, many believe that engineering should be a pathway to post-secondary engineering education. From this perspective, content and curriculum should be designed to maximize and enrich the mathematics and science backgrounds of highly capable students, typically in applied design situations, to prepare them for the rigors of college-level engineering. At the other extreme, many believe that K–12 engineering programs should advance technological and scientific literacy, thus helping to prepare students for informed participation in a world permeated with technology.

From the first perspective K–12 engineering is appropriate "for a select few." From the second perspective, engineering is important "for all students." Resolving this issue will have profound implications for content, curriculum, and pre-service and professional development.

> *In this era of high-stakes assessments and accountability, the question of content is crucial.*

Conceptual Base

Professional development for teachers of engineering tends to include a variety of engaging design activities. Much of the formal work is based on implementing funded curriculum projects, which are also activity- and design-based. Given the process-based nature of engineering design and the history of programs that typically house engineering at the pre-college level, this is not surprising.

However, a solid conceptual basis for these activities and classroom experiences is much less in evidence. The lack of emphasis on concepts and content in professional development activities for teachers of engineering differs from the strong emphasis on content in professional development for teachers of mathematics and science. The question of what students are learning is particularly important in an era of standards, high-stakes assessments, and federally mandated accountability.

In a project designed to identify and validate core engineering concepts, we attempted to identify a conceptual base. In addition, *Engineering in K–12 Education: Understanding the Status and Improving the Prospects*, a new study by the National Academy of Engineering and National Research Council released in September 2009, provides an in-depth discussion of the need for and desirability of developing K–12 engineering standards. The results will directly affect curriculum developers and in-service providers of professional development.

Advocacy and Policy

There is considerable confusion and a general lack of information about engineering at the K–12 level, both in the educational community and in the general public. In the educational community, serious concerns have been raised about where engineering content should be located and what it might replace in an already crowded curriculum. Even if a compelling case were made for including engineering in the curriculum, school leaders worry about where it would fit and what would be displaced. Should it be part of the existing science curriculum, which would have the associated benefits of engaging students in real-world science and mathematics applications? Or should efforts be focused on retooling technology-education classes to include engineering?

The second approach raises significant issues about capacity and public perceptions. First, there are not enough teachers in the technology-education field to teach engineering on a large scale. Second, many in the general public confuse design-oriented technology education with computers and other instructional technologies used in various ways throughout the schools. Thus incorporating engineering into K–12 schools would require significant, sustained advocacy to support changes in both school and public policies.

Student Access and Diversity

An ongoing issue in engineering education is how to diversify the field. For example, only 20 percent of degrees in engineering were awarded to women in 2005 (DOEd, 2005), and women's presence decreases as one ascends the tenure track and academic leadership hierarchy (NAE, 2007). A national survey of minorities in science and engineering at research universities found that the number of underrepresented minority faculty in the top 100 departments for science and engineering increased by only 0.5 percent, rising to 5 percent (Nelson, 2007). Although educational and career choices are ultimately individual decisions, research suggests that a variety of factors contribute to the disproportion of women and minorities in engineering; these include differences in learning styles and work-life priorities and the absence of role models (Lukas, 2008; Nelson, 2007; Science Daily, 2009).

A variety of programs and initiatives have been developed and funded in recent years to address this concern (e.g., Girls in Engineering, Math, and Science [GEMS], Champions of Diversity, LSAMP, Expanding Your Horizons, Society of Women Engineers). We believe that engaging, context-based engineering activities at the K–12 level could significantly increase the diversity of students who participate in STEM classes and ultimately pursue careers in these areas.

Pre-service Teacher Education

Incorporating engineering into K–12 schools on a large scale will challenge colleges of education and engineering to develop new models of teacher education. This will, of course, depend on policy decisions, such as deciding with which discipline(s) it will be aligned. One model could be to restructure pre-service science and technology education programs to focus on the delivery of engineering content. Another model would be for colleges of education to certify students with undergraduate engineering degrees to teach engineering through programs at the master's degree level.

Regardless of the model, preparing teachers to deliver engineering content in the public schools will require significant changes in the way they are prepared at the pre-service level. Important issues include requirements for mathematics and science, core engineering content, curriculum and activity development, unique pedagogical demands of teaching engineering, and appropriate collaboration with other STEM teachers. Decisions will also have to be made about the extent to which pre-service programs engage with nationally oriented professional development programs (e.g., Project Lead the Way, The Infinity Project, Engineering by Design).

Issues Specific to Professional Development

Teachers with Diverse Backgrounds

A number of engineering-oriented professional development programs are designed to include teachers from a variety of academic disciplines, generally mathematics, science, and technology education, but sometimes teachers from other disciplines as well. Although interdisciplinary collaboration often has positive results, diverse backgrounds frequently pose difficulties for professional developers. Because of differences in pre-service teacher education, teachers' backgrounds and capabilities often vary across and within the three major disciplines.

Preparing teachers to deliver engineering content will require changes in their pre-service training.

Even for professional development programs designed to facilitate cross-disciplinary teams, it is sometimes difficult to transplant the same level of collaboration into schools, which have scheduling, curricular, and assessment constraints. Thus professional development must be flexible enough to meet the needs of teachers, particularly teachers who have varying levels of science, technology, engineering, and mathematics abilities. At the same time, it must be comprehensive enough to ensure that all teachers have the skills to transfer their learning into classroom practice.

Pedagogy

One significant deficiency we observed in engineering professional development at the secondary level is a lack of critical analysis and reflection on pedagogy per se. In many cases, teachers were engaged in exciting activities, worked with well developed curricular materials, and interacted with one another in constructive and positive ways. But the general tendency was for teachers to concentrate on completing design challenges that they could then take back to their classrooms. In many cases, the primary focus was on tools, techniques, processes, and technical details and not on teaching methods or learning processes.

Although all of these are appropriate, there must also be a corresponding emphasis on teaching and learning. For example, teachers could be encouraged to ask themselves what concepts can be learned through a specific activity, what students are actually learning and which aspects of the activity are most effective in this learning, how a lesson might be changed to improve its transfer to a real classroom, and whether there might be opportunities to connect and reinforce learning from other content areas.

Engineering professional development should be designed so that teachers actively and routinely engage in this type of analytical and critical reflection on their teaching. Given the active, authentic, interdisciplinary nature of engineering content, the lessons learned through reflection on learning could inform other disciplines across the curriculum.

Conclusions

Engineering at the K–12 level has the potential to contribute to the vitality of schools. In a world infused with technology, it is becoming increasingly important that students know something about the role of engineering in creating the technologies they use every day. Active involvement in a democracy requires awareness to enable citizens to make good consumer choices and participation to voice their preferences at the ballot box. In addition, for the United States to retain its competitive edge, it is vitally important that students be well prepared to pursue high-tech careers in STEM disciplines. To realize this potential, the preparation and ongoing development of engineering teachers should be a top priority.

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Experience with engineering in K–12 classrooms in Massachusetts has become a reference point for other states.

The Incorporation of Technology/ Engineering Concepts into Academic Standards in Massachusetts

A Case Study

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Jacob Foster

Efforts by Massachusetts over the past decade to develop academic technology/engineering standards and implement related programs has become a reference point for a number of other states and countries looking to support K–12 engineering education. This paper outlines the process Massachusetts has undertaken and describes some successes and challenges related to the development and implementation of engineering programs in K–12 schools.[1]

The development of state technology/engineering standards was made possible by the enactment of the 1993 Massachusetts Education Reform Law, but it was begun in earnest as a result of the advocacy of teachers of technology education and engineers interested in education. In Massachusetts, technology/engineering is now considered a science discipline equivalent to physical science, life science, and earth and space science, and a number of state policies, such as policies related to licensing and assessment, support the implementation of school technology/engineering programs. However, a number of challenges must still be overcome before technology/engineering will have developed to a point equivalent to traditional science disciplines.

[1] This paper focuses on academic standards and programs. The state also has career/vocational technical education (CVTE) frameworks with engineering foci, including engineering technology, biotechnology, robotics, and automation technology. CVTE frameworks can be found at *http://www.doe.mass.edu/cte/frameworks/*.

Legislative and Policy Origins of Technology/ Engineering in Massachusetts

The development of technology/engineering standards was made possible by specific language in the 1993 Massachusetts Education Reform Law:

> The board shall . . . develop *academic standards* for the core subjects of mathematics, *science and technology*, history and social science, English, foreign languages and the arts. . . . The board may also include in the standards a fundamental knowledge of *technology education* and computer science and keyboarding skills . . . (Massachusetts General Laws, Chapter 69, Section 1D, italics added)

The inclusion of "science and technology" in the legislation was the impetus for the development of the first *Massachusetts Science and Technology Curriculum Framework* (MA ESE, 1996). The word "technology" in the title sparked a statewide discussion of what that term should include. For the science education community, the word connoted a science-technology-and-society (STS) perspective as described in *Science for All Americans* (AAAS, 1989) and *National Science Education Standards* (NRC, 1996). For the technology education community, it referred to technological literacy, as described in *Technology for All Americans* (ITEA, 1996). There was even some discussion about whether "technology" meant computers—instructional technology—but it was decided that the inclusion of "technology education" in the legislation quoted above referred to computers.

Science staff, administrators, and parents were slow to embrace an academic technology/ engineering program.

The result of the statewide discussion was an initial framework in 1996 defining "science and technology" as an academic subject that included both the STS and technology education perspectives. Later, in the 2001 framework revision (MA ESE, 2001), the STS perspective was replaced with more specific engineering principles, leading to the modified title of "science and technology/engineering."

Emergence of Academic Technology/ Engineering in Massachusetts

The introduction of technology/engineering standards into the core academic framework, initially led by the state technology education organization, was the first step in incorporating engineering concepts into the educational system. In the early to mid-1990s, industrial arts courses became technology education courses. Unlike the traditional industrial arts programs, technology education programs (many of which still exist in the state) can be characterized as elective, supplementary programs that focus primarily on the development of student skills and products and secondarily on trade skills and tool use.

The discussion about making technology education a core academic discipline raised the possibility of another shift, this time away from being a supplemental, technically oriented program toward an academic, knowledge-oriented technology/engineering program. This second shift was even farther from the long and productive history of skills development and tool use taught in industrial arts programs. Although some teachers were able to make this transition, creating the initial technology/engineering courses in the process, many have struggled to adapt to the second shift.

The implications of the second shift continue to pose significant challenges to the systematic implementation of technology/engineering standards in Massachusetts. Many technology education teachers were resistant to the change, causing a split in the state's technology education organization. One side was aligned more with the industrial arts-technology education perspective; the other with the technology/engineering-academic perspective. Those who were watching this process, including school science staff, curriculum coordinators, and administrators, saw the unresolved conflict as a reason to delay the incorporation of technology/engineering concepts into school programs.

Until the mid-2000s, most science staff and organizations did not take ownership of technology/engineering standards, which they considered the responsibility of technology education teachers. In addition, science staff, administrators, and parents were slow to change their conceptions and embrace the possibility of an academic technology/engineering program. Only recently have more schools begun to transition technology

BOX 1 High School Technology Topics in the *1996 Massachusetts Science and Technology Curriculum Framework*.

1996 technology topics (high school)

- the design process
- the nature and impact of technology
- technology yesterday, today, and tomorrow
- the tools and machines of technology
- resources of technology
- technological areas of communication, construction, manufacturing, transportation, power, and bio-related technologies

BOX 2 Sample Standards for Two Technology Topics, 1996.

Resources of technology

- Identify particular characteristics of material resources (i.e., synthetic, composite, and biological). Explain how various energy sources and forms of information are also resources with specific characteristics.
- Discuss issues of resource management including safety, costs, and environmental and political concerns. Discuss a current example, such as waste management or nuclear power systems.

Technological areas of communication, construction, manufacturing, transportation, power, and bio-related technologies

- Give examples of how combinations of graphic and electronic communication processes are used in developing high-technology communication systems.
- Describe uses of material conversion processes (i.e., separating, forming, conditioning, and combining), in production processes.

education programs into their science departments, often merging the two into a "science and technology/engineering department."

Acceptance of the change can be attributed, at least in part, to several factors. First, the Massachusetts Department of Elementary and Secondary Education (hereafter called the Department) has worked over the years to align state policies so that technology/engineering is treated the same way other science disciplines are treated. This has provided support for schools and school districts that were prepared to develop academic technology/engineering programs. Second, relations between the two technology education organizations are improving. Finally, the Boston Museum of Science (MOS), with its associated National Center for Technological Literacy, has become a leader in promoting technology/engineering.

All of these factors helped to distance the discipline from organizational tensions and associations with past technical programs. The museum's development of technology/engineering curricula (Engineering is Elementary [EiE][2] and Engineering the Future [EtF], for high school students) not only provided administrators, science staff, and parents with an image of what a technology/engineering curriculum could look like, but also showed how technology/engineering concepts could be integrated with traditional science concepts. The EiE and EtF curricula have also had a significant impact on the attitudes of administrators and guidance staff and on the establishment of technology/engineering programs across the state.

The National Center for Technological Literacy (NCTL) associated with MOS has trained more than 750 teachers in Massachusetts in the EiE curriculum, which is now used by approximately 115 elementary schools. In addition, about 60 high schools have purchased the EtF curriculum, and many high school teachers have participated in training workshops. NCTL also supports leadership teams (involving more than 250 teachers and administrators) in approximately 55 Massachusetts school districts; these teams are actively working to design and implement technology/engineering programs.

The Academic Framework over Time

Technology Topics and Sample Standards in the 1996 Framework

The *1996 Massachusetts Science and Technology Curriculum Framework* drew upon seminal standards documents for science education (AAAS, 1993; DOEd, 1996; NRC, 1996). With input and advocacy from both the science and technology education communities, the topics in the 1996 framework reflect the combined STS and technology education perspectives (Box 1). The combined perspectives are also reflected in the specific standards (Box 2).

[2] See the article by Christine Cunningham on p. 11 in this issue.

Technology/Engineering Topics and Sample Standards in the 2001 Framework

With the advocacy of engineers interested in education, a number of changes were made to the technology topics and standards in the *2001 Framework*. For example, technological design was changed to the engineering design process, topics for energy and power systems were added, and the social implications of technology were removed. The technology/engineering topics in the *2001 Framework* (Box 3), as well as the specific standards (Box 4), reflect the combined technology education and engineering perspectives. The *2001 Framework* drew on additional seminal documents (DOEd, 2000; ITEA, 2000) and the strong emphasis on content and standardized assessments being developed in the 2001 No Child Left Behind (NCLB) Act.

Development of Department Policies

Successes

After years of effort, significant progress has been made in aligning policies to ensure that technology/engineering is treated as an academic discipline. This would not have been possible without the 1993 Education Reform Law, which provided both a foundation for developing the standards and a rationale for the corresponding policies. The Department has argued that the structures of technology/engineering and traditional sciences are similar—each articulates a core body of knowledge and each has a closely aligned articulated process to guide practice and generate new knowledge. Based on these parallels, technology/engineering can be counted *as a science* from a policy perspective.

Once the first *1996 Framework* had been developed with technology/engineering as a discipline equivalent to other science disciplines, technology/engineering items were incorporated into the Massachusetts Comprehensive Assessment System (MCAS) tests. Technology/engineering currently counts for 15 percent of the 5th grade test, 25 percent of the 8th grade test, and is one of four options for the high school end-of-course test.

Changing the licensing requirements for teachers of technology/engineering was much more difficult. The Department currently offers an academic license in "technology/engineering," which has expectations equivalent to those of other science licenses in terms of required content knowledge (including passing a content test), completion of a practicum, license for grades 5–12, and a requirement for being rated "highly qualified" in keeping with NCLB requirements.

BOX 3 High School Technology/Engineering Topics in the *2001 Massachusetts Science and Technology/Engineering Curriculum Framework.*

2001 Technology/Engineering topics (high school)

- Engineering design
- Materials, tools, and machines
- Communication technologies
- Manufacturing technologies
- Construction technologies
- Transportation technologies
- Energy and power systems—fluid systems
- Energy and power systems—thermal systems
- Energy and power systems—electrical systems
- Bioengineering technologies

BOX 4 Sample Concepts and Standards for Two Technology/Engineering Topics, 2001.

2. Construction Technologies

2.3 Explain Bernoulli's principle and its effect on structures such as buildings and bridges.

2.4 Calculate the resultant force(s) for a combination of live loads and dead loads.

2.5 Identify and demonstrate the safe and proper use of common hand tools, power tools, and measurement devices used in construction.

3. Energy and Power Technologies—Fluid Systems

3.2 Explain the differences and similarities between hydraulic and pneumatic systems, and explain how each relates to manufacturing and transportation systems.

3.3 Calculate and describe the ability of a hydraulic system to multiply distance, multiply force, and effect directional change.

3.4 Recognize that the velocity of a liquid moving in a pipe varies inversely with changes in the cross-sectional area of the pipe.

However, because technology/engineering developed through a progression from industrial arts to technology education to technology/engineering, the license also went through the same transition. Thus all industrial arts and technology-education certified teachers were grandfathered into the system and are licensed to teach a core academic technology/engineering course. In this way, a pool of teachers licensed to teach the new subject was made available, but administrators raised reasonable questions about whether all of them were truly qualified.

Finally, because the state recognizes technology/engineering as a core academic science option, schools and school districts can give science credit for these courses and apply those credits to high school graduation requirements. The alignment of all of these policies means that schools and school districts now have the necessary support to develop academic technology/engineering programs.

A Remaining Challenge

One significant policy challenge remains—the alignment of high school graduation expectations and state college admission requirements. This issue only arose recently when enough technology/engineering programs were in place to produce a significant number of students with these credits. Addressing this challenge will require aligning policies of the Department, the Massachusetts Department of Higher Education, and, interestingly, the National Collegiate Athletic Association (NCAA).

Although the Department allows schools to accept technology/engineering courses as fulfilling science graduation requirements, the Department of Higher Education has not yet recognized those courses as "natural/physical science" courses for admission purposes. Most institutions of higher education have separate science and engineering departments and thus do not necessarily consider these disciplines equivalent. In addition, state colleges and universities have not been made aware of the nature and rigor of high school technology/engineering courses. Thus when they review a transcript for the purposes of student admission, technology/engineering is not counted as fulfilling science requirements. This issue is currently being addressed and may be resolved soon.

The alignment with NCAA requirements is a bit more abstract but just as important. NCAA reviews the transcripts of students who want to participate in sports or receive sports scholarships at NCAA-affiliated institutions. NCAA pre-approves all high school academic courses based on reviews of syllabi submitted by high school guidance departments. When Massachusetts high schools submitted technology/engineering courses for review as science courses, NCAA rejected them as "vocational" rather than academic courses, no matter what evidence the school provided.

Once the rejection letter was received, the guidance department notified the science and/or technology education department that the course could not be added to the school's program of studies for science credit. To address this problem, the Department wrote to NCAA explaining how the state incorporates technology/engineering into science as an academic subject and asked that future requests be reviewed in light of that information. NCAA has agreed to do so and is beginning to approve these courses.

Aligning high school graduation and college admissions requirements is a significant challenge.

Implementation by Schools, School Districts, and Institutions of Higher Education

Successes

Schools and school districts have implemented a variety of K–12 curricula aligned with the Department's technology/engineering standards. Although the Department has not collected unit lessons or course syllabi, evidence of the successful implementation of these curricula is apparent in inquiries from other schools about these programs, newspaper articles about technology/engineering offerings, and the number of students taking the high school technology/engineering MCAS test. The Department has also noticed that more district administrators are taking an interest in technology/engineering, particularly those who follow discussions of state economic policy, in which biotechnology and high-tech have had a high profile for the past several years. Finally, published curricula and textbooks aligned with state standards have made it easier to start new programs.

Local successes are also reflected in the recruitment of "career changers" to the teaching force. Many school districts have hired former engineers who have decided to become teachers and to help in the development and teaching of technology/engineering programs.

Career changers bring real-world experience to their instruction and a perspective that assumes the value of integrating traditional science topics with technology/engineering topics.

Changes have also been made on the organizational level. A number of high schools have merged their science and technology education departments, and the state technology education professional organizations now explicitly include engineering in their names and mission statements. The state science fair organization changed its name in 2006 to the Massachusetts State Science and Engineering Fair and expanded the types of projects that can be submitted and judged.

Challenges

Although state policies now provide schools and school districts with clear support for implementing technology/engineering programs, a number of implementation challenges must still be navigated. First, school administrators must distinguish between technical and academic offerings, which can be difficult given the history and experiences of particular schools and school districts. As they look around the state for examples and models, they are confronted with a wide range of programs and courses that vary in quality, many of them initially designed by individuals. Until the science and technology education staff and organizations begin to collaborate in more specific ways, teachers and schools may not know where to turn for support in developing programs.

Another challenge confronting schools is the limited number of certified teachers and teacher-preparation programs. Currently, there is only one active teacher-preparation program in the state, which graduates on average fewer than five new technology/engineering teachers per year. The Department is actively working to increase the number of preparation programs offering support for technology/engineering licenses. Unfortunately, preparation programs have been hesitant to invest in program development until there is a demand for teachers, but the demand has been held down, in part, because not enough teachers are available to design and implement K–12 programs.

Lessons Learned

The development of technology/engineering programs in Massachusetts can provide insights for others who may want to engage in similar efforts. In the author's opinion, the five lessons listed below have been learned from the particular experiences and circumstances in Massachusetts:

- Determine how the subject will be classified early on, because all subsequent policy decisions will be based on that determination. For example, will engineering concepts be incorporated into a core academic subject, such as science? Will engineering be treated as an elective subject? Will it be defined as a vocational discipline? Or will there be some combination of these options?
- If engineering concepts will be incorporated into core academic science, determine if they will constitute a distinct subject (as they do in Massachusetts) or a topic in other subjects (some states have a "technological design" topic as part of each science subject). This decision will have implications for policies related to licensing and assessment.
- Determine the focus of the standards early. Will they focus on engineering concepts, technology education concepts (ITEA, 2000), or a combination?
- Provide examples of what courses/curricula should look like and then monitor them for quality and alignment. A number of resources are now available for schools to review.
- Focus on relationships. Mediate tensions between maintaining a "technology/engineering" identity and folding technology/engineering into "science." Mediate tensions between "technologists" (technology educators) and "engineers." Encourage interactions between technology/engineering and science organizations early on, so all of them take ownership of the program/curriculum.

Summary

Articulating technology/engineering standards, implementing policies to support them, and developing programs to implement them have been major endeavors in Massachusetts. Students now have the opportunity to participate in relevant, engaging, and necessary programs of study that we believe will help meet the need for technologically literate citizens and a technical and engineering workforce. Elements throughout the educational system have been changed to support the implementation of technology/engineering standards, although change continues to be somewhat sporadic.

The articulation of technology/engineering standards as part of science was the first crucial step in making this possible. The efforts of professional organizations were crucial to making these changes, although if closer attention had been paid to organizational relationships over the past 10 years, change might have been easier.

As the first state to include engineering concepts in state academic standards, Massachusetts has worked diligently since 1993 to overcome a number of policy and implementation challenges. Our hope is that this case study will be of help to other states making similar efforts. The development of technology/engineering resources and programs is much more likely to succeed when many states are working toward similar goals.

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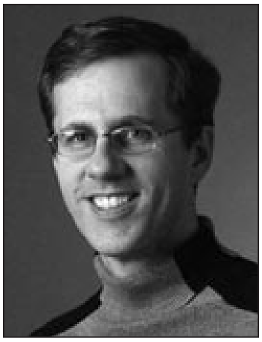
Researchers are investigating how and when children can learn engineering concepts and skills.

How Kids Learn Engineering

The Cognitive Science Perspective



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The number of U.S. students who enter engineering programs in college is projected to drop, a trend that many believe will have a negative impact on the U.S. workforce (NAS et al., 2007; NAE and NRC, 2009). In addition, students who do pursue engineering degrees do not reflect the diversity of students in the United States, a pattern of enrollment that is likely to have a number of negative consequences, both for the successful practice of engineering and for the resolution of broader societal issues (NAE and NRC, 2009).

Although a relatively small number of children go on to become engineers, citizens in our technology-based society need to understand engineering issues, perhaps even be prepared to work collaboratively with engineers (NAE, 2002; NAE and NRC, 2009), which requires an understanding of what engineering is and what engineers do. The number of engineering exposure programs in formal (e.g., schools) and informal settings (e.g., museums, competitions, after-school programs, summer programs) is growing, but we have a long way to go before a majority of U.S. children have significant exposure to engineering (NAE and NRC, 2009). A dramatic increase in exposures to engineering could ultimately lead to an increase in the number and diversity of engineers.

Concerns about the lack of exposure to engineering for all children and ensuring a larger, more reliable supply of future engineers have been accompanied by the realization that we have not yet determined the best way to expose children to engineering skills and concepts. We are still investigating which aspects of engineering are developmentally appropriate for children of different ages and what kinds of experience are most effective. Because engineering has not generally been emphasized in pre-college settings, the body of literature on how children learn engineering is small. However, a few of the critical findings that have emerged are synthesized in this article.[1]

Defining Engineering for Instruction

A general principle for designing good educational environments is to begin with a specification of the end state, in this case, a definition of engineering (Wiggins and McTighe, 2005) and what we hope to accomplish through engineering education. On the most general level, I assume that engineering involves using analytical and empirical processes to design complex systems that meet stated objectives and take into account specific scientific and societal constraints.

There is some debate about whether the focus of pre-college instruction should be on preparing kids to learn engineering in college (e.g., focusing on math and science and stimulating interest in engineering) or on trying to develop engineering skills and thinking per se. Clearly skills in math and science are a requirement for filling the pipeline of future engineers.

Complex activities like engineering are usually divided into skills and concepts (Table 1). Although engineering overlaps and is symbiotic with science and math, some skills and concepts are much more specific to engineering. Thus providing all children with a broad exposure to engineering requires moving beyond basic skills in math and science. Stimulating interest in engineering as a career will require exposure to the practices of engineering.

TABLE 1 Examples of Focal Engineering Skills and Concepts

Skills	Concepts
Design	Systems
Optimization	Subsystems
Modeling	Structure-behavior-function
Experimentation	Constraints
Teamwork	Trade-offs
	Requirements
	Side effects

Developmentally Appropriate Engineering Material for Kids

Many college engineering students struggle to meet the rigorous standards demanded in their college courses, especially when they are asked to apply science and math principles to complex design problems. Consequently, many universities continue to have serious retention problems among engineering majors. When engineering faculty look at things from this perspective, they may wonder if teaching engineering concepts and skills is developmentally appropriate for pre-college age children.

A number of existence proofs have shown that teaching engineering is developmentally appropriate for kids, if it is done with the proper support. At the high school level, for example, thousands of kids engage in robotics competitions that require large teams of students to collaborate on meeting mechanical and electrical engineering design challenges.

I run a regional high school design competition in which the top teams from participating high school science classes bring in the results of eight-week-long innovative design projects (Reynolds et al., 2009). Teams are judged on how well they integrate science into innovative design solutions. Surprisingly, 9th graders (from biology classrooms) sometimes outperform much older children (from chemistry, physics, or environmental sciences classrooms), suggesting that innovative engineering design skills can be learned before the late teenage years (Figure 1).

A number of engineering-based curricula, even at the early elementary school level,[2] are being used to teach thousands of U.S. children from diverse backgrounds. The success of these curricula suggests that some aspects of engineering are generally accessible to a broad range of children at many different age levels.

However, working with pre-college-aged children is not the same as working with college-aged young adults. Clearly, there are differences in how quickly children

[1] For overviews of what we know about teaching complex skills and knowledge in general, see *How People Learn* (NRC, 1999) and *Taking Science to School* (NRC, 2007).

[2] See for example City Technology (*http://www.citytechnology.ccny.cuny.edu*) and Engineering is Elementary (*http://www.mos.org/eie*) and p. 11 in this issue.

FIGURE 1 Two winning high school engineering design teams.

reason, how well they integrate complex information, and how much relevant science and mathematics knowledge they have mastered.

Even though a college-level curriculum is not developmentally appropriate for younger kids, the concept of "developmentally appropriate" material has relatively little to do with age per se (i.e., a time-locked biological progression) and much to do with how far the child has moved along relevant developmental progressions, for which there is huge variability, depending largely on environmental conditions (NRC, 2007). Under the right conditions, young students can engage in relatively sophisticated engineering design activities long before they reach young adulthood.

Helping Kids Learn Engineering

Once we know kids can learn important aspects of engineering, the natural question becomes: What are useful environmental supports? The four principles described below have been found to be useful in supporting early engineering learners.

1. Engage children in solving significant design problems from the beginning.

An important part of learning complex skills and concepts is engaging in versions of the main end-state performance task, in this case engineering design. Skills and concepts are acquired through systematic practice, not through magic bullets (Anderson and Schunn, 2000). Unfortunately, in educational environments, complex activities are sometimes so oversimplified that critical aspects are completely lost, and thus key skills are not learned (Chinn and Malhotra, 2002).

It may seem logical to teach the foundational concepts for a design problem first (e.g., the background engineering science or background mathematics) and only then introduce the design task. In many ways, the traditional engineering curriculum follows this model, often leaving significant design challenges until the last year. However, the "basics-first" approach is a poor instructional strategy for a number of reasons.

First, students find design engaging, and thus it can be a motivator for learning the precursors or foundational skills and concepts that must be in place before higher level engineering skills can be learned. For example, design problems can create a powerful motivation for learning relevant science (Hmelo et al., 2000; Schauble et al., 1991), and presenting design problems after the science has been learned eliminates this motivator. In the United States, poor performance in basic math and science (in contrast to reading) is considered socially acceptable, and many students are not motivated to do well in those subjects. To address this problem, new motivators are urgently needed, and engineering design activities is one of them.

Second, design can be integrated closely with science instruction to the point that it becomes the vehicle through which relevant science is learned (Hmelo et al., 2000; Mehalik et al., 2008). For example, a number of researchers have created instructional models in which science-learning activities are naturally integrated into design cycles. Students begin a design challenge; the early design fails, creating a need for scientific knowledge; the knowledge is acquired through experimentation and reading; and the design task is resumed, with new scientific knowledge in hand (see Figure 2).

Third, if students are involved in design only at the end of a unit, they spend relatively little time actually engaged in engineering design and thus learn relatively little about it. In many settings, the tail end of a sequence of activities receives short shrift, that is, the last activities are either skipped entirely or are done very rapidly in whatever time happens to be left. As a rule of thumb, if an activity is important, it should not be the last one.

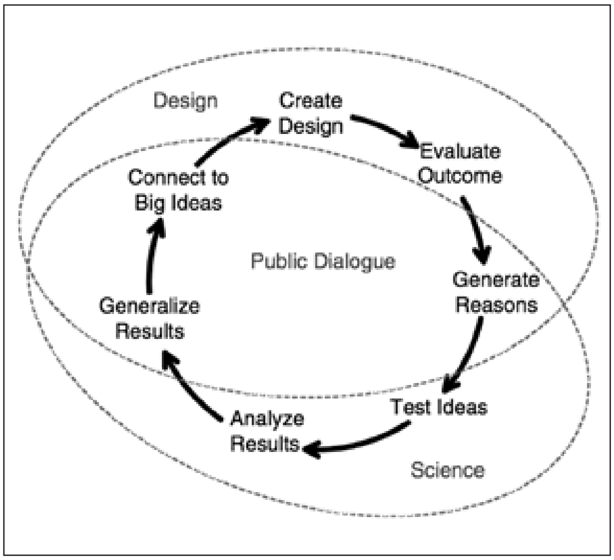

FIGURE 2 The design-science learning cycle. Source: Adapted from Apedoe et al., 2009.

Fourth, when science is learned as abstract formalisms with no connections or context, students often have trouble using that knowledge later to solve problems (NRC, 2007). Engineering design problems create a natural context for connecting to science concepts, just as engineering and science create a natural context for connecting to math concepts.

Finally, engaging in solving significant design problems appears to change students' career interests in engineering (Reynolds et al., 2009). The impact on children's career goals can be strongest in the early and middle school years, before they have been given an opportunity to make significant choices about elective courses and informal learning opportunities when they may choose to opt out of science and engineering-relevant activities.

Interest in engineering as a career is influenced not only by role models, but also by perceptions of the career itself. For example, introducing engineers to children as people who solve everyday problems has been correlated with interest in engineering careers, and experience using engineering design to solve everyday problems appears to reinforce that perception and increase interest in engineering careers (Reynolds et al., 2009).

2. Make visible models to support the design task.

Engineering design is often based on multi-layered abstract concepts, both of which can be barriers to learning. For example, design requires reasoning about trade-offs, which inherently means reasoning about many factors at once. We know that, compared to adults, children specifically have problems in dealing with multiple factors at once (Kuhn, 1991; Sweller, 1988).

Even engineering experts can have some cognitive limitations, that is, they can only consider so many variables at once. Most engineering problems are much too complicated to be addressed mentally. Therefore, engineers use models in various forms to offload the cognitive strain to a larger, partially externalized, computational system (Hutchins, 1995). In the early days of engineering, offloading was to paper and slide rules; today engineers make heavy use of analysis and design software.

Children can address the problem of cognitive overload in the same way. Just as external models help engineers solve design problems, they can also help children understand and define a problem by presenting requirements and constraints in a form that can be inspected externally (Penner, 2001; Resnick and Wilensky, 1998). However, although models are often transparent and directly meaningful to an expert, they can be confusing and laborious to translate for a novice (Berthold and Renkl, 2009; Hegarty et al, 2003). For each kind of model (e.g., data table, line graph, force diagram, or mathematical equation), children need time to understand what the model represents and how to interpret it.

More concrete models (e.g., diagrams, physical prototypes) can be subjects of discussion for groups of children, giving them an opportunity to build on each other's ideas (Roth, 2001). But mathematical models can also be helpful because they help children focus attention on critical information, stripping away irrelevant or superficial details. Although younger students clearly have much weaker mathematical skills than college students, even third graders can learn to use mathematical relationships to support design thinking (Lehrer et al., 2000).

3. Iterative design and redesign are better than single design cycles.

Actual engineering design is a complex, iterative process by which a design slowly moves toward better, more effective solutions. For students, this iterative process not only improves the solution, but also provides important learning opportunities for developing a better understanding of engineering concepts and skills. When students actually experience more than one design cycle for a given problem, they begin to appreciate that design is an iterative process.

Unfortunately, students are often only given time for one design cycle. As a result, the design is sometimes very poor, although the outcome might be improved with heavy-handed hints from the teacher. In either case, the child is left wondering how engineers manage to solve multifaceted problems.

Multiple design cycles enable children to develop a more complex, more complete understanding of relevant engineering concepts. Early in a design task, students tend to focus on superficial aspects of models, often misunderstanding the functional aspects of the design and making poor conceptual connections between models and engineering design. For example, children may create a prototype of an elbow that is the color of a human elbow but is otherwise dissimilar to the elbow joint and thus not a useful artificial limb. The initial model tends to become more functional and complex through design iterations and evaluation cycles (Penner et al., 1997), which not only lead to better designs but also to a richer understanding of the functional role of models in design. With each iteration, students can take into consideration more of the functional requirements of the design and more tradeoffs (Sadler et al., 2000).

Designing a model from scratch, however, tends to take so long that children often run out of time before they get to critical iterations (Hmelo et al., 2000). When time is short, a redesign task may be an effective way to "create" time for additional design cycles.

4. Provide sufficient time for exposure to engineering material.

Sometimes, engineering material is inserted into a curriculum, but only for a very short time, five hours or less, perhaps (e.g., a single museum visit, a single weekend workshop, or a few classroom periods at the end of a unit). These short-duration exposures are not long enough to involve significant, iterative design problems; therefore visible models are not likely to lead to meaningful learning about engineering. However, they might be effective as supplements to other engineering instruction.

Unfortunately, short-duration opportunities are the easiest for teachers to plan and implement, especially considering the typical teacher's investment in early engineering education. Typically teachers only spend a few hours or days in designing engineering activities for their students, a level of effort that can only support the design of a few hours of instruction.

In addition, for most teachers the K–12 curriculum is already packed, and pressure to cover more core content has increased with the advent of high-stakes testing. Thus engineering may be considered merely an enrichment activity, which means the teacher has very small windows of instructional opportunity.

I am not arguing here that enough instructional time should be provided in every experience to teach children the broad range of engineering skills, concepts, and dispositions for literate 21st century citizens or to prepare them for engineering college pathways. Either of those outcomes will certainly require a multiyear engineering curriculum. The point here is that children must have a minimal amount of time for each exposure to engineering content or design for it to have a real impact on student learning. It takes time for children to grasp big ideas about engineering.

Successful early engineering design experiences may last a total of only 20 to 30 hours (e.g., a week of summer camp, a month of Saturday museum workshops, a semester of Monday after-school sessions, or six weeks of everyday science class). Within that time frame, however, children can decompose a design task into subsystems, iterate on each subsystem, acquire relevant science concepts along the way, and come to understand a critical engineering concept or two.

Conclusion

Much remains to be learned about which aspects of engineering concepts, skills, and dispositions are difficult for children to master and the best ways to help them overcome those difficulties (NAE and NRC, 2009). However, the principles described above can provide some guidance for introducing children to engineering.

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Providing opportunities for girls to learn about engineering can eventually increase diversity in the engineering workforce.

EngineerGirl! A Website to Interest Girls in Engineering

Suzanne Jenniches

Catherine Didion

Suzanne Jenniches and
Catherine Didion

I want us all to think about new and creative ways to engage young people in science and engineering, whether it's science festivals, robotics competitions, fairs that encourage young people to create and build and invent—to be makers of things, not just consumers of things.

President Barack Obama
April 27, 2009
National Academy of Sciences

Meeting the challenges in our increasingly complex and interconnected world will require the talents of all of us. The National Academy of Engineering (NAE) recognizes the importance of reaching students early in their studies and providing them not only with an understanding of engineering but, equally important, an opportunity to explore engineering careers in a way that resonates with their interests and passions. As part of NAE's commitment to increasing diversity in the engineering workforce and to improving the technological literacy of Americans, we have developed a website, *www.EngineerGirl.org*, to attract middle school and high school students, particularly girls, to engineering at a time in their lives when they are being

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asked to make important educational decisions (e.g., deciding whether or not to take algebra) that will have an impact on their career options and opportunities for years to come.

Although more than half of the nation's population and a majority of students who earn bachelor's and master's degrees are women, in the past decade their representation in the engineering workforce has increased to only 12 percent, in stark contrast to their representation in other occupations (see Figure 1).

A survey of first-year students in all four-year colleges revealed that only 14.5 percent of male students and 2.5 percent of female students intend to major in engineering (NSF, 2009). The number of women among freshmen engineering students peaked at approximately 20 percent in 2001 and has stubbornly remained at that level, despite all efforts to attract them to the profession. As Table 1 shows, the disparity between male and female holds true for students of all racial and ethnic backgrounds.

What are the implications of these numbers? In *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, a 2005 NAE report, a committee of experts noted that students with degrees in engineering are "technically grounded graduates" who are "prepared to work in a constantly changing global economy." The lack of interest in engineering by both male and female students was underscored in an article in the June 3, 2009, issue of *Forbes*, "The 10 Hardest Jobs to Fill in America." The author, Tara Weiss, reported that "for the second year in a row, engineer is the hardest job to fill in America." She went on to quote Larry Jacobson, executive director of the National Society of Professional Engineers: "We have whole generations of people loving liberal arts, not going into science and math" . . . and he "anticipates a shortage of engineers into the foreseeable future" (Weiss, 2009).

Although no one knows what the future will bring in terms of workforce demands or new job opportunities,

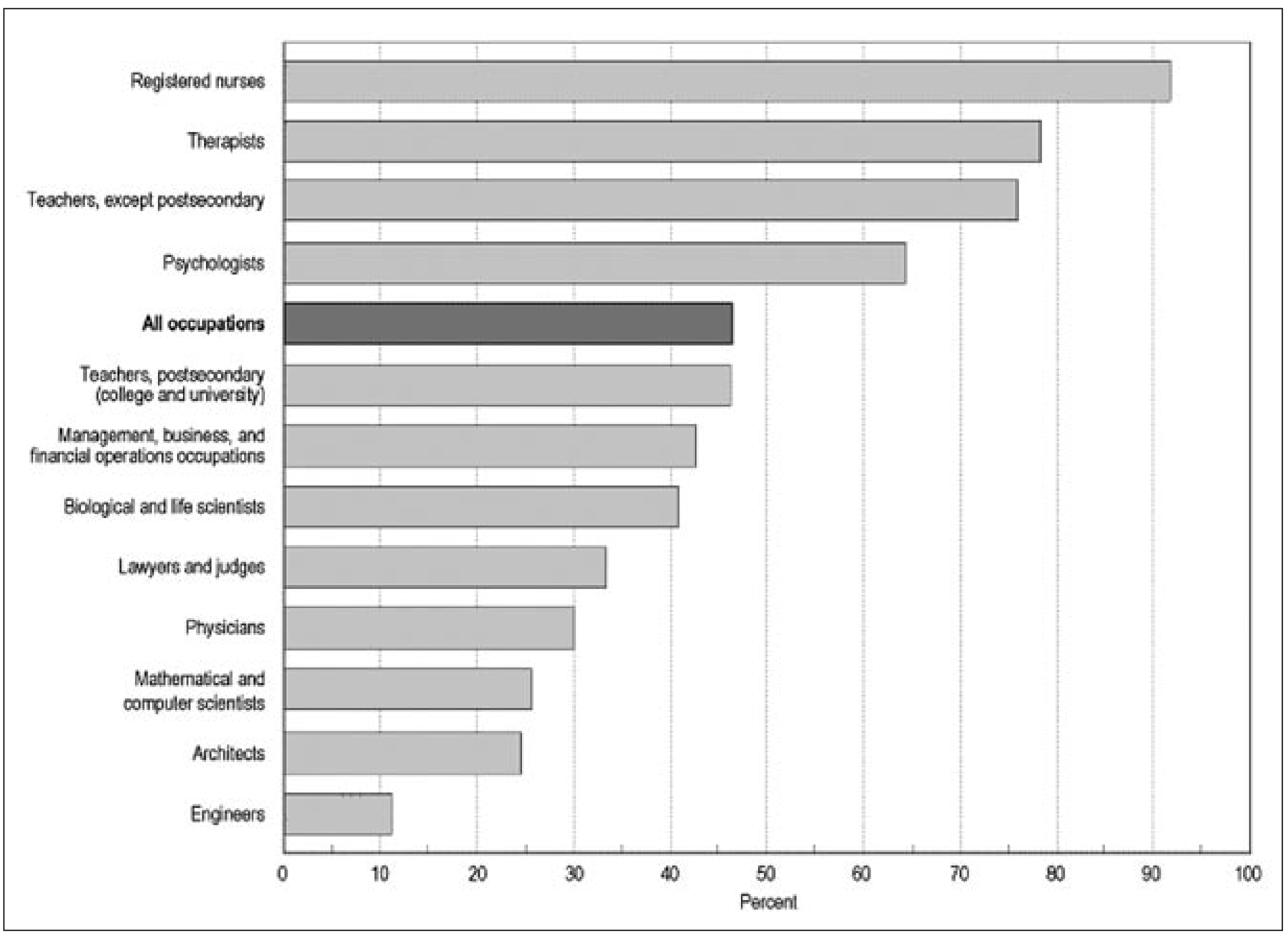


FIGURE 1 Employed women 16 years and older as a percentage of selected occupations, 2008. Source: Bureau of Labor Statistics, 2007.

TABLE 1 Intentions of Freshmen to Major in Engineering, by Race/Ethnicity and Gender, 2006

Race/Ethnicity and Gender	Engineering (percentages)
All Races	8.0
Female	2.5
Male	14.5
White	7.6
Female	2.2
Male	14.2
Asian	11.7
Female	4.6
Male	19.7
Black	7.2
Female	2.3
Male	14.4
Hispanic of Mexican/ Chicano/Puerto Rican descent	6.4
Female	2.1
Male	13.5
Other Hispanic	7.6
Female	2.8
Male	14.6
American Indian	7.5
Female	2.4
Male	14.2

NOTE: Includes first-year students at all four-year colleges. Race/ethnicity categories are those used in the survey's data collection.

Source: NSF, 2009.

many would agree that students who are grounded in a technical field, such as engineering, with an equal emphasis on strong oral and written communication skills, will be well prepared to face the challenges of the future. An engineering degree provides an ideal background for improving critical thinking and problem solving skills that are important for success in all fields.

Current Data on Women in Engineering

Many people are not aware that women have earned the majority of bachelor's and master's degrees in science, technology, engineering, and mathematics (STEM) fields since 2000 (NSF, 2009). Despite the overall increase in women pursuing undergraduate degrees in STEM majors, however, the percentages of female students who receive degrees in engineering has leveled off and even dropped over the last decade (Rosser and Taylor, 2008). From 2006 to 2007, the number of women who received bachelor's degrees in engineering dropped to its lowest level since 1996 (Table 2).

TABLE 2 Engineering Bachelor's Degrees by Gender, 1999–2007

Year	Male (percent)	Female (percent)
1999	78.8	21.2
2000	79.2	20.8
2001	80.1	19.9
2002	79.1	20.9
2003	79.6	20.4
2004	79.7	20.3
2005	80.5	19.5
2006	80.7	19.3

Source: ASEE, 2009.

The same is true of women in engineering at the graduate level. In 2005, 23 percent of master's degrees in engineering were earned by women, although the percentage varies greatly by the field of engineering (40 percent of those were in bioengineering; only 14 percent were in mechanical and electrical engineering) (CPST, 2008).

Why Increase the Number of Women in Engineering?

There are many reasons for the poor representation of women in engineering, beginning in the very early years with lower expectations of female interest and competence in math, science, and engineering and the stereotype of engineering as a male-dominated profession that is not open or welcoming to women (Burke and Mattis, 2007).

Nevertheless, the lack of participation by women in engineering and the sciences is a critical issue for the United States, where innovation in science and technology is a major factor in our economic growth, military capabilities, and living standards (Babco et al, 2005). Talented females who could contribute greatly to our technological growth are deciding very early, consciously or not, that engineering is not for them.

EngineerGirl! Website

The *EngineerGirl!* website is designed to inform and inspire middle school and high school girls to consider careers in engineering. The site provides an abundance of information:

- the great variety of engineering careers
- the importance of engineering for our society
- up-to-date career and salary information and job descriptions
- fun general facts about engineers and their achievements

Gallery of Women Engineers

The website has three distinct features. The first is a "Gallery of Women Engineers," which provides profiles of more than 100 women in the engineering workforce. These profiles portray women in engineering as successful, competent professionals and provide information on how each of them discovered her interest in engineering.

Nisha Agrawal, a chemical engineer, explains in her profile why she decided to become an engineer:

> *Engineering has such diverse applications, such as everyday tasks, medicine, and advanced research. Today more than ever, engineers contribute to almost every single aspect of our lives—the products and technology we use for work and play, the way we communicate and travel, the foods we eat and the air we breathe. I chose engineering because I wanted to do something that had the potential to affect people's everyday lives.*

The profiles also provide insights into the personalities and interests of these potential role models. Research has shown that students want to be reassured that they can pursue their personal, as well as professional goals and ambitions. The profiles in the "Gallery of Women Engineers" provide three-dimensional views of women engineers. Jenn Dandrea Spadafora, a flight-test engineer for the Boeing Company, describes her interests and hobbies:

> *I love dogs and do a lot with my foster dog from training to running and hiking. I also really love to cook and bake! I want to own a restaurant later in life. I make bead jewelry like earrings and bracelets. I love to shop, remodel in the house, go to sporting games and movies, and travel.*

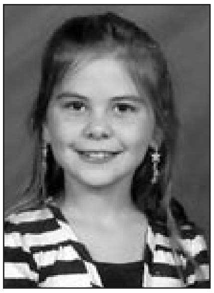
Ask an Engineer

The second feature, "Ask an Engineer," is unique to *EngineerGirl!* This interactive question and answer program allows girls (or any other visitor) to ask any engineer in the gallery questions about engineering professions or education. All of the women profiled participate, and questions are answered directly and by name. For many young women, this is their first opportunity to have a virtual interaction with a role model who can share her insights and experience. The questions and answers are also made available on the website, so other viewers can learn from them.

Annual Essay Contest

The third major feature is an annual essay contest for pre-college students (boys and girls) in grades 3 through 12. Every year, contestants are presented with a different essay topic that highlights the importance of engineering. The winners in each age group receive cash prizes, as well as an opportunity to publish their entries on the *EngineerGirl!* website. One year, participants were asked to work in teams and design a website that provided information on what girls need to know and do to explore engineering. Another year, they were asked to describe how real-world issues could be addressed using processes and principles from different engineering fields.

The theme of the contest in 2009 was "Engineering Innovation." Contestants were asked to choose one of three images of unfamiliar objects (Figure 2) and write an essay describing its important features, applying certain principles of engineering (which were provided), and describing the engineer's role in making the object.



Meg Rominiecki

The elementary school (grades 3–5) winner of the 2009 contest was Meg Rominiecki, a fourth-grader from Pennsylvania. Meg identified Image #1 as a junk recycler and explained how it might operate and the engineering principles necessary to create it. She also described her concerns about problems created by space junk:

> *If I were an engineer, I would need to know about the kinds of things that are in space junk and what they are made of. I would need to know about the materials because I would need to know about what happens to things in outer space without much gravity, in very cold*

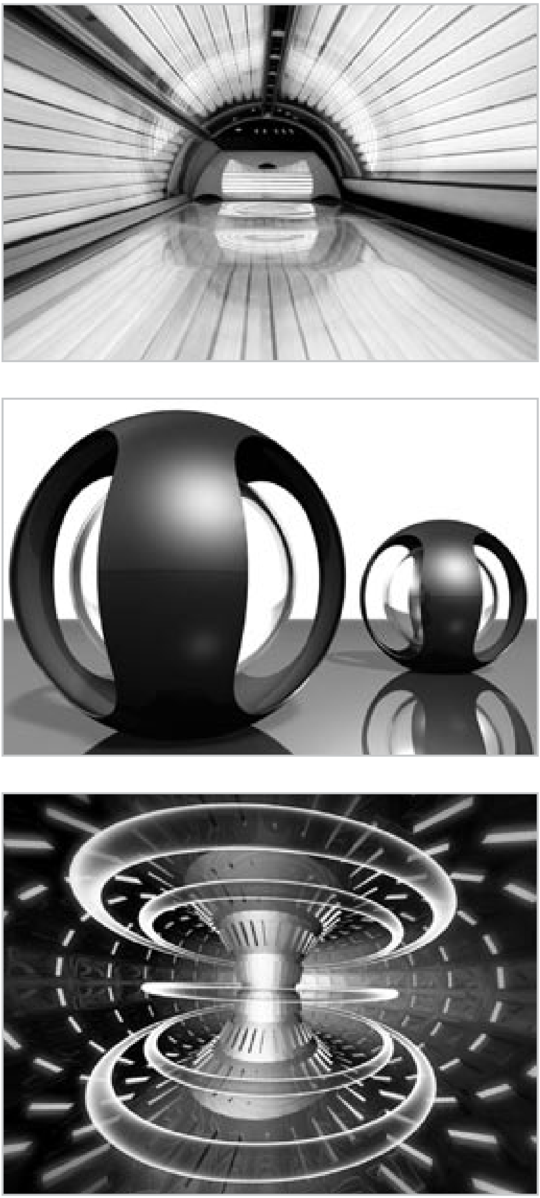


FIGURE 2 Images for the 2009 *EngineerGirl!* website essay contest on "Engineering Innovation."

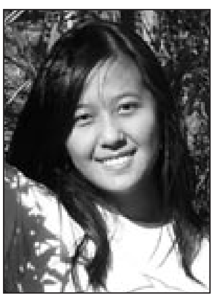
conditions, without oxygen, and without a protective atmosphere. So I would have to investigate how to burn something without oxygen.

In order to build this machine I would need to study mechanical engineering and also the physics of outer space. I would work with a team of engineers because if we all work together we could work faster and have more ideas.

Nora Belkhayat

In the middle-school category (grades 6 to 8), the winner was Nora Belkhayat, a 7th grader from Virginia, who used Image #2 to describe a new transportation system nicknamed "the spit-baller." Nora explains in this excerpt from her essay:

The engineer who created the pod worked for NASA because in 2012 President Obama gave NASA a budget for a magnetics program. NASA used this budget to create the National Transport System called magLev pods. This engineer worked with a team of engineers to design the way the pod would be propelled through the tunnels, and the system of magnets needed in the tunnels to allow the pod to move. Some of the engineering principles that were used would be a stylish, yet simple design that every age would like. Another principle would be to make the spit-baller easy to use. The pod uses today's simple technology of computerized maps. You enter your destination, and the pod pulls up a map that it can follow automatically through the series of underground tunnels. This feature works like an autopilot. The spit-baller is a high-tech green way of transportation. It is energy-efficient and less expensive over-all than cars and planes, and petroleum-based transportation methods. Citizens are satisfied with the speed of the product, and appreciate the luxuries the magLev pod has to offer. This new idea of a National Transportation System has revolutionized travel.



Qingliu Yang

Qingliu Yang, the first place winner in the high school category (grades 9 to 12), described Image #3 as a new source of energy. In her essay, she noted the importance of having the skills to communicate with non-engineers about the significance of such a discovery:

Engineers have to consider all aspects of a design: the science, the aesthetics, and the practicality. Before the blueprint would go into effect, I would also have to write proposals and convince the city council to make a budget for the Hourglass. Taking the cost into consideration, I had opted for more cost *effective materials: plastic substrates, carbon nanotubes (carbon being abundant in the biosphere), simple yet sturdy organic polymers, and an aluminum cathode. While gold cathodes have a higher difference in work function from the anode and would result in a brighter device, I decided that the OLEDs only required 2000 candela to light the pathways of the Hourglass.*

The physicist smiled. "Tell me, Miss Yang, do you see any problems with your plan? It seems rather farfetched."

As a woman engineer, I must have the conviction to follow through with the plan. While I have the passion for science, unless I strongly believe in the success of this combined solar cell—OLED matrix—the city council might not be convinced. I looked towards the glowing OLED 4 feet away, a miniature prototype of the larger scale OLEDs in my plan.

"No, I don't see any impossible problems." While there may be some, as an engineer, it is my job to find a way to make it happen.

The more than 500 boys and girls who participated in the 2009 contest reflect the diversity of the *EngineerGirl!* audience. These students, and many more like them, may someday be part of the engineering workforce.

Responses to the *EngineerGirl!* Contest and Website

Survey data collected in June 2009 (30 percent response rate, n=173) reveal that viewers generally have very positive reactions to the website. In fact, 95 percent of respondents to a recent online poll said that the website either met or exceeded their expectations. In the same survey, 58 percent of high school girls and 69 percent of middle school girls said they were likely to visit the website again. Fifty-four percent of girls in high school and 69 percent of girls in middle school said they expected to tell others to visit the website as well.

Even more encouraging, 41 percent of female high school respondents who participated in the 2009 essay contest reported that they would be studying engineering in college, and an almost equal number (40 percent) were interested in engineering (Table 3). The challenge for NAE and others in the engineering community is to reach out to the 51 percent of middle school girls who said they might be interested in engineering and provide them with opportunities to learn more about the possibilities and rewards of engineering careers.

Finally the survey asked contestants if participating in the *EngineerGirl!* essay contest had changed their view of engineering in a positive way. Roughly half of the students answered yes, and an additional third said that participation in the contest had "somewhat" changed their views (Table 4).

Next Steps

The goal of *EngineerGirl!* is to provide up-to-date resources for students, parents, and teachers and to

TABLE 3 Consider Engineering in College?

	High School Boys (percent)	High School Girls (percent)	Middle School Girls (percent)
Absolutely! Engineers are awesome!	55	28	31
Yes, I want to be an engineer.	10	13	3
Maybe, I might be interested in engineering.	15	40	51
No, engineering is just not my thing.	20	20	15

TABLE 4 Did Participating in the Contest Change Your Views about Engineering?

	High School Boys (percent)	High School Girls (percent)	Middle School Girls (percent)
Yes	45	55	56
Somewhat	40	33	36
No	15	10	3
Not Sure	0	3	5

challenge the notions that engineering is only for a select few and only for males. Because the essay contest is clearly an effective tool for changing young women's perceptions about engineering careers, we will try to increase participation in the contest through more extensive outreach, better incentives for winners, and more interaction with teachers and schools. In addition, we plan to update the career descriptions to include a wider range of engineering fields. By reaching out to the next generation of professionals, we hope to ultimately increase diversity in the engineering workforce.

Members of the *EngineerGirl!* Steering Committee, many of whom did not learn about engineering until they were in their mid-twenties, see the website as a first step in providing options for the next generation, a vehicle for reaching out to girls and enlightening them about the exciting career opportunities available to those who pursue a science, technology, engineering, and math-focused educational track. The *EngineerGirl!* website and other technical programs can provide a window on engineering for a generation of students the world over. Our hope is that young girls will be encouraged and motivated to look into careers in engineering and think, "Yeah, I can do that, and engineering makes the world a better place."

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NAE News and Notes

NAE Newsmakers

Bhakta B. Rath, head, Materials Science and Component Technology Directorate, and associate director of research, Naval Research Laboratory, was presented with the **Padma Bhushan Award of Honors and Excellence** by the president of India on April 1. Dr. Rath received the award for excellence in the field of science and for exceptional service toward the advancement of science. The Padma Bhushan, which is second in the hierarchy of civilian Padma awards in India, is a prestigious civilian award given in recognition of distinguished service of a high order in the arts, sciences, and public service.

Robert W. Tkach, director, Bell Laboratories, Alcatel-Lucent, and **Andrew R. Chraplyvy**, vice president, Optical Networks Research, Bell Laboratories, Alcatel-Lucent, have been awarded the **2009 Marconi Fellowship and Prize** for their research on optical fiber nonlinearities and their development of novel mitigation techniques that have vastly increased the transmission speed and capacity of optical fiber communications systems. The Marconi Society, established in 1975, annually recognizes a living scientist whose work in the field of communications and information technology advances the social, economic, and cultural improvement of all humanity. The award will be presented on October 9, 2009, at the annual Marconi Awards Dinner at the Palazzo Re Enzo in Bologna, Italy.

P. Hunter Peckham, Donnell Institute Professor of Biomedical Engineering and Orthopaedics and director, Functional Electrical Stimulation Center, Cleveland Louis Stokes Veterans Affairs Medical Center, is the recipient of the **Frank and Dorothy Humel Hovorka Prize**, one of the highest honors given to a faculty member at Case Western Reserve University. Dr. Peckham was recognized for developing cutting-edge technologies that enable paralyzed individuals to perform essential daily tasks. The award was presented at the commencement ceremonies on Sunday, May 17.

Jon M. Kleinberg, professor, Department of Computer Science, Cornell University, is the recipient of the **2008 Association for Computing Machinery (ACM)-Infosys Foundation Award** for his contributions to the science of networks, specifically his work on link analysis, a search technique that ranks the absolute number as well as the most relevant trusted sources of pages linked to a web search query.

The Industrial Research Institute (IRI) bestowed its **2009 National IRI Medal** on **Norman R. Augustine**, retired chairman and CEO, Lockheed Martin Corporation. The medal was established in 1946 to honor leaders of technology for outstanding accomplishments in technological innovation that contribute to the development of industry and benefit society. Mr. Augustine was chosen for his commitment to the ethical conduct of business and his visionary leadership in the fields of aerospace engineering and industrial production. "Norman R. Augustine, through his work has not only made the nation safer and more secure, but he has also been a leading advocate in making education in science, technology, engineering and math education national priorities," said Edward Bernstein, IRI President. "He also conducted business by the highest ethical standards and promoted investment in innovation that directly improved the lives of Americans." Dr. Augustine also recently was awarded the American Chemical Society 2009 **Public Service Award** for his vision and leadership in science and engineering policy.

The Smithsonian National Air and Space Museum **Trophy for Lifetime Achievement**, the museum's highest honor, has been awarded to **John R. Casani**, special assistant to the director, Jet Propulsion Laboratory. The award was presented at a private evening ceremony at the National Air and Space Museum on the National Mall in Washington, D.C., on April 29. Dr. Casani was chief engineer or project manager on pioneering deep-space programs, from the Mariner missions to Voyager, Galileo, and Cassini. At the very genesis of robotic planetary exploration, he mastered the challenges of designing craft to perform tasks never before attempted. His leadership and engineering expertise have advanced knowledge of the solar system through missions that have yielded increasingly detailed and beautiful images and data.

Every year, the **National Inventors Hall of Fame** inducts individuals whose work has changed society and improved the way we live with new tools that shape the future and celebrate invention. The 2008 class was inducted in May 2008 at the annual induction ceremonies held in Akron, Ohio. NAE inductees were: **Amar Bose**, chairman, Bose Corporation, for audio technology, including the 901® Direct/Reflecting speaker system, customized sound systems for automobiles, and active noise-reducing headphones; and **Nick Holonyak Jr.**, John Bardeen Chair Professor of Electrical and Computer Engineering and Physics, University of Illinois, for inventing the first visible light-emitting diodes (LED), which made possible the technology used to develop red lasers in CD and DVD players.

The 2009 class, which was inducted on May 2 in Mountain View, California, included five NAE members. **Alfred Y. Cho**, vice president (retired), Semiconductor Research Laboratory, Bell Laboratories, Alcatel-Lucent, achieved molecular beam epitaxy (MBE) at Bell Labs, a process in which materials are layered atop one another with great precision to form devices like transistors, light-emitting diodes, and lasers. The switches in cell phones use MBE, as do most of the lasers in CD/DVD players and drives. **George Heilmeier**, Chairman Emeritus, Telcordia Technologies Inc., was inducted for pioneering the first liquid crystal displays at RCA Laboratories. **Larry Hornbeck**, TI Fellow, Texas Instruments Incorporated, holds a number of patents for inventions that created the foundation for the DMD, an array of up to 2 million hinged microscopic aluminum mirrors on a silicon chip. Under digital control, the tiny mirrors create an image by directing pulses of "digital" light through a projection lens and onto a television, presentation, or movie theater screen. **Carver Mead**, Gordon and Betty Moore Professor of Engineering and Applied Science Emeritus, California Institute of Technology, was honored for inventing the VLSI method of designing chips. The standards and tools he helped to develop made it possible to package thousands of transistors on a single silicon chip, known as very-large-scale integration (VLSI). **Gordon Moore**, Chairman Emeritus, Intel Corporation, was recognized for setting the pace and standards for chip manufacturing methods in Silicon Valley. The author of Moore's Law, he established the model of the computer industry researcher-entrepreneur and helped make Intel a world-leading chip maker. **Andrew S. Grove**, senior advisor to executive management, Intel Corporation, was also honored at the event with the **2009 Lifetime Achievement Award**.

R. Wayne Skaggs, William Neal Reynolds Distinguished University Professor, Department of Biological and Agricultural Engineering, North Carolina State University, was awarded the **Massey-Ferguson Educational Gold Medal Award** by the American Society of Agricultural and Biological Engineers at their annual international meeting in June. Skaggs was recognized for his dedication and extraordinary contributions to agricultural and biological engineering as a teacher, mentor, researcher, and national leader. In March, Dr. Skaggs received the **Charles A. Black Communications Award** from the Council for Agricultural Science and Technology. The award is presented annually to an individual who has demonstrated outstanding achievement in his/her area of expertise within the agricultural, environmental, or food sciences sectors. Both award presentations cited DRAINMOD, a computerized water management model developed by Dr. Skaggs that helps predict how particular water management procedures will affect the depth of the water table, the soil-water regime, and crop yields. DRAINMOD is used by consulting engineers, researchers, and government agencies worldwide.

Report from the Foreign Secretary

George Bugliarello

On June 18, 2009, the Russian Academy of Sciences and the U.S. National Academy of Sciences issued a joint statement on the occasion of the 50th anniversary of Russian-American inter-academy cooperation, in which NAE has been an active participant. The statement underscored the contributions of inter-academy activities to building trust between the governments and peoples of the two countries through successful exchanges, joint studies, and seminars. The statement also emphasized the importance of continued bilateral cooperation and with other partners throughout the world. Current subjects of scientific interest include energy, climate change, biomedical and agricultural technologies, and international security.

The biennial convocation of the International Council of Academies of Engineering and Technological Sciences (CAETS), of which NAE is a founding member, was held in Calgary, Alberta, Canada, from July 13 to 17, 2009. Attended by NAE President **Charles Vest** and Executive Officer **Lance Davis**, the 2009 meeting focused on the general theme of "Our Heritage of Natural Resources—Management and Sustainability." At the conclusion of the meeting, CAETS issued a statement on "Global Natural Resources—Management and Sustainability":

Society faces an urgent need to reduce the demands on all kinds of raw materials and energy. New approaches are required to managing global resources and the supply chains they feed, to ensure that humanity's needs are fulfilled for current and future generations. A balance must be struck between economic gain derived from resource exploitation and utilization, and the impacts on society and the environment. Issues related to energy, water management, forestry, and mining/minerals must be considered in an integrated approach and in harmony with nature, which examine their interdependencies and taps the cross-sector opportunities for novel strategies, processes, technologies and solutions.

Based on this statement, CAETS offered three overarching recommendations:

1. Industry and government must consider sustainable development, stewardship, conservation, recycling, re-use, substitution, and responsibility to local inhabitants when assessing the present and future management of our natural resources base.

2. Engineering design as well as industry and government evaluation of a product's sustainability must account for its entire life cycle, including processes for manufacture, services for use, and disposal.

3. Adaptations to climate change must be robust against uncertainty, informed by data and research, integrated across sectors, and consistent with climate change mitigation policies.

The CAETS annual symposium will be held in June 2010 in Copenhagen, Denmark.

A Memorandum of Understanding between the Indian National Academy of Engineering (INAE) and NAE was also signed at the CAETS meeting by INAE President Goel and NAE President Vest. The two academies agreed to promote cooperation in engineering and technological sciences for the mutual benefit of both countries and to further global economic and social progress. Future activities may include study visits, exploratory missions, joint seminars/workshops, exchanges of information, and continued Indo-U.S. Frontiers of Engineering (IAFOE) symposia (the next IAFOE symposium is scheduled for March 11 to 13, 2010, in India).

A symposium on "Food Processing Technologies for Food Safety and Innovation," co-chaired by NAE member **Darsh Wasan** of Illinois Institute of Technology, will be held in Mumbai, India, on February 25 and 26, 2010.

From April 22 to 25, 2009, the 12th German-American Frontiers of Engineering Symposium (GAFOE) was held in Potsdam, Germany, with 60 German and American participants. The symposium was co-sponsored by the Alexander von Humboldt Foundation and NAE. President Helmut Schwarz of the Alexander von Humboldt Foundation and NAE Foreign Secretary **George Bugliarello** welcomed the participants, together with NAE Executive Officer Lance

Davis. Janet Hunziker of the NAE Program Office was the coordinator for NAE. The symposium was co-chaired by NAE member **Tresa Pollock** of the University of Michigan and Kai Sundmacher of the Max-Planck-Institute for Dynamics of Complex Technological Systems. The four themes addressed during the meeting were materials for extreme environments, bio-systems engineering, complex systems design and controls, and renewable energy. GAFOE symposia have been held yearly since 1998, alternating between Germany and the United States.

The 2009 Japan-America Frontiers of Engineering (JAFOE) symposium will be held in Irvine, California, from November 9 to 11, 2009.

Dialogue continues with the Royal Academy of Engineering of the United Kingdom and other European academies about a new symposium series, the European Union-American Frontiers of Engineering symposia. The first event will take place in 2010 at a place and date yet to be agreed upon.

Respectfully submitted,

George Bugliarello

George Bugliarello

News from the NAE Center for Engineering, Ethics, and Society

Rachelle Hollander, director of the NAE Center for Engineering, Ethics, and Society, was recently elected to a four-year term as a member of the Executive Committee of the Association for Practical and Professional Ethics (APPE), located at Indiana University. APPE facilitates communication and joint ventures among centers, schools, colleges, business and nonprofit organizations, and individuals concerned with the interdisciplinary study and teaching of practical and professional ethics. Members include both individuals and organizations.

Hollander has proposed that a workshop, "NSF and Ethics Education in Science and Engineering," be held as part of the American Association for the Advancement of Science (AAAS) annual meeting in February 2010. The purpose of the workshop would be to educate AAAS members about new NSF ethics requirements introduced in the "America COMPETES Act of 2007." Find out more at *http://www.nae.edu/15406.aspx*.

Complexity and competitiveness in research settings, along with interdisciplinary and international involvement and the close coupling of commerce and academia, have created an environment in which ethical challenges for research scientists and engineers are increasing and ascertaining the right thing to do is not intuitively obvious. In August 2008, NAE held a workshop, "Ethics Education and Scientific and Engineering Research: What's Been Learned? What Should Be Done?" to explore the history of support and future directions for mentoring and ethics training in graduate education in research. A workshop summary was released earlier this month that includes summaries of workshop presentations, panel and general discussions, and breakout-session discussions. The report is available from the National Academies Press <*http://www.nap.edu/catalog.php?record_id=12695*>.

The APPE annual meeting, scheduled for March 2010 in Cincinnati, Ohio, will feature two events of special interest to engineers. The meeting will open with a two-day workshop, "Ethical Guidance for Research and Application of Pervasive and Autonomous Information Technology (PAIT)," the culmination of a year-long planning process, case development and analysis, and networking among information technology engineers and researchers, ethicists, and other interested parties. The meeting will feature discussions of previously prepared case studies describing actual and anticipated uses of PAIT.

The second event will be "Engineering toward a More Just and Sustainable World," a mini-workshop inspired by a meeting in October 2008 sponsored by NAE/APPE on conflicting positive goals that can arise when engineers work in areas undergoing social and environmental upheavals. At that meeting, the question of engineering and social justice was hotly contested. The APPE mini-conference will focus on whether and how engineers, the organizations in which they work, and professional societies can contribute to meeting the goals of social and environmental justice.

For more information contact Kenneth D. Pimple at *pimple@indiana.edu* or Rachelle Hollander at *rhollander@nae.edu*, or visit *http://www.indiana.edu/~appe/*.

NAE Regional Meeting at Texas A&M University Focuses on Transportation, Water, and Energy

"Three Great Challenges Facing America—Transportation, Water and Energy," a half-day symposium held in conjunction with an NAE Regional Meeting on April 29, 2009, addressed strains on our natural resources caused by the booming U.S. population and how we might overcome them. The symposium was chaired by NAE member **B. Don Russell**, Distinguished Professor in the Department of Electrical and Computer Engineering at Texas A&M and holder of the Harry E. Bovay Jr. Endowed Chair.

Transportation

In the opening talk, Dennis L. Christiansen, director of the Texas Transportation Institute, noted that discussions in the Texas legislature about transportation have continued, even during this time of economic turmoil. Christiansen said the results of these discussions will have "profound impacts on the economic competitiveness of Texas as well as the quality of life enjoyed by our citizens."

The most obvious effect of the population boom on transportation is congestion, a major concern in cities in Texas as well as throughout the Unites States. "The annual cost of congestion in Texas, conservatively estimated, now exceeds $6 billion," Christiansen said. "Congestion in larger cities is growing at rates in excess of 10 percent per year." He pointed out that Austin, the capital of Texas, is the most congested city of its size in the United States. And, he said, things will only get worse.

The question is what can be done to alleviate congestion and how those measures should be financed. One solution is high-speed rail, which, according to the next speaker, David M. Laney, former chair of the Amtrak Board of Directors and former chair of the Texas Transportation Commission, is sure to be built in Texas. "Texas has the perfect alignments and distances between urban areas," he said. But, he noted, Texas does not have funding for such a project.

One way to raise the money, he suggested, would be to increase the state gas tax. But, according to Christiansen, that might not be an option in today's consumption-conscious society. "In today's environment, virtually every policy of government—for energy, environment, and security reasons—is designed to *decrease* gasoline consumption," he noted. "Congress, which is supposed to reauthorize federal surface transportation legislation this year, has a huge challenge in front of them."

Water

Daene McKinney, W.A. Cunningham Professor and associate chair of the Department of Civil, Architectural and Environmental Engineering at the University of Texas, discussed his project on water management in the Rio Grande Basin, a 558,000 km^2 area that stretches from Texas through New Mexico and into Colorado. With a population of about 12 million people, the Rio Grande Basin is one of the fastest growing areas in North America.

The basin also crosses the border between Texas and Mexico, which raises the issue of water-rights management governed by two sets of regulations. This is "a very important problem along the border between Texas and Mexico," McKinney said. "Management of the basin is complicated because you have a set of regulations in Texas, a set of regulations in Mexico, and then the international treaty. The problems are becoming more acute as time goes on." Water rights in the area, according to McKinney, are already over-allocated, and the basin is prone to longer-than-normal droughts. In fact, decade-long droughts are a severe problem.

On the subject of droughts, Texas A&M professor Vijay P. Singh, the Caroline and William N. Lehrer Distinguished Chair in Water Engineering, presented some staggering numbers, both for Texas and for other parts of the United States. According to Singh, who has a dual appointment in the Department of Biological and Agricultural Engineering and the Zachry Department of Civil Engineering, from 1980 to 2003 droughts cost the United States $144 billion. In Texas, the number reached $4.1 billion in 2006, where drought-related crop and livestock losses were the worst for a single year.

Singh also posed the question of whether we have enough water. Opinions vary, he said, with some saying we have plenty and some saying there won't be enough clean water to support our current lifestyle. Singh believes the answer lies somewhere between these extremes. But, he said, we must all do our part to ensure that future generations have enough water.

"If we are to make water available at an affordable cost, in a sustainable manner, we have no choice but to use it efficiently, recycle it, reuse it, and develop additional sources," Singh said. "We owe it to future generations to leave it to them in better shape than the shape we got it in."

Energy

The final session of the symposium was focused on wind energy, the newest trend in energy generation, and the possibilities it offers electrical providers. Carsten H. Westergaard, global technology manager for Vestas Technology R&D Americas, which has a 20-percent market share and 38,000 installed wind turbines, is the world's leading supplier of wind power. Thus Westergaard is well acquainted with the challenges facing providers of wind energy. "Being a young industry, it is important that we move the research upstream," he said. "The challenge is to drive the cost of energy down, so service reliability is extremely important."

Ross Baldick, professor and Leland Barclay Fellow in the Department of Electrical and Computer Engineering at the University of Texas in Austin, pointed out that, although wind may appear to be the energy source of the future, there are still hurdles to be cleared. The most pressing of these involves transmission price risk, he said. Baldick pointed out that wind sources tend to be far away from the areas of demand, which adds to transmission costs.

Another hurdle will be overcoming the intermittency of wind, which Baldick said imposes requirements for additional resources. In the short term, it would require more regulation; in the medium term, it would require increased reserves and ramping capabilities [the capability of increasing power generation]. In the longer term, as the regulation, reserves, and ramping capabilities of the existing thermal generation portfolio are used up, additional flexible thermal resources or storage will be necessary.

Baldick noted that various studies have estimated "wind integration" costs anywhere from a few dollars to a few tens of dollars per megawatt hour. "We need to admit that wind energy is going to cost more money," Baldick said. "We have to show that there are energy opportunities. There is no doubt in my mind that we need to use more wind."

NAE President Charles Vest, Executive Officer Lance Davis, and Home Secretary Thomas Budinger, as well as more than 200 NAE members, Texas A&M faculty, students, and guests attended the symposium, which was hosted by the Dwight Look College of Engineering at Texas A&M University.

Anderson-Commonweal Interns Join Program Office

Priscilla Arriaga

Hannah During

Priscilla Arriaga, a fourth-year Anderson-Commonweal Intern, joined the NAE Program Office for a third summer. This year she is working on several projects, including updating some content for the *EngineerGirl!* website; checking and repairing broken links on the Online Ethics Center website; and conducting research on organizations that might be interested in collaborating on outreach programs for the Engineer Your Life website. With her accumulated experience at the National Academies, she also spent time with first-year interns helping to familiarize them with National Academies procedures.

Priscilla is currently an undergraduate student at the University of Maryland-Baltimore County (UMBC) where she is studying information systems. Before transferring to UMBC, she attended Montgomery College in Rockville, Maryland, where she studied chemical engineering. She transferred to UMBC in 2008. In her spare time, Priscilla enjoys solving Sudoku puzzles, reading fiction, and taking road trips with her family.

Hannah During, a first-year Anderson-Commonweal Intern at the National Academies, worked this summer in the NAE Program Office with Catherine Didion. This fall, as a new freshman at the George Washington University, she plans to major in psychology, and either go on to medical school to study psychiatry or obstetrics/gynecology or to graduate school to pursue a doctorate in psychology.

Inspired by Mahatma Gandhi, who said, "Be the change you want to see in the world," Hannah plans to remain involved in community service throughout her college and professional career. As a way to serve her community in Washington, D.C., and to choose a career goal, she joined Teens Against the Spread of AIDS (TASA), a group that works with Children's Hospital of Washington, D.C. Through this program she has learned about the problems of drug and alcohol abuse, sexuality, violence, and parent-teen relations. She also volunteered to work in the adolescent clinic at Children's Hospital, entering patient information and preparing STD test kits for doctors. During her four years at Banneker Academic High School in Washington, D.C., she completed more than 270 hours of community service with TASA and Today's New Teens (TNT) and as a mentor and teacher's aide at an elementary school.

While at NAE, Hannah attended workshops, checked references for reports, and conducted research for several projects. She says she is "grateful to have been awarded privileges that many students her age only dream of." Just three weeks into the program, Hannah had already attended two conferences (one on a new STEM education model and one on women's maternal health in Afghanistan). She hopes these opportunities to listen and interact with professionals will help her to attain a position in which she too can make a difference.

Calendar of Meetings and Other Events

September 8	K–12 Engineering Education in the United States: Symposium and Release of the National Academies' Report
September 23	News and Terrorism: Communicating in a Crisis Workshop Baltimore, Maryland
September 28	NAE Nominating Committee Meeting
September 30	Finance and Budget Committee Meeting
October 3	NAE Council Meeting NAE Peer Committee Meetings Orientation Session for NAE Class of 2009 Irvine, California
October 4–5	NAE Annual Meeting Newport Beach and Irvine, California
October 7–9	Meeting of the Joint Committees on U.S.-China Cooperation on Electricity from Renewables Irvine, California
October 15	Governing Board Executive Committee Meeting
October 17–21	China-America Frontiers of Engineering Symposium Beijing and Changsha, China
November 9–11	Japan-American Frontiers of Engineering Symposium Irvine, California
November 10	Governing Board Executive Committee Meeting
November 10–11	Governing Board Meeting
November 15–18	Frontiers of Engineering Education Meeting Dulles, Virginia
December 7	Governing Board Executive Committee Meeting
December 8	2010 NAE Election Committee on Membership Meeting

All events are held in the Academies Building, Washington, D.C., unless otherwise noted.

In Memoriam

H. TED DAVIS, 71, professor, Chemical Engineering and Materials Science Department, University of Minnesota, died on May 17, 2009. Dr. Davis was elected to NAE in 1988 "for leadership in applying chemical physics, and in uniting chemical engineering and materials science teaching and research."

VICTOR F.B. DE MELLO, 82, principal, Victor de Mello & Associates, Geotechnical Engineering Consultants, died on January 1, 2009. Dr. de Mello was elected an NAE foreign associate in 1980 "for development of geotechnical engineering and international leadership in design of embankment dams and in situ testing for foundation design."

GUNNAR FANT, 89, Professor Emeritus, KTH Computer Science and Communication (CSC), Department of Speech, Music and Hearing, The Royal Institute of Technology, Stockholm, Sweden, died on June 6, 2009. Dr. Fant was elected an NAE foreign associate in 1992 "for pioneering development of acoustic theory of speech production, and innovative leadership in communications technology and in development of prosthetic devices."

RAPHAEL KATZEN, 93, consulting engineer, died on July 12, 2009. Dr. Katzen was elected to NAE in 1996 "for the advancement of biotechnology for chemicals from renewable resources worldwide."

HANS W. LIEPMANN, 94, Theodore von Karman Professor of Aeronautics Emeritus, Division of Engineering and Applied Science, California Institute of Technology, died on June 24, 2009. Dr. Liepmann was elected to NAE in 1965 "for fundamental contributions to the field of fluid mechanics."

CRAIG MARKS, 79, retired vice president, technology and productivity, AlliedSignal Inc., died on July 20, 2009. Dr. Marks was elected to NAE in 1985 "for his advancement of the engineering art in automotive power trains, safety, aerodynamics, and emissions control, along with his concerns for the engineering profession."

ALEXANDER SQUIRE, 91, retired president, Westinghouse Hanford Co., died on May 16, 2009. Mr. Squire was elected to NAE in 1979 "for contributions to engineering and project management of U.S. submarine and breeder reactor programs."

Z.J.J. STEKLEY, 75, consultant, Board of Directors, Facioscapulohumeral Society, died on April 3, 2009. Dr. Stekley was elected to NAE in 1981 "for contributions to the design, manufacture and application of superconducting materials and superconducting magnets to power, transportation, and industrial systems."

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at <*http://www.nap.edu*> or by phone at (888) 624-8373. *(Note: Prices quoted are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Ethics Education and Scientific and Engineering Research: What's Been Learned? What Should Be Done? Summary of a Workshop. The increasing complexity and competitiveness in research environments, the prevalence of interdisciplinary and international involvement in research projects, and the close coupling of commerce and academia have created an ethically challenging environment for young scientists and engineers. For the past several decades, federal research agencies have supported projects to meet the need for mentoring and ethics training in graduate education in research, often called training in the responsible conduct of research. Recently, these agencies have supported projects to identify ethically problematic behaviors and assess the efficacy of ethics education in addressing them. The workshop, supported by the National Science Foundation and the National Academy of Engineering Center for Engineering, Ethics, and Society, included discussions of the social environment of science and engineering education; the need for ethics education for graduate students and postdoctoral fellows in science and engineering; models for effective programs; and assessment of approaches to ethics education, among other topics.

NAE member **John F. Ahearne**, director, Ethics Program, Sigma Xi, The Scientific Research Society, chaired the workshop planning committee. Paper, $21.00.

Mapping the Zone: Improving Flood Map Accuracy. Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps, which show the height and extent of expected floods, are used as a basis for establishing flood insurance premiums and regulating development in flood plains. The FEMA maps are used by individuals, businesses, communities, and government agencies to estimate risk and prepare for flood hazards. Thus the accuracy of these maps is not an academic question. Making and maintaining an accurate flood map is a costly and complex undertaking. After more than $1 billion was invested in producing digital maps, only 21 percent of the population lives in areas with maps that meet or exceed national data-quality thresholds. In addition, land development and natural changes in the landscape or hydrologic systems can render previously accurate maps useless. Thus continuous map maintenance and updates are necessary to ensure their accuracy. This study by a committee of experts describes factors that affect the accuracy of flood maps, assesses the benefits and costs of having more accurate flood maps, and recommends ways to improve the mapping, communication, and management of flood-related data.

NAE member **Gerald E. Galloway Jr.**, Glenn L. Martin Institute Professor of Engineering, University of Maryland, College Park, was a member of the study committee. Paper, $32.00.

Resident Duty Hours: Enhancing Sleep, Supervision, and Safety. Medical residents in hospitals are often on duty for long hours. In 2003, the organization that oversees graduate medical education adopted program requirements that restricted the number of hours residents could work per week. The new regime mandated an average of 80 work hours over a period of four weeks and set a limit of 30 hours as the longest period of consecutive work hours. The purpose of these limits is to protect both patients and residents from unsafe conditions resulting from excessive fatigue. This timely report focuses on how the requirements have been implemented and what effect they have had on safety, education, and training institutions. The study committee's in-depth review of the evidence on sleep and human performance revealed the need for more sleep time during residency training to prevent acute and chronic sleep deprivation and to minimize the risk of fatigue-related errors. The committee recommends opportunities for sleep during long work periods and breaks between work periods that allow residents to get enough sleep. The committee also recommends changes in supervision, workloads, and the work environment to improve safety and create better learning situations. This report will be useful to residents, medical educators, academic training institutions, specialty societies, professional groups, and consumer/patient safety organizations, in short, everyone who advocates for a culture of safety in our medical facilities.

NAE member **James P. Bagian**, director, National Center for Patient Safety (10X), Veterans Health Administration, Department of Veterans Affairs, was a member of the study committee. Hardcover, $49.95.

Beyond "Fortress America": National Security Controls on Science and Technology in a Globalized World. Regulations meant to control access to and the export of science and technology actually undermine our national and homeland security and stifle American engagement in the global economy. Policies developed for different conditions in an earlier era have led to these unintended consequences, and the United States now runs the risk of becoming less secure, less competitive, and less prosperous than it was in the past. The committee that conducted this study offers recommendations for reforming export controls, ensuring scientific and technological competitiveness, and improving the non-immigrant visa system that regulates entry of foreign science and engineering students, scholars, and professionals into the United States. The committee provides vital information and action items for the president and policy makers whose actions affect our ability to compete globally. Military personnel, engineers, scientists, professionals, industrialists, and scholars will find this report a valuable tool in their efforts to stop the serious decline in our security and our economy.

NAE members on the study committee were **John L. Hennessy** (*co-chair*), president, Stanford University; **William F. Ballhaus Jr.**, retired president and CEO, Aerospace Corporation; **Ruth A. David**, president and CEO, Analytic Services Inc.; and **Anita K. Jones**, Lawrence R. Quarles Professor of Engineering and Applied Science, University of Virginia. Paper, $42.00.

Advice on the Department of Energy's Cleanup Technology Roadmap: Gaps and Bridges. When the Cold War ended, most of the massive industrial complex constructed to produce and test nuclear weapons and related technologies was shut down or placed on standby, and the U.S. government began a costly, long-term effort to clean up the materials, wastes, and environmental contamination from its nuclear materials production. In 1989, Congress created the Office of Environmental Management (EM) at the U.S. Department of Energy to manage the cleanup. Although EM has made substantial progress, the scope of future cleanup operations will be enormous. This report provides advice to support the development of a cleanup technology road map. The study committee identifies and prioritizes existing technology gaps, strategic opportunities to leverage research and development by working with other organizations, necessary core capabilities, and infrastructure at national laboratories and other sites that should be maintained.

NAE member **Edwin P. Przybylowicz**, retired senior vice president, Eastman Kodak Company, chaired the study committee. Paper, $59.00.

Cleaning Up Sites Contaminated with Radioactive Materials: International Workshop Proceedings. This volume includes papers presented at the Workshop on Cleaning Up Sites Contaminated with Radioactive Materials, held in Moscow in June 2007. The workshop was organized by the National Academies in cooperation with the Russian Academy of Sciences and was funded by the Russell Family Foundation. The purpose of the workshop was to promote exchanges of information on contaminated sites in Russia and elsewhere and to call attention to the urgency of cleaning up sites of concern to local and international communities.

NAE member **Frank L. Parker**, Distinguished Professor of Environmental and Water Resources Engineering, Vanderbilt University, chaired the study committee. Paper, $50.50.

Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life—Special Report 296. This special report from the Transportation Research Board explores the promising results of the second phase of the Strategic Highway Research Program (SHRP 2) and recommends the most effective ways to implement them. The authoring committee of this report believes that the widespread implementation of products developed by SHRP 2 is critical to addressing issues related to the nation's roadway safety, renewal, reliability, and capacity.

NAE member **Thomas B. Deen**, retired executive director, Transportation Research Board, National Research Council, was a member of the study committee. Paper, $36.00.

Strengthening High School Chemistry Education Through Teacher Outreach Programs: A Workshop Summary to the Chemical Sciences Roundtable. A strong chemical workforce in the United States will be essential to addressing many issues of societal concern in the future, including demands for renewable energy, more advanced materials, and more sophisticated pharmaceuticals. High school chemistry teachers, who are critical to educating and supporting the chemical workforce of the future, are not always as knowledgeable and skilled as they need to be to turn out students who have the high level of scientific literacy they will need to succeed. To identify key points for improving high school chemistry education, the National Academies Chemical Sciences Roundtable held a public workshop in August 2008 that brought together representatives of government, industry, academia, scientific societies, and foundations involved in outreach programs for high school chemistry teachers. The workshop presentations summarized in this volume addressed the current status of high school chemistry education, provided examples of public and private outreach programs for high school chemistry teachers, and explored ways of evaluating the success of outreach programs.

NAE member **Mark A. Barteau**, senior vice provost for research and strategic initiatives, University of Delaware, was a member of the study committee. Paper, $21.00.

The National Academies Keck Futures Initiative: Complex Systems: Task Group Summary. The National Academies Keck Futures Initiative was launched in 2003 to stimulate new modes of scientific inquiry and break down conceptual and institutional barriers to interdisciplinary research. At the Conference on Complex Systems, participants were divided into 12 interdisciplinary working groups that spent nine hours over a period of two days exploring challenges at the interface of science, engineering, and medicine. Participants in each group were drawn from researchers in science, engineering, and medicine and representatives of private and public funding agencies, universities, businesses, journals, and science media. Thus each group was faced with the challenge of communicating and working with individuals with different areas of expertise and different perspectives to solve complicated, interdisciplinary problems in a relatively short time. The summaries in this volume describe the problem and outline the approaches taken by each group, including the research necessary to understand the fundamental science behind the challenge, the plan for engineering the application, the reasoning that supported their choices, and the social benefits of the solution to the problem.

NAE members on the steering committee were **James B. Bassingthwaighte**, professor of bioengineering and radiology, University of Washington, and **M. Elisabeth Paté-Cornell**, Burt and DeeDee McMurtry Professor and chair, Management Science and Engineering, Stanford University. Paper, $31.25.

Gender Differences at Critical Transitions in the Careers of Science, Engineering, and Mathematics Faculty. This congressionally mandated study reveals surprising findings about career differences between female and male full-time, tenure-track, and tenured faculty in science, engineering, and mathematics at the nation's top research universities. The findings are largely based on a faculty survey and departmental survey at major U.S. research universities in six fields: biology, chemistry, civil engineering, electrical engineering, mathematics, and physics. The departmental survey collected information on department policies, recent tenure and promotion cases, and recent hires in almost 500 departments. The faculty survey, a stratified, random sample of about 1,800 faculty members, collected information on demographics, employment experiences, allocation of institutional resources (e.g., laboratory space), professional activities, and scholarly productivity. The results provide an up-to-date picture of the status of female faculty at top universities.

NAE member **Linda M. Abriola**, dean of engineering and professor, School of Engineering, Tufts University, was a member of the study committee. Hardcover, $48.95.

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