The 21st-Century Engineer: A Proposal For Engineering Education Reform

By Patricia D. Galloway, Ph.D., P.E., F.ASCE

This month the ASCE Press will publish The 21st-Century Engineer: A Proposal for Engineering Education Reform, *by Patricia D. Galloway, Ph.D., P.E., F.ASCE, the chief executive officer and chief financial officer of the Nielsen-Wurster Group, Inc., and a former president of ASCE. In her book Galloway contends that the existing system for educating engineers must change, and she proposes a new master's degree in professional engineering management. In this groundbreaking manifesto Galloway explains the global changes that are leaving many engineers unprepared and outlines a proposed master's program—a master of professional management. Chapters 7 and 8 are excerpted here.*

CHAPTER SEVEN

Engineering Education Reform

In the 21st century, an ever-increasing need will emerge for a holistic breed of engineer—one who can work across borders, cultural boundaries, and social contexts and who can work effectively with nonengineers. As the trend toward a more global and more knowledge-based society continues, the practice of engineering must be changed, and this change must be accomplished through engineering education reform. The engineering curriculum can no longer remain as it has for essentially the past 40 years. The subjects of globalization, diversity, world cultures and languages, communication, leadership, and ethics must constitute a core component of the overall engineering education just as physics and mathematics do.

For nearly 20 years, numerous journals, articles, reports, and studies have been prepared by the American Society for Engineering Education, the National Academies Press, the National Science Board, the National Science Foundation, and the American Society of Civil Engineers (ASCE) that discuss the critical need for change in engineering education (Task Committee on the First Professional Degree, *Engineering the Future of Civil Engineering,* ASCE, Reston, Virginia, 2001). Yet despite this large library of literature on the subject of engineering education reform, the engineering curriculum of today still does not provide the foundation necessary to ensure the engineer's success in the 21st century. A report by the American Electronics Association in 2007 (*We Are Still Losing the Competitive Advantage: Now Is the Time to Act,* Washington, D.C.) notes that the 21st-century global economy portends to be very different from that of the 20th century and that national public policy must be viewed through the prism of education as a lifelong process. In the past, the skills workers acquired would serve them well for decades. In the 21st century, however, the success of engineers and firms will be measured against how well they can adapt to new conditions and technologies. Thus to remain competitive in this global and knowledge-based economy and to ensure that the quality of life improves for everyone around the world, engineers must be educated differently.

The content of engineering education was diminished across the globe over the course of the past century in an

0885-7024-/07-0011-0046/$25.00 per article

effort to reduce the cost burden to students and to produce more engineers and to process more revenue through the educational business faster. While this devolution resulted in an emphasis on the technical aspects of engineering, it eliminated other critical aspects of engineering education and studies that are fundamental to the very essence of engineering, which is to improve the quality of life and to protect the public safety, health, and welfare. If an engineer is not trained in public policy, ethics, leadership, communication, and management, an engineer cannot adequately serve the public.

In *Educating the Engineer of 2020: Adapting Engineering Education to the New Century* (National Academies Press, Washington, D.C., 2005), the National Academy of Engineering notes (page 13) that

> today, the practice of engineering needs to change further because of the demands for technologies and products that exceed existing knowledge bases and because of the changed professional environment in which engineers need to operate. That change must be encouraged and facilitated by change in engineering education.

In an article entitled "Twenty-First Century Leadership Challenges," published in May 2005 in *Engineering Times,* the magazine of the National Society of Professional Engineers, Ralph R. Peterson, the chairman and chief executive officer of CH2M HILL, a global engineering firm, wrote:

> It's not enough to simply design and build projects. We must 1) grasp the totality of our client's mission, 2) develop solutions that add value to the client's mission, and 3) link our compensation to the value-added outcomes as defined by our clients. . . . No single firm can move the industry, but if our profession takes on the challenge . . . together we can make a difference. . . . As the developing and developed worlds strive to improve their economic prospects and quality of life, we will come to grips with the fact that we live in a finite world. Our profession's leadership challenge is to reposition itself as an effective steward of natural resources and the environment.

The evolving global environment in which the 21st-century engineer must succeed demands that engineering education be reformed. While the basics of engineering education will not change—that is, the mathematical and scientific fundamentals—the skill set of engineering graduates must be much broader than it is today. Engineers must be much better equipped not only to function in the global economy but to flourish in it, and their education must include instruction in communication, in multiteam participation, in the design of complex systems, in multiculturalism, and in languages.

Engineering education reform will require engineers themselves to demand such reform—engineers working in academia and engineers working in industry. In other parts of the world, engineers are celebrated as heroes and leaders, and in such countries as China and India engineering enrollment is increasing significantly. In the United States, in contrast, engineers are viewed as technology enthusiasts slavishly devoted to intellectual or academic pursuits. As the American Electronics Association notes, this outlook is extremely unfortunate in that it is rooted in ignorance, and ignorance is poisonous to an economy fueled by technology and innovation. Engineers must determine a way to foster a public image of innovation and creativity that is so inspirational that the young people of today yearn to pursue careers in engineering. Our educators must instill within their students the belief that engineers are engaged in creative, stimulating, challenging, and satisfying work that significantly improves the lives of people the world over. If the engineering profession is to succeed in attracting, preparing, and retaining greater numbers of qualified individuals to the profession, it must reform its educational system by shattering stereotypical images and strengthening and extending engineering education so that it is comparable to the demands of a legal or medical education, for example; by broadening the content of engineering education so that engineering graduates are confident in their ability to work effectively on multicultural teams and ultimately supervise multicultural and multidisciplinary teams; and by including instruction in management, leadership, ethics, and professionalism so that they can better serve the public in whichever nations they find themselves working.

In 2004, Judith Ramaley eloquently made the point that engineering education today must foster "richer social networks" in an effort to broaden engineering education to instill a deeper understanding of civil responsibility and international justice as well as a deeper understanding of human capacity. In a lecture entitled "Engineering as the Practical Expression of Liberal Education," which she delivered on June 23, 2004, in Salt Lake City at a meeting of the American Society for Engineering Education, Ramaley recommended an approach to engineering education that

- Develops the intellect and the capacity and inclination for lifelong learning;
- Shapes ethical judgment and the capacity for insight and concern for others, the world in which we live, and the future we will bequeath to our children and their children;
- Fosters an increased understanding and openness to other cultures, languages, and societies and the connections that bind us together as fellow travelers on an increasingly connected globe;
- Builds an understanding of the effect of the human presence on the land and the effects of the systems we build to advance our efforts as a community;
- Expands our scientific horizon and our appreciation of the influence of new technologies on our lives, both as individuals and as we live them in community with others;
- Supports our capacity to nurture democratic and global knowledge and engagement, and . . . hardest of all . . . helps us acquire the ability to reach out to our adversaries and those who seek to harm us and to understand why they act as they do.

Inadequacy of the Four-Year Bachelor's Degree

Heretofore, engineering education has emphasized technical content and has all but ignored professional obligations to the public. Engineering education has largely been developed by educators rather than practitioners, but collaboration between the two segments is essential if engineering curricula are going to impart a thorough understanding of what is required for an engineer to best serve society today.

A comparison of the historical educational requirements for the legal and medical professions serves as an ideal starting point for formulating a platform for engineering education reform. In 1900, the U.S. medical profession required of its graduates three years of college academics followed by a one-year internship. At that same time, the legal profession required two years of collegiate study. The engineering profession—in stark contrast—required four years of college study and was considered the most demanding profession in which to gain entry. But not only did the engineering profession fail to maintain a competitive pace with the legal and medical professions during the ensuing century, it actually reduced the number of credit hours required to earn an engineering degree. A few decades ago, the average number of credit hours required for an engineering degree was 140; today—in more than half of American colleges and universities—the number of credit hours required is 128. The engineering profession is no longer comparable to the legal or medical professions in terms of educational demands, and this is one reason that its image on the professional stage has been diminished. The public shares this view: engineering is not perceived as being as "tough" as law or medicine in terms of educational rigor.

Engineers themselves have grown complacent in terms of their education, failing to grasp the importance of a well-rounded educational experience. As Brent Strong observed ("Beat Back the Nerd and Awaken Your Inner Leader—Why Engineers Should Read Shakespeare," *Composites Fabrication* [February 2003]), there is a disturbing tendency among engineers to simply comply with general educational requirements and not seek a real understanding of the world—an interdisciplinary understanding based in liberal arts and humanities that provides enrichment. Strong suggests that engineers strive to become Renaissance men and women.

To some extent this is what the medical profession did by requiring medical students to understand human behavior and to develop a sensitive bedside manner so that they could more effectively treat their patients and establish a sense of trust. Additionally, the medical profession determined that general practice would require four years of preprofessional collegiate study followed by four years of professional study and one year of internship. Physicians aspiring to practice as specialists would be obligated to undertake an additional two to three years of study followed by residency in a hospital. The legal profession also increased its educational requirements; aspiring attorneys must complete four years of collegiate study followed by three years of study in law school.

The objectives of engineering education simply cannot be achieved within a four-year period of study. As Dan Henry Pletta observed in *The Engineering Profession: Its Heritage and Its Emerging Public Purpose* ([Lanham, Maryland: University Press of America, 1984] 138), the objectives to which the engineering profession should aspire should be

- To educate novices for the responsible practice of a specified professional art;
- To transmit applicable existing knowledge after first "distilling" it for concise presentation;
- To search for new knowledge that enhances the art involved;
- To convey a sense of ethics and professionalism;

- To motivate novices for public advocacy roles to protect the public health, safety, and welfare as well as the earth's resources and its environment; and
- To groom societal leaders for a technological civilization that will protect freedom.

The diminishment of engineering education requirements is perhaps rooted in the splintering of the profession into areas of specialization that include, for example, civil, mechanical, chemical, nuclear, mining, electrical, and metallurgical engineering. In 1980, ABET, Inc., listed 21 programs in engineering and 48 in technology. Unlike the legal and medical professions, which speak via one primary professional organization respectively, engineering speaks via dozens of specialty organizations. The engineering profession must compensate for this splintering by making a concerted effort to reestablish unity and focus on shaping educational curricula that educate engineers who can succeed in the 21st-century global marketplace and knowledge-based society.

Today's engineers are faced with challenges that are vastly different from the challenges faced by previous generations. These challenges include global commercial competition, intelligent technology, and a constantly changing work environment. These demands require knowledge that cannot be acquired by means of a four-year curriculum; they require knowledge acquired via graduate study. It is critical for the engineering profession to understand that the four-year curriculum is no longer adequate—that given the rate of change within the field of technology and the need to cope with the increased breadth and complexity of modern engineering practice, additional subjects of study must be incorporated into engineering curricula at both the undergraduate and graduate levels. These subjects include management and the subsets of finance, leadership, and human resources; probability; teamwork; communication—both oral and written; interdisciplinary project work; and foreign language and cultural study.

Heretofore, engineering education has emphasized technical content and has all but ignored professional obligations to the public. Engineering education has largely been developed by educators rather than practitioners, but collaboration between the two segments is essential if engineering curricula are going to impart a thorough understanding of what is required for an engineer to best serve society today. The consistent lack of emphasis on professionalism, ethics, and leadership—even within doctoral programs—has hampered engineers in their service to society.

In its 2001 report *Engineering the Future of Civil Engineering,* ASCE notes significant and rapid changes confronting the profession. Almost all discussion of educating the 21st-century engineer presumes additions to the engineering curriculum that would include courses on communication, social sciences, business and economics, cross-cultural dynamics, and information technology. Unfortunately, the typical undergraduate engineering program requires 10 percent more course work than nontechnical degree programs and thus adding these new elements to the current four-year bachelor's program is not a viable solution. *Engineering the Future of Civil Engineering* recommends that the civil engineering profession revamp its 150-year-old educational system to meet the challenges of the 21st century. Specifically, it recommends education beyond the four-year bachelor's degree that will provide the knowledge, skills, and attitudes necessary to ensure high professional standards and protect the public safety, health, and welfare.

In *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, the National Academy of Engineering recommends that the four-year engineering bachelor's program be considered merely a pre-engineering or engineer-in-training degree and that a master's degree be considered the professional degree.

Engineering Accreditation In the United States

During the 1920s, the American Association of Engineers established the Committee on Accredited Schools and called for more comprehensive and discriminating standards for evaluating engineering schools. Recognition of the need to ensure the quality of education prompted the National Council of Examiners for Engineering and Surveying and a number of engineering organizations to form a joint committee to establish improved standards for accredited schools. That committee called for the formation of the Engineers' Council for Professional Development, which later became known as the Accreditation Board for Engineering Education and Technology, or ABET. ABET is an organization of member societies in engineering and engineering-related fields. As part of its mission, ABET accredits educational programs and promotes quality and innovation in education.

In 1995, ABET published a draft of *Engineering Criteria 2000* as a mandate to educators to design curricula that could produce engineers with adequate skills with which to enter the job market. On November 2, 1996, the ABET Board of Directors approved what was initially known as the *Engineering Criteria 2000* but is now known simply as the ABET engineering criteria. These criteria include a set of 11 outcomes that all engineering baccalaureate graduates should achieve. The authors of these criteria concentrated on what all engineers should be able to accomplish regardless of their discipline of practice. The criteria can be divided into two categories: hard skills and soft skills. The six soft skills have come to be known as the "professional skills" and include an ability to function on multidisciplinary teams; an understanding of professional and ethical responsibility; an ability to communicate effectively; the broad education necessary to understand the impact of engineering solutions within a global, economic, environmental, and societal context; a recognition of the need for and an ability to engage in lifelong learning; and a knowledge of contemporary issues.

Although the curricula of many colleges and universities have been tweaked—or, in some cases, overhauled—in response to ABET's criteria, there is some frustration that this has not happened quickly enough. The most difficult piece to address has been the ability to communicate effectively. Historically, those who have been attracted to engineering have not been deemed to be naturally proficient in terms of communication. The reality of today, however, is that an understanding of the technical aspects of engineering will get an engineer only so far. Engineers must now demonstrate proficiency in technical writing, oral presentation, social interaction, consensus building, and survival on the political landscape of business.

According to the American Society of Engineering Education, employers seek engineers who demonstrate an ability to apply their knowledge of mathematics, science, and engineering to design and conduct experiments and analyze data; an ability to perform on multidisciplinary teams and communicate effective solutions within a global and societal context—which demands a grasp of everything from history to sociology to psychology; a yen for lifelong learning; and a bona fide knowledge of contemporary issues. In an issue of the National Academy of Engineering's *The Bridge* that was devoted to reforming engineering education, Lisa R. Lattuca, Patrick T. Terenzini, J. Fredericks Volkwein, and George D. Peterson reported ("The Changing Face of Engineering Education," 36, number 2 [2006]: 5–13) on a survey of 1,622 employers. Barely half of these employers considered engineers' understanding of organizational, cultural, and environmental contexts and constraints to be adequate. Moreover, skills in these areas, according to employers, appear to have declined within the past decade. Graduates' teamwork and communication skills were rated just "adequate."

In another article in the same issue of *The Bridge,* Theodore C. Kennedy ("The 'Value-Added' Approach to Engineering Education: An Industry Perspective," 36, number 2 [2006]: 14–16) writes,

> We have to change what we expect from engineers, and we have to turn out graduates with broader skills, interests, and abilities. With the commoditizing of basic design engineering and the migration of that function overseas, the traditional training ground for recent graduates is no longer available in the United States. . . .
>
> I look for different skills than I did 10 years ago. Today, it is not unusual for good candidates to have global references and experience on projects and assignments around the world. I think we must prepare our graduates for that type of career. . . .
>
> I need graduates who can speak before an audience to make a point, either to me or a client. Comfortable or not, engineers today are constantly selling—selling an idea, a concept, a study, an alternative, or just the need for a new document control system. . . .
>
> Engineers must be able to write reports, studies, or routine business letters . . . I am tired of "cite," "sight," and "site" being used interchangeably.

The ABET criteria constitute a solid first step toward reforming engineering education. It is not possible, however, to provide to engineers within a four-year period all of the skills they need to practice. The master's degree is essential to professional practice today. It is essential for ABET—and other accreditation institutions the world over—to recognize this fact and promote the benefits of the master's degree. This is the only way in which the engineering profession can protect its members from becoming commodities in the world market and gain the public trust and professional recognition that will elevate the engineering profession to a higher plateau.

The Next Steps Forward

In 1957, the Soviet Union's Sputnik satellite was launched, sparking an aggressive crusade to improve math and science education in the United States. In *The World Is Flat: A Brief History of the Twenty-First Century* (New York City: Farrar, Straus and Giroux, 2005), Thomas L. Friedman observes that the generation of scientists and engineers who were motivated to pursue careers in science by the threat that Sputnik represented are reaching their retirement years and are not being replaced in the numbers needed to sufficiently advance the United States within the fields of science and technology so that it remains competitive with other nations. In 2007, fifty years after Sputnik's launch, the United States is once again facing the threat of scientific diminishment—at a time when engineering will nonetheless continue to grow increasingly complex. As a result of the rapid rise of information technology, the explosion of knowledge within the field of engineering, and the growing complexity of civil infrastructure systems, the job performed by the engineer will continue to become more demanding. Thus, engineers today must possess both greater breadth of capability and greater specialized technical and managerial competence. Engineering practice today requires engineers to take a broader view of their work environment and to interact with the public and with policy makers on a regular basis. This interaction requires effective communication skills as well as strong negotiation skills.

Twenty-first-century engineering practice demands fundamental change in engineering education. Most of the senior members of the profession are graduates of baccalaureate programs that required the successful completion of between 145 and 160 credit hours for graduation. The norm today ranges from 120 to 135 credit hours, and these requirements continue to be reduced steadily by various universities and legislatures. How can engineers continue to do more with essentially less education? They cannot, and if engineers within academe and industry do not work collaboratively with government to effect change, engineering will cease to be a profession and will become a trade on the world commodity market. The practice of civil engineering has become increasingly more complex technically within the past 30 years—and will continue to increase in complexity—and yet the technical content of the undergraduate curriculum is not keeping pace with this complexity.

ASCE took a bold step in 2004, when it released its report *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future.* The current version of the body of knowledge assumes the form of 15 outcomes, which represent much more technical and professional practice capability than is found in today's civil engineering programs. Of those fifteen, the technical desiderata are as follows:

- An ability to apply knowledge of mathematics, science, and engineering;
- An ability to design and conduct experiments, as well as to analyze and interpret data;
- An ability to design a system, component, or process to meet desired needs;
- An ability to identify, formulate, and solve engineering problems;
- An ability to understand the techniques, skills, and modern engineering tools necessary for engineering practice;
- An ability to apply knowledge in a specialized area related to civil engineering;
- An understanding of the elements of project management, construction, and asset management.

With respect to professional practice, the outcomes would be as follows:

- An ability to function on multidisciplinary teams;
- An understanding of professional and ethical responsibility;
- An ability to communicate effectively;
- The broad education necessary to understand the impact of engineering solutions in a global and societal context;
- A recognition of the need for, and an ability to engage in, lifelong learning;
- A knowledge of contemporary issues;
- An understanding of business and public policy and administration fundamentals;
- An understanding of the role of a leader and of leadership principles and attitudes.

The second edition of the report is due in 2008 and includes additional outcomes. This body of knowledge—or "raise the bar"—initiative is intended to apply to all engineering graduates seeking licensure, not just to those who choose to or are able to attend graduate school. It is anticipated that in the future those earning bachelor's degrees will be able to attain the additional required education in a variety of ways, including distance education from well-respected engineering institutions and the use of in-house educational programs within engineering firms, agencies, and technical societies that are able to provide educational experiences that are documented to be equivalent in content, rigor, learning, and assessment to current engineering education. ASCE also recommends that those who teach engineers should predominantly be licensed.

The move forward to reform engineering education will require consistent and effective collaboration among members of academia, industry, and professional engineering organizations. If engineers are going to be adequately prepared to work in the knowledge-based 21st-century society, engineering education must undergo immediate reform—reform institutionalizing a master's degree program that provides the skill set needed by engineers to work in the 21st-century world.

As Claudio da Rocha Brito and Melany da Rocha Brito put it in an undated paper of theirs entitled "A New Engineer for a New Global Market" (Department of Applied Sciences and Mathematics, University Center of Lusíada, Brazil), "As engineering is the agent of progress and so the agent of transformation of human life, it is time not only to meditate but to change, and to do effectively something to make it better."

As a result of the rapid rise of information technology, the explosion of knowledge within the field of engineering, and the growing complexity of civil infrastructure systems, the job performed by the engineer will continue to become more demanding. Thus, engineers today must possess both greater breadth of capability and greater specialized technical and managerial competence.

Reforming Engineering Education. The CDIO Initiative. CDIO stands for Conceive â€“ Design â€“ Implement â€“ Operate.Â academics took up the challenge to reform engineering education. The. result of that endeavor is the CDIO Initiative. The reform and development of international engineering education has influence and enlightenment on China. The study of the development and reform of international engineering education can pave the way and provide a reference to build higher engineering educational system with Chinese characteristics. And it has strategic importance to the national comprehensive strength and enhancing the national core competitiveness. Engineering Education Reform: Signs of Progress. FRANK G. SPLITT Northwestern University, McCormick School of Engineering and Applied Science, 2145 Sheridan Road, Evanston, IL 60208Â±3100, USA. E-mail: fgsplitt@ece.northwestern.edu.Â about educating the stakeholders and motivating them to play their respective roles. To this end, the International Engineering Consortium published a trilogy on engineering education reform as a service to academia, government and industry. This paper discussed the engineering education reform in the synchronization of higher education management from these aspects, such as higher engineering education innovations of principle in school management, construction and management of teaching staff, construction of a new student management system, and so on. Keywords. Engineering Education Project teaching School Management. This is a preview of subscription content, log in to check access. Preview. 5. The engineering education establishment, for example, the Engineering Deans Council, should endorse research in engineering education as a valued and rewarded activity for engineering faculty as a means to enhance and personalize the connection to undergraduate students, to understand how they learn, and to appreciate the pedagogical approaches that excite them.Â 8. Engineering schools introduce interdisciplinary learning in the undergraduate environment, rather than having