

# The Bridge

## A Call for K–16 Engineering Education

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*Engineers are packaged as problem solvers rather than creators and innovators addressing grand challenges.*

The best-intentioned diversity-recruitment initiatives by engineering colleges nationwide have had little success in increasing access to the richly textured future afforded by careers in engineering. After years of focusing on increasing diversity in engineering, I am convinced that elementary school is not too early to start building the foundation for an engineering education—one that supports an informed citizenry, scaffolds an adaptive workforce, and leads to responsible innovations for our planet. A solid foundation that begins in the early, formative years would also ensure that young people and adults understand the contributions of engineers to our quality of life and would cultivate an interest in engineering in youngsters from all walks of life.

Consider the potential contributions today's young people—as tomorrow's engineers—could make toward closing our record \$726 billion trade gap, if only we could interest them in our profession! Opportunities abound. The explosion of new fields, such as nanotechnology, biotechnology, and cyberinfrastructure, offers unprecedented opportunities for engineers to address significant societal challenges. And the pervasiveness and complexity of technology in our public infrastructure calls for the involvement of engineers in setting public policy—a change from the traditional, behind-the-scenes role engineers have played in the past. Increasingly, an engineer's place is in the House—and in the Senate—creating responsible, informed public policies.

As engineers, we create things, and we're proud of it. We improve society's standard of living, and we know we make a difference. But, astonishingly, most of the U.S. population is unaware of the role of engineers in medical advances, in alleviating human suffering, or even in creating the iPod that puts 10,000 tunes at our fingertips. We package engineers as problem solvers rather than creators and innovators who address the grand challenges of our time—environmental contamination, world hunger, energy dependence, and the spread of disease. Journalists report scientific achievements and engineering failures, as though engineering hasn't made profound contributions that have dramatically extended the human life span through public infrastructures. How did we let this happen?

### **K–16 Design Challenge**

In the real world, engineers must respond to sudden changes. Yet we balk at making transformative

changes in our educational system. Our educational challenge is itself a design challenge—making the “right” engineers for our nation’s future. Half the U.S. population will be non-white by 2050, and engineers will increasingly serve diverse consumers (NAE, 2005). How do we attract native talent to engineering? How do we overcome the conspicuous absence of women and minority students in engineering colleges and professional practice? How do we turn around the disinterest in engineering among high school students? And, on a broader scale, how do we ensure that youngsters learn the skills they will need to thrive in a global, change-driven society?

We understand that innovative, technological breakthroughs are made at the convergence of disparate disciplines, yet we continue to draw unnatural distinctions between college-level engineering education and K–12 educational experiences that could tap into the passion of youngsters and prepare them to pursue engineering futures. Our collective challenge is to design a seamless K–16 engineering education system that integrates engineering with the liberal arts so technological literacy is considered a component of basic literacy. All engineering graduates should have excellent communication skills, and, evidenced by reading broadly and thinking deeply, a sophisticated understanding of the roles and responsibilities of engineers in our society. We must prepare tomorrow’s leaders to be responsible stewards of our planet.

### **Making Engineering Attractive**

Fewer U.S. students pursue careers in science, technology, engineering, and math (STEM) than in many other countries, where STEM studies are perceived as a path to a secure future. When we compare the participation of U.S. university students in STEM majors with the participation of students of Asian nations, such as China, Japan, and South Korea, the differences are stunning (Figure 1 - see PDF version). Is it a coincidence that in some of these countries engineers are pervasive in top government ranks and engineering students occupy up to a third of undergraduate university seats? And, in contrast, that not one engineer can be found in the U.S. Congress?

The number of engineering B.S. degrees earned by U.S. students peaked in 1985, steadily declined through 1992, and then came to rest on a decade-long plateau. The number began to climb again in 2002, but it is still lower than it was in the mid-1980s (NSB, 2006). Coupled with a dramatic increase in retirements expected in the next two decades, these numbers signal a national imperative that we attract more—and different—U.S. students to the engineering fold (NAE, 2005).

### *Diversity-Driven Creativity*

Our entire citizenry and demographic mix should be represented in engineering. The lack of interest in engineering studies among U.S. youths is a problem—and a challenge—and a tremendous opportunity. The goal of engineering education should be the full participation of women, people of color, low-income students, and first-generation, college-bound young adults. We want and need people educated in cross-disciplinary, quantitative decision making at the helm, developing the new technologies and policies that will shape our nation’s economic future and preserve the health of our planet. Our nation needs today’s youngsters to be more than just users of tomorrow’s technologies; we need them to be the developers of responsible technologies and products.

Although engineering is ultimately a creative endeavor, a recent poll shows that only 3 percent of U.S. adults perceive engineering as creative (Harris Interactive, 2004). Yet the goal of engineering is to create innovative solutions to meet the needs of people. The key word is create, and creativity is

stimulated when design teams include contributors with diverse perspectives and life experiences.

### *The Gender Divide*

Young women dominate the top deciles of U.S. high school graduates, yet they have a minimal presence in the engineering pipeline. Females account for only 20 percent of new B.S. engineering graduates. Even as our society becomes more technology driven, the number of women contributing to the technological revolution is shrinking. Are we content to let the best and brightest students shun our profession?

We must overcome this gender divide. Young women halfway through high school express scant interest in engineering. PSAT data for the May 2006 graduating cohort show that only 2 percent of U.S. college-bound eleventh-grade female students indicate an interest in majoring in engineering (College Board, 2004, 2006). Beyond the inequity, our profession's inability to connect with this vast reservoir of talent has economic implications.

A recent study established a quantitative link between women's representation in senior leadership and corporate financial performance (Catalyst, 2004). The 353 companies that remained in the Fortune 500 for four of five years between 1996 and 2000 boasted a higher representation of women in senior management positions than the companies that dropped off the list. It is time our engineering profession learned from this and began to leverage the full potential of our nation's diversity.

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A profound gender distinction pervades the information technology world, where the representation of women contributing to the technological revolution is shrinking. Increasingly, girls are turning away from being creators of the very technologies that shape their lives. "Boys invent things, and girls use things boys invent" (Margolis and Fisher, 2002). In 2005, only 15 percent of high school students who took advanced placement (AP) computer science exams were girls, by far the lowest percentage in any AP test. By comparison, girls made up 46 percent of the AP exam takers in calculus, 47 percent in chemistry, and 31 percent in physics (College Board, 2006). The absence of women's voices is disconcerting; a cyberspace culture designed and dominated by men alienates the sensibilities of women and represents a substantial lost opportunity.

### *The Public Image of Engineering*

As we reflect on our slow progress in increasing diversity in the engineering workforce, it is worth pondering the relationship between diversification and the poor public image of engineering. The dominant messages—that engineering is tough and that one must *love* math *and* science to pursue engineering—are dead on arrival with girls. The Extraordinary Women Engineers Project, a coalition of engineering associations and societies, confirmed that the engineering gender divide is thriving. A needs assessment of more than 5,000 high school girls, teachers, and counselors found a profound

lack of interest in engineering among mid-teen girls, who perceive engineering as a man's profession, have personally experienced little encouragement to consider engineering, and do not understand what engineering is really about (EWE, 2005).

Just think about it. How would they know? Which sitcoms highlight teams of engineers creating new products or addressing societal challenges in a stimulating and satisfying environment? Which engineering icons are empathetic role models, demonstrating that caring for humanity requires engineering solutions? The people who influence today's teenage girls are, in rank order, parents, peers, teachers/counselors, and the media. Little wonder that girls are neither encouraged nor guided toward engineering when they are steered by an adult public that perceives engineers as insensitive to societal concerns, doing little to save lives, and caring only marginally about community (Harris Interactive, 2004).

Today's engineering messages are misaligned with women's career motivators, and they do not convey the benefits or rewards of being an engineer. Our "engineering is tough" message does not resonate with young women seeking a flexible profession in which they feel they can make a difference. Clearly, we're simply not talking with teenage girls, and we delude ourselves if we think we are even talking to them.

As a creative profession, we can tackle this challenge. With National Science Foundation (NSF) funding, NAE has embarked on a public understanding of engineering study to gain insights into more effective messaging approaches. We can, and must, figure out how to market our profession to attract talented and well prepared young women.

### *The International Divide*

One approach to probing the roots of economic competitiveness and creating better lives for a nation's citizens is to look closely at how the invention and innovation workforce is educated. If we look at a 27-year period, from 1975 to 2002, we see alarming global trends (Figure 2). The percentage of U.S. 24-year-olds who earned first STEM degrees increased by 43 percent. During this same period, the number increased astoundingly—in most cases more than quadrupled—in Taiwan, South Korea, France, Spain, Mexico, and China. The United States dropped from second among these nations (behind Japan) in 1975 to sixth in 2002.

The obvious question is: *How can our nation sustain a leadership role in innovation without STEM-proficient college graduates to fuel the technological and leadership workforce?* Who will be our inventors and creators? Or are we destined to become a lower wage service economy?

### *Poor High School Preparation*

If we look closely at the preparation of high school students (Figure 3), we note that only slightly more than half of Hispanic and African American students even graduate, and less than one-quarter of them are prepared to succeed in college. These numbers are astonishing. In a knowledge-based economy, how can anyone attain a decent standard of living without even a high school degree? And how can the engineering profession benefit from the rich diversity of our nation if more than half of our students of color (the largest growing sector of the U.S. population) are not prepared to engage in college-level engineering education?

The latest data available on math proficiency among our nation's twelfth-grade students does not portend well for the creation of a diverse workforce. Readiness for success in college-level calculus is a known gatekeeper for success in engineering education. According to *The Nation's Report Card* (NCES, 2001), only 20 percent of U.S. Caucasian twelfth-grade students test proficient or above in mathematics; fewer than 5 percent of Hispanic or African American twelfth-grade students achieve at the proficient level (Figure 4). For our nation's 350+ engineering colleges to compete for this limited pool of qualified students is like rearranging deck chairs on the Titanic. Not only is this a compelling reason to form meaningful, outcomes-based partnerships between universities, the K–12 community, engineering societies, and engineering professionals to improve the preparation and engage the interests of American youth, it is an economic necessity.

### **Legitimizing Engineering Education**

At the college level, fewer than 60 percent of our bright, first-year engineering students graduate. Only 35 percent of college students think engineering is “worth the extra effort” (NAE, 2005)—although their peers studying medicine and law think their extra college work is worth the effort. Why not engineering? Perhaps providing pervasive K–12 engineering experiences would stimulate students to join the engineering ranks and motivate them to stay the course.

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Despite ABET reforms, engineering colleges have changed little in three decades. Most of us still teach the way we were taught; we have capitalized little on advances in the science of learning; we resist implementing strategies known to help retain students from underrepresented groups; and we do not take responsibility for the promotion of widespread technological literacy.

Overall, engineering curricula do not look much different than they did 30 years ago, despite a much-changed world. The challenge for today's engineering educators is to develop world citizens with highly honed critical thinking and creativity skills to support the transfer of knowledge to myriad problem contexts. To aid in that pursuit, engineering education is gaining traction as a legitimate field of research.

We now understand that educating engineers who can contribute to global engineering solutions will require changes in engineering education based on research into the most effective new educational methodologies. With advances in neuroscience and imaging, we can now apply, as never before, knowledge gleaned from the *science of learning* to engineering education.

The American Society for Engineering Education is beginning a year of dialogue on the topic of scholarship in engineering education. And, NSF now invests \$10 million per year in research to create a body of knowledge to help us understand if our students are learning what we think we are teaching them. Purdue University recently created the first Department of Engineering Education in

the country, followed quickly by Virginia Tech—the beginning of a trend to study engineering education and research-based connections to the K–12 community.

The passage of the No Child Left Behind (NCLB) Act in 2002 left no question that K–12 education must be driven by educational content standards and that students must master specified skills and knowledge at each grade level. Resistance from the K–12 educational community abounds, and early results are mixed, but NCLB is pushing us toward a national, standards-driven educational environment.

Massachusetts is the only state that currently has educational content standards in engineering, although standards in technology, which include engineering components, have been developed in many states. Six states—Massachusetts, Arkansas, New Hampshire, Florida, Texas, and Maryland—already mandate some high school coursework in engineering (Shuman et al., 2005). Texas even requires parental authorization for a student to *opt out* of the college track. However, in some high schools, engineering courses are relegated to the vocational-education track and are taught by former shop teachers. Unfortunately, these courses target non-college-bound students who generally do not have the academic fundamentals to pursue an engineering education.

### **Success Stories**

*Educating the Engineer of 2020* clearly laid out our challenges (NAE, 2005). We now have an undercurrent of awareness, though not yet a consensus, that the challenges facing us are so complex and daunting that tinkering at the edges of the problem will not suffice. And, we must admit that our scattered approaches to reforming engineering education have not resulted in systemic change. From what successful programs might we learn and extrapolate a way forward for K–16 engineering education?

#### *Small High Schools*

High schools with about 400 students have been able to address the plight of urban youth by drastically reducing the harmful effects of poverty. In these schools, promising achievement gains have been noted for low-income and ethnic-minority students (Cotton, 1996; Howley and Bickel, 2000). Small high schools capitalize on the body of knowledge that shows that the quality and intensity of coursework are more important in predicting college success than class ranking or SAT score. Personalized learning environments cultivate student/adult relationships that reduce student alienation and dropout rates.

A new school to watch, for both achievements and challenges relevant to the engineering community, is the Denver School of Science and Technology, a public charter school completing its second year of operation this June ([www.scienceandtech.org](http://www.scienceandtech.org)). The state of Texas is considering founding 25 such schools.

#### *Teach for America*

Teach for America (TFA) is a highly selective, professional, semi-volunteer program that leverages the altruism of bright college graduates with strong leadership potential. The TFA program challenges the status quo of the regulatory, school-of-education-based approach to controlling teacher preparation and quality. Through TFA, new graduates with non-education majors are teaching in the most troubled schools.

In 2005, 7,000 new college graduates vied for 1,650 TFA openings, including 12 percent of new graduates from Yale and 8 percent from Princeton and Harvard. A recent independent program evaluation in a range of settings found that TFA teachers had outstanding educational qualifications and that they were largely successful as teachers (Decker et al., 2004). Overall, they generated a 10 percent increase in math achievement scores and maintained the current level of achievement in other subjects.

Is TFA a model program in which our profession should participate? TFA engineering teachers could increase awareness of engineering while advancing the education of the neediest students in the subjects that youngsters shy away from and for which urban schools have great difficulty recruiting teachers. Might newly graduated engineers who commit two or more years to teaching in TFA become a significant component in our campaign to shape a better future for engineering and for our country?

### *K–12 Engineering Outreach Corps*

My personal bias is that community involvement should be an essential part of every engineering student's educational experience. Service learning brings together academic subject matter with real-world, community needs. Isn't that what engineering is all about?

If we are looking for a low-cost, high-impact approach to exposing K–12 students to the joys and creativity of engineering, let's initiate a national K–16 service-learning-based Outreach Corps. As all good teachers know, one learns best when one teaches. In this model, engineering students would connect with youngsters by teaching in K–12 classrooms.

From my own experience with such a project, I know that engineering students are highly motivated teachers of K–12 engineering material and that they can improve STEM learning (Sullivan and Zarske, 2005). Teaching-based community service promotes empathy in engineering students and can spread the word about the value of engineering to students, teachers, and parents.

### **An Integrated K–16 Approach**

In spite of soaring U.S. college enrollments, fewer engineering degrees are awarded annually today than were awarded 19 years ago. The numbers tell us that it is not enough to harvest the brightest high school graduates; we must also *grow the talent* to fuel our profession. So, what is to be done?

A K–16 engineering “conversation” has been initiated and is picking up steam. This involves establishing long-term and skill-building relationships between engineering colleges and K–12 schools and exploiting *engineering as a vehicle for the integration of science and math* in ways that connect youngsters to the joys, challenges, and relevance of a future in engineering. Such experiences help students recognize the pervasiveness of engineering in their everyday lives and enable them to internalize engineering as a helping profession. Furthermore, early and extensive engineering experiences can prepare children and young adults to thrive in a technologically driven society—helping them to recognize the complexities of contemporary issues, engage intelligently in the discourse of our times, and make informed choices that take future generations into consideration.

Exposure to engineering may be most profound in grades 3 through 8. In these formative years,

hands-on engineering experiences, conveyed through inquiry-based, design-oriented instructional methodologies, can support the learning of standards-based science and mathematics while stimulating student learning and making engineering come alive. By including engineering in early STEM learning, youngsters can begin to imagine themselves as engineers creating new products and processes for the benefit of humankind. The *TeachEngineering* digital library, a free and growing National Science Digital Library collection, provides curricular resources to support K–12 engineering initiatives with standards-based science and math curricula (Sullivan et al., 2005).

## Conclusion

We are facing both great challenges and great opportunities. It is critical to our nation’s health that we make bold, coherent K–16 engineering choices and bring engineering out of the shadows. As long as it remains a “stealth profession,” the excitement of engineering will continue to be one of the best kept secrets on the planet. It’s up to us to make engineering visible and relevant in the lives of K–12 students, teachers, counselors, and parents.

As we face increasing competition from low-wage, high-human-capital communities across the globe (and as wealth, thankfully, spreads and the global standard of living increases as never before), we must design engineering education to capitalize on an interrelated K–16 system. As my favorite professor once said, “It is our choices . . . that show what we truly are, far more than our abilities” (Rowling, 1999). We know what is possible. Our challenge is to *make the possible probable* for our educational system and our profession.

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