McGraw-Hill Education

Engineering Literature Review

Part II — The Increasing Demand for Engineering Education

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Our collective challenge is to design a seamless [6]–16 engineering education system that integrates engineering with the liberal arts so technological literacy is considered a component of basic literacy. (Sullivan, 2006)

Source: McGraw-Hill Essentials Pre-Engineering, 2012

Every day, the news media report public, government, and industry concerns about the ability of the United States to maintain its position as a global leader and economic powerhouse. Government and policy leaders are concerned that a weak economy leads to an inability to respond to national and international challenges. The consequences of falling behind other nations are many; a few of the most significant are decreased standard of living, shorter life expectancy, dependency upon other nations, and an inability to defend ourselves.

INNOVATION AND CREATIVITY IN THE GLOBAL MARKETPLACE

Several nations are challenging the ability of the United States to compete in the global marketplace. Increasing amounts of work are being outsourced. In *Tough Choices or Tough Times*, the New Commission on Skills in the American Workforce (2007) reports that several factors contribute to this trend. It has become increasingly efficient and cost-effective to automate certain functions. And as more and more information is digitized, employers can efficiently share files internationally. Employers who cannot find resources locally can look outside of their firms to perform all the tasks involved in getting a product to the market. Highly educated people in China and India, for example, are willing to work for lower wages than their counterparts in the United States. In the current economic climate, an increasing amount of work is going abroad.

According to the Commission, the countries that produce the most important new products and services will dominate the global market, enabling employers to pay top salaries, and as a result, provide for and maintain a high standard of living. Economic leadership is dependent on a highly educated and creative workforce, extending from top management, right down to the assembly line. The Commission summarizes the situation:

A world in which routine work is largely done by machines is a world in which mathematical reasoning will be no less important than math facts, in which line workers who cannot contribute to the design of the products they are fabricating may be as obsolete as the last model of that product. *(New Commission on Skills in the American Workforce, 2007)*

One proven method for maintaining economic vitality is to lead the world in technological innovations and creative problem solving. Research and innovation by highly-trained engineers and scientists not only leads to the creation of new products and solves problems, it produces a significant amount of work for the whole population as well.

. . . a primary driver of the future economy and concomitant creation of jobs will be innovation, largely derived from advances in science and engineering. While only four percent of the nation's work force is composed of scientists and engineers, this group disproportionately creates jobs for the other 96 percent. *(Rising Above the Gathering Storm Committee, 2010)*

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The United States thrives on creativity and ingenuity. Many nations have sent their best and brightest students to the United States to learn to apply their knowledge and skills in an environment that encourages thinking out of the box. People who understand engineering are at the forefront of innovation and problem-solving. They combine iterative, open-ended, problem-solving methods with a depth of knowledge in science and mathematics that enables them to respond to the needs of individuals and society.

Engineers and technicians are in great demand now, and the need will only increase throughout the coming decades. To meet this need, educators will

Sources: AGE Fotostock, SuperStock, Getty Images be called upon to include engineering content throughout the 6–12 years. The term “STEM education” has been in use for over a decade, yet not enough has been done to acknowledge or address the “E” for *engineering*. As we continue into the second decade of the 21st century, three important stakeholders — industry, government, and engineering educators—aim to redress this omission. Their concerns will affect 6–12 education for years to come.

Stakeholders will demand that 6–12 educators begin the process of inspiring, engaging, and educating students to become engineers. Educators and administrators must understand these concerns so they can successfully respond to the demands that will be placed upon schools as the United States struggles to maintain its economic strength and innovative leadership in an increasingly globalized world.

- **Industry:** The demand for qualified and innovative workers grows while the number of students from the United States completing an undergraduate engineering degree decreases.

- **Government:** Maintaining economic vitality and global leadership depends on educating individuals to their greatest potential. The promotion of engineering education in grades 6–12 would increase student knowledge and experience and provide more opportunity for students to enroll in post-secondary engineering paths.

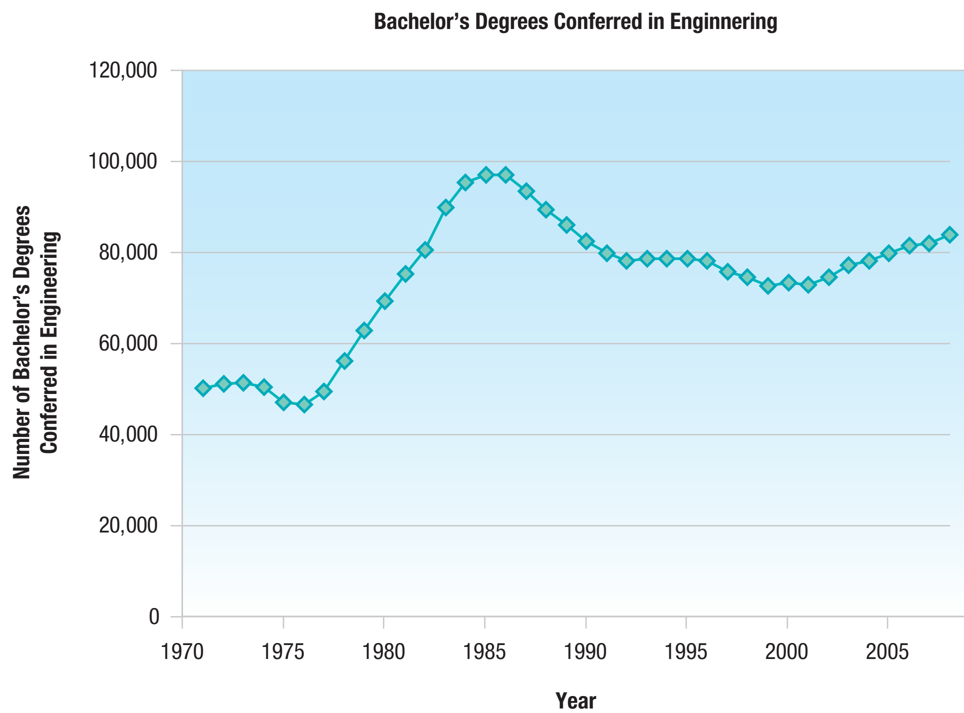
- **Educators:** To maintain and increase the number of engineering graduates, undergraduate enrollment in engineering must be encouraged at the earliest levels, underrepresented populations must be inspired to seek engineering degrees, and provisions must be made for student success and retention.

Source: McGraw-Hill Essentials Pre-Engineering, 2012

INDUSTRY CONCERNS: WORKFORCE DEPTH AND STRENGTH

The United States has long demonstrated global leadership in the application of scientific and mathematical knowledge to the design and development of innovative technologies and to solving challenging problems. Engineers have participated in every step of the way, from designing and building the first settlements to exploring the Solar System and the structure of the atom. Today’s engineering students will participate in the exponential growth of knowledge and applications in medicine, and energy, resource, and environmental management, just to mention a few fields.

Industry Goals
- Increase number of qualified candidates
- Improve ability to compete globally
- Correct perceptions of the role of an engineer
- Create a robust K-16 pipeline



Source: *Digest of Educational Statistics*

Figure 2-1: Bachelor's Degrees Conferred in Engineering

However, in spite of the excitement and enthusiasm surrounding 21st-century innovation, few students enter college or post-secondary schools with the intention of becoming engineers. In the fall of 2010, only 9.7% of freshmen declared engineering as their major (Higher Education Research Institute, 2011). Although more students are currently taking a B.S. in engineering than in the 1990s, that number has not recovered to the heights of the mid-1980s. The number of bachelor's degrees granted in engineering in 2000-2001 dropped below the number for the 1980–1981 academic year, but has been climbing slowly since (see Figure 2-1).

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More Jobs than Candidates

Engineering job growth is projected to increase in the 21st century. Within the next decade, the rate of growth varies by specialty from a slight decline, 22% for chemical engineers, to a whopping 72% increase in biomedical engineering (see Part I).

In the past, American firms generally turned first to U.S. citizens to fill jobs, hiring foreign staff only if local talent were not available. In past decades, the United States hired much of the developing world's talent, creating a "brain drain" for other countries. Today, instead of remaining in the United States, however, many of those experts are returning to their homelands to start businesses which may compete with their past employers, or to work for global U.S. firms in their countries of birth.

Source: PictureQuest

Figure 2-2: Students like these can now attend schools like Pathways in Technology Early College High School, in Brooklyn, NY. P-Tech was created through a collaboration of The NYC Department of Education, the New York City College of Technology, and the IBM Corporation.

Ability to Compete Globally

Recognizing the need for a skilled and knowledgeable workforce to compete globally, some industries have begun to partner with the government and educators at various levels. These partnerships address several needs and provide funding or resources to help reach their primary goals, which include improving public understanding of the engaging work that is engineering, increasing engineering education resources and training for teachers, and reinforcing the need for a comprehensive 6-16 engineering education pipeline.

In 2009, President Obama launched Educate to Innovate, a national initiative to create public-private partnerships committed to improving STEM education, drive awareness of STEM education, and inspire and educate students for STEM-related careers. As engineering is one of the targeted STEM disciplines, the government encourages 6–12 educators to adopt the goals proposed by Educate to Innovate. These goals include:

- increasing STEM literacy so that all students can learn deeply and think critically in science, math, engineering, and technology;
- moving American students from the middle of the pack to the top in the next decade;
- expanding STEM education and career opportunities for underrepresented groups, including females and minorities.

Local Initiatives

Leadership at the national level reinforces local efforts, too. National efforts with overarching goals lend credence to specific programs with targeted outcomes at regional and local levels. Individual corporations have recognized the importance of helping educators and students to explore the engineering profession. Some have created educational foundations to provide educators with professional development and standards-based instructional materials that provide for teaching engineering in developmentally appropriate contexts. Many companies encourage their engineers to volunteer in local classrooms as a way of supporting students and teachers who take on engineering design challenges. For example, the Society of Automotive Engineers gives teachers kit-based curricula that address a variety of engineering challenges unique to the transportation industry. The ACE Mentoring program matches experienced engineer mentors with aspiring young students to complete projects and activities.

Engineering is an ideal discipline for project-based instruction.

Engineering has gained a strong foothold in some communities through informal education including camps, afterschool programs, and competitions. Outreach programs such as FIRST Robotics and SuperMileage provide opportunities that make learning about engineering relevant to students (Brophy, Klein, Portsmore, & Rogers, 2008). Industry and other stakeholders view the success of competitions such as For Inspiration and Recognition of Science and Technology and Odyssey of the Mind as a signal that students of all ages enthusiastically engage in the engineering design process. Proponents argue for the establishment of a national 6–12 curriculum for engineering education, explaining that young children and middle and high school students find appropriately crafted engineering challenges inherently interesting and motivating. Engineering is an ideal discipline for project-based instruction. (See Part III for more about teaching engineering.)

Students in districts that institute a 6–12 engineering program will benefit from its interdisciplinary nature. In most school districts, each discipline is taught in relative isolation, and teachers often encounter the question, “Why do I need to know this?” Engineering helps teachers provide the answer, for its practice involves the interweaving and application of knowledge and skills from multiple disciplines.

Call to Action for a Comprehensive 6–12 Pipeline

Guiding students through various phases of the engineering design process encourages the application of science, art, technology, mathematics, and communication skills.

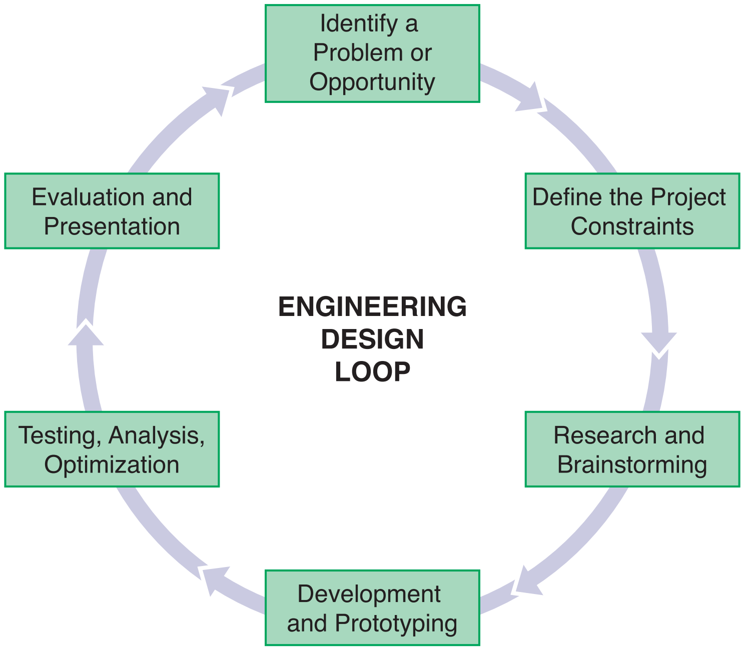


Figure 2-3: Key to meeting the industry goal of creating a robust K-16 engineering pipeline is an understanding of the engineering design process among both teachers and students. Engineering design is an interactive, cyclical process, not a discrete step-by-step process with a set beginning and end.

In order to successfully channel students into an engineering career, a 6-12 engineering education program must include

- A developmentally appropriate and pedagogically sound scope and sequence from grade 6 through grade 12 that authentically represents the discipline.
- Professional development for educators.
- Materials that support teachers in the classroom.
- Recommendations for scheduling courses in an already crowded day.
- Ways to ensure that credits earned in high-school engineering courses apply toward college acceptance.

Industry Recommendations

An extensive review of the literature on engineering education in the grade schools through undergraduate schools suggests that to fulfill industry workforce needs and remain globally competitive, the United States should

- Formalize engineering education in grades 6–12.
- Improve teacher training, both pre-service and professional development, for educators specializing in engineering.
- Increase the rigor of science and mathematics to meet college expectations.
- Improve teacher understanding of the profession so they may encourage and support student exploration of engineering as a career choice.

Government Goals

- Maintaining local and national economic growth and strength
- Improving the nation's ability to adapt and innovate

Not since the launch of Sputnik in 1957 has the U.S. government invested so much in trying to improve STEM education.

GOVERNMENT CONCERNS: BOOSTING ECONOMIC GROWTH AND INNOVATION

> *It is clear that, given the dynamics of today's economy, this nation can ill-afford to wait to innovate. States can and should lead the way by strengthening the innovative processes within their boundaries and staying ahead of the global competition unleashed by the computing and communications revolution.*
>
> *States know they must raise educational systems so they meet international benchmarks and provide children with the 21st-century skills that students need to succeed in the knowledge economy. They must also create entrepreneurial economies that can compete in the new innovation-based global marketplace. (Fitzpatrick, 2007)*

Maintaining Economic Growth and Innovation

Not since the Soviet Union launched *Sputnik* in 1957 has the U.S. government invested as much time and energy identifying and addressing ways to improve STEM education. Indicators of the need to improve mathematics and science education include national and international assessments of student academic performance such as NAEP, TIMMS, and PISA. These and other reports have resulted in a flurry of efforts that attempt to understand, describe, and pose solutions to a national decline in academic success. Notable reports include Pathways to Prosperity (2011), the recently updated *Rising above the Gathering Storm (2007, 2008, 2010)*, *Tough Choices or Tough Times (2007)*, and *Engineering in K-12 Education: Understanding the Status and Improving the Prospects (2009)*.

Elected officials have initiated a number of national and local efforts to address workforce need and create the necessary 6–12 education resources. At the national level, the America COMPETES Act was signed into law in 2007 and reauthorized in 2010. The goal of the act is "to invest in innovation through research and development, and to improve the competitiveness of the United States."

At the state level, the National Governors Association responded to economic and educational challenges by creating a taskforce known as *Innovation America*. In 2006–2007 the taskforce produced a series of reports and a toolkit for governors (Figure 2-4). The resources provide recommendations to "support states in reaching the goal of graduating every student from high school with the essential STEM knowledge and

KEY MESSAGE 1	KEY MESSAGE 2	KEY MESSAGE 3
STEM education prepares *all students* for the challenges and opportunities in the 21st century economy.	**STEM education improves the impact and overall effectiveness of the state's K–16 *education system.***	**A STEM-literate workforce adds value, productivity, and innovations to the *state's economy.***

Source: National Governors Association, 2008

Figure 2-4

competencies to succeed in postsecondary education and work" (NGA Center for Best Practices, 2008). The toolkit provides governors with the resources to communicate the importance of STEM education to and build alliances with three key audiences: teachers and school administrators, the business community, and higher education administrators and faculty.

Government Recommendations

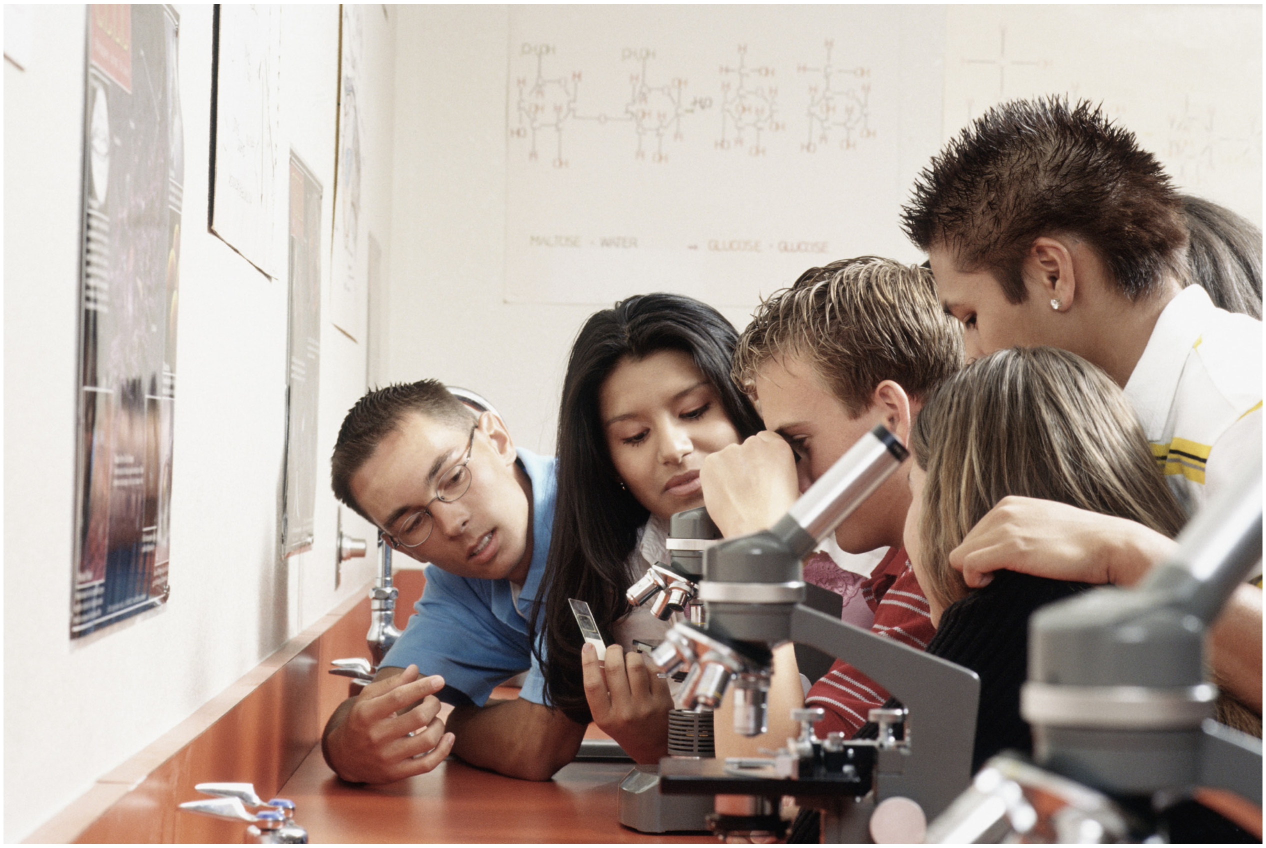
To foster public understanding of the importance of engineering education to economic vitality, the following recommendations have been suggested:

- Provide business and educators with government support and direction for incorporating engineering education into the 6–12 system.
- Promote a public discussion about the importance and benefits of STEM education to all students.
- Engage regional and local business and education leaders in the effort to improve 6–12 STEM education, and specifically engineering education.
- Adopt state engineering education standards and standards-based engineering curricula.

Educator Goals
- Increase enrollment
- Improve academic ability of entering freshmen
- Increase diversity among engineering students

EDUCATOR CONCERNS: STUDENT PREPARATION AND RETENTION

> *The number of engineering bachelor's degrees awarded in the United States has increased gradually over the past seven years to slightly more than 74,000 in the 2005–2006 school year. This is a jump of about 20 percent since 1999. In China, by contrast, the number of students graduating with four-year degrees in engineering, computer science, and information technology more than doubled between 2000 and 2004. A similar doubling occurred in India. (Katehi, Pearson, & Feder, 2009)*



Source: Corbis

Although community colleges and universities in the United States graduate many engineers, engineering technologists, and technicians, the number may not be enough to compete with the growing number of engineers graduated by other nations.

Educators of grades 6–12 face two challenges in helping the universities supply the demand for labor: inspiring all capable students to pursue a career in engineering and academically preparing them to enroll in and complete a rigorous engineering program.

Early Encouragement of All Students

On most university and college campuses, women and students of color make up slightly more than 50% of the student population. Yet, few of these students elect to major in engineering. As we enter the 21st century, the perception of engineering as the domain of white males remains intact, drastically reducing the pool of talent from which the profession draws.

In the future, 6–12 teachers will be tasked with the responsibility for inspiring all students capable of rigorous academics to consider engineering as a profession. This will require teachers to develop a strong understanding of the skills and knowledge of the profession. In addition, 6–12 educators will be expected to communicate the creativity and teamwork that engineers enjoy, the importance of the engineering to society, and the comparatively high salaries available upon completing an Associate or Bachelor of Science degree.

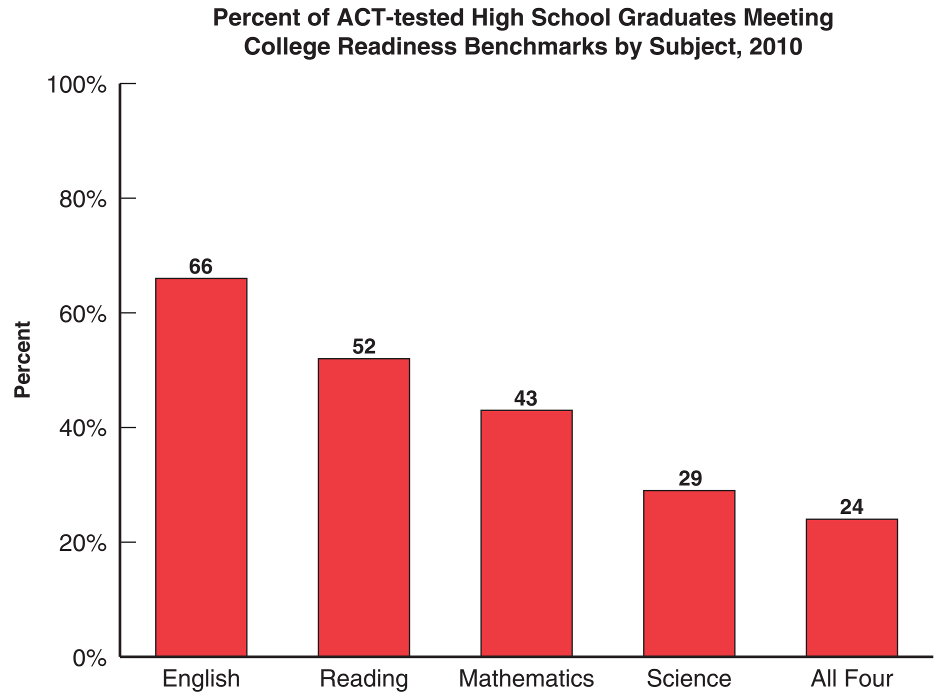
Educators and publishers at the 6–12 level are developing ways to encourage female students to enroll in middle school and high school engineering classes. One way is to provide gender segregated classes in engineering and physics. Educators have also found that female students respond to the collaborative nature of engineering. Students perform better when they can work in groups, and especially with other female students, to talk through solutions and designs. They also respond to the real-world, cross-disciplinary aspects of engineering and to choosing projects, for they can focus on their interests, such as art, social services or medicine. Some female students benefit from a hands-on component to help them grasp the abstractions related to engineering. Pairing female students with professional female engineers who mentor them, taking field trips to engineering sites, and inviting female engineers to lecture are other strategies that boost interest in engineering for female students. These students also develop an interest when personally invited to enroll in a class or participate in a group.

Minorities also need to be engaged and encouraged through personal interaction with their teacher. An invitation to enroll in the class can provide them the encouragement they need. They, too, need to see the relevance of engineering and apply it to their own lives. Identifying role models helps them see the value in engineering and bolsters self-confidence that they, too, can become engineers. Some students are also inspired by the earning potential of engineers. A wide variety of projects helps capture the interest of these students.

The Need for Rigorous Academic Preparation

> *Even those students who do graduate from high school often find a chasm between the requirements for a high school diploma and what is needed to succeed in college—one result of which is that 77 percent of college freshman are unable to pass a college preparatory examination in at least one of three core subjects, and about one third have to take remedial work in college. (Rising Above the Gathering Storm Committee, 2010)*

Many post-secondary and college freshmen struggle to succeed (Figure 2-5). Of those students who elect to major in engineering or technical courses, many more struggle to meet the academic rigor associated with the program. Engineering requires a depth of knowledge and ability in both mathematics and science. Rigorous study of mathematics, primarily calculus, is standard for all accredited undergraduate programs. Engineers use math throughout their careers to model or simulate products or systems during the design process.



Source: ACT, 2010

Figure 2-5

In addition, students who elect to further refine their expertise in a particular field of engineering (*e.g*., biomedical, chemical, nuclear) must also commit to in-depth study of the related science. It is not unheard of for undergraduates to double major in engineering and the science of their interest.

Across the board, post-secondary institutions have seen a rise in the need for remedial mathematics education in freshman year. The increase in these remedial classes poses challenges for both the institution and the student. Students bear the additional burden of time and expense related to earning their undergraduate degrees.

The Need for a Strong Preparation in Mathematics

> *The highest level of mathematics studied in secondary school is strongly correlated with bachelor's degree completion in any field. (Adelman, 1998)*

The undergraduate and career choices students make upon leaving high school are heavily influenced by a variety of factors including academic experience and performance. Research demonstrates that mathematical preparation plays a significant role in the future success of students in all STEM fields and especially engineering.

The high school academic background of students who complete an undergraduate degree in engineering differs markedly from their peers.

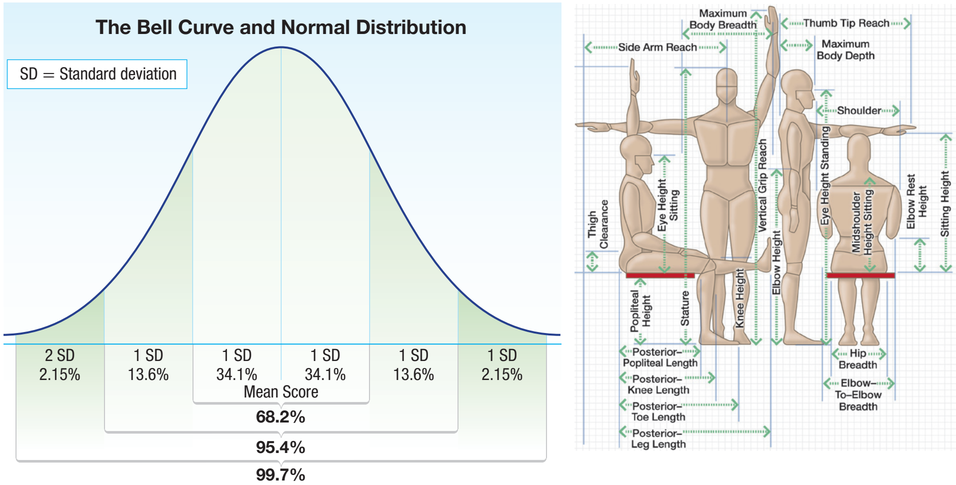


Figure 2-6: Students must have a strong understanding of math and statistics in order succeed in engineering.

Most completed and excelled in challenging pre-calculus or calculus courses in high school. Students who enter the field having completed Algebra 2 often earn bachelor's or associate's degrees in engineering technology.

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A rigorous and challenging high school mathematics program must also include application to the other STEM disciplines. Application of mathematics in science, technology, and engineering courses enhances and extends the value of these disciplines and the depth of the learning experience.

Educator Recommendations

To prepare students for post-secondary education in an increasingly technological society, the following recommendations have been advanced:

- Implement 6–12 engineering instruction equally with mathematics, science, and technology education.
- Increase the rigor of 6–12 mathematics and science required for high school graduation.
- Improve public understanding of the nature, value, and creativity of the engineering profession.
- Encourage diversity in engineering programs by engaging students at younger ages and through appropriate experiences.
- Address the math and science deficiencies of disadvantaged students.

Benefits of 6-12 Engineering Education

- *Improved learning and achievement in science and mathematics*
- *Increased awareness of engineering and the work of engineers*
- *Understanding of and the ability to engage in engineering design*
- *Interest in pursuing engineering as a career*
- *Increased technological literacy.* (quoted from Katehi, Pearson, and Feder, 2009)

MEETING THE CHALLENGE IN 6-12 EDUCATION

To help address the concerns of industry, government, and universities, 6–12 educators familiar with the challenge of creating an engineering

As a nation, we will greatly benefit from a population that understands the role of engineering in society.

program for their district need the following:

- Pre-service and in-service training on engineering concepts and habits of mind unique to engineering.
- Access to a comprehensive engineering education curriculum, including teacher-support materials, and associated professional development required to implement it in a classroom.
- Funding and other forms of support to promote engineering education.

Innovate or Fail: The Benefits of 6–12 Engineering Education

The three stakeholders, industry, government, and educators, have clearly defined their goals and needs for engineering education in the 21st century. To meet these expectations, stakeholders will demand participation and support from the 6–12 education community. Many states and districts have already begun to respond to these demands. They have created standards for engineering education, assigned teaching of engineering to specific departments, identified professional development opportunities, selected standards-based curricula, and sorted out scheduling challenges. Educational publishers like McGraw-Hill are rising to the challenge with the creation of new curricula and professional development materials that address stakeholder needs.

Early adopters of a core 6–12 engineering strand will quickly recognize and reap the benefits. These benefits are numerous and long-lasting.

- Students will benefit from improved learning and teaching of science and mathematics and will be prepared for any field of study at the college level and for many post-secondary careers.
- Students will develop engineering habits of mind, suitable for problem solving in multiple environments.
- Schools and districts will see increased academic proficiency in science and mathematics as a result of studying engineering.
- Communities with increased intellectual capacity will improve their ability to attract businesses and remain vital.

As a nation, we will greatly benefit from a population that understands the role of engineering in society. Nationally, a well-trained and knowledgeable workforce will provide us with the ability to remain economically and innovatively strong on a playing field that has global dimensions.

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