McGraw-Hill Education

Engineering Literature Review

Part I — Engineering for the 21st Century

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By nature, humans are engineers. We use knowledge, experience, and skills to solve challenges creatively to meet our needs or wants. Engineering is a practical science; engineers apply scientific principles to solve our everyday problems as well as complex global concerns.

The terms *engineer* and *engineering* often evoke images of mathematical formulas, flickering computer screens, and rooms full of machine parts and shop tools. These terms may be daunting if you are charged with teaching fundamental engineering concepts and skills in grades 6–12 and have no formal training or experience in the discipline. Alternatively, you may eagerly anticipate the opportunity to engage your students in hands-on activities that encourage them to creatively and analytically apply a range of knowledge and skills to solve design challenges.

Regardless of your response, the conversation about how to embed engineering education in grades 6–12 has taken root. The question is not "if" but "when" schools, districts, states, and the nation will adopt standards and assessments to demonstrate proficiency in the unique knowledge and skills required of engineers.

Sources: Ingram Publishing; Almay Images; Getty Images

WHAT IS ENGINEERING?

At its most basic, engineering can be defined as "the process of refining the human-made world." Unlike scientists, who seek to understand the natural world, and mathematicians, who try to understand patterns and relationships, the basic role of the engineer is to "modify the world to satisfy people's needs and wants." (Katehi, Pearson, & Feder, 2009)

Engineering applies the principles of science and mathematics to

- solve problems.
- design, develop, or improve tools and systems.
- respond to a variety of human needs.

While scientists engage in scientific inquiry to expand our body of knowledge, engineers employ a variation of a systematic, but creative, *design process* to study a particular problem and devise ways to solve it.

Engineers engage in scientific inquiry to solve problems.

> *Engineering design involves the following essential components: identifying the problem; specifying requirements of the solution; sketching and visualizing the solution; modeling and analyzing the solution; evaluating alternative solutions, as necessary; and optimizing the final decision.*
> *(Katehi, Pearson, & Feder, 2009)*

Scientists seek to explain the effects of individual variables whereas engineers manipulate multiple variables to optimize results. Consequently, engineering is a discipline in its own right and as such represents an independent body of knowledge and set of skills.

Scientific Inquiry	Engineering Design Process
• A process of investigation • Focused on concepts, laws, and theories • Demands evidence • Tries to identify and avoid bias • Explains and predicts • A blend of logic, factual knowledge, and creativity • Not authoritarian	• A process of creation • Focused on finding solutions to particular problems • Purposeful • Proceeds with desired outcome in mind • Limited by constraints • Requires a blend of logic, factual knowledge, and creativity • Systematic • Iterative • Allows for many possible solutions

Sources: Katehi, Pearson, and Feder, 2009; AAAS, 1989; ITEA, 2000

Figure 1-1: Science vs. Engineering

Sources: Getty Images; Punchstock

Figure 1-2: Engineers use science, technology, and mathematics to solve problems.

WHAT DO ENGINEERS DO?

Many of the oldest applications of engineering revolve around meeting basic human needs. Examples include constructing the system of aqueducts to supply water to citizens of Rome, terracing land to improve food production, designing weapons for protection, and building roads and the means of transportation to encourage commerce.

The profession of engineering arose through civil and military channels and became formalized in Western civilization during the Renaissance. The growth and specialization of engineering is intimately tied to advances in science, mathematics, and technology—each one driving advances in the others. For example, in 1610, Galileo Galilei turned a new tool, the telescope, on Jupiter and saw moons revolving around the planet. His discovery shook the foundations of scientific and religious belief. The telescope, developed by eyeglass makers in the Netherlands in 1608, ushered in one of the greatest revolutions in our understanding of the universe and our position within it. In the summer of 2011, NASA will launch *Juno*, a mission to Jupiter that seeks answers to questions about the birth of our solar system. Like Renaissance eyeglass makers, modern engineers will contribute equipment designed to expand our view of the universe.

While many engineers work with scientists to further our understanding of the world around us, others work in industrial settings designing or improving equipment and systems that support modern society, creating innovative equipment to entertain and inform, or seeking solutions that balance human needs with the need to preserve the natural world. Engineers help conceive, design, produce, manage, and analyze every type of human-produced object and system as well as the interface between the designed and natural environment (Figure 1-3). They work in a variety of environments from the field to the laboratory to complex industrial plants. Engineering has become specialized along the lines of scientific disciplines. For example, biomedical engineers develop strong knowledge of

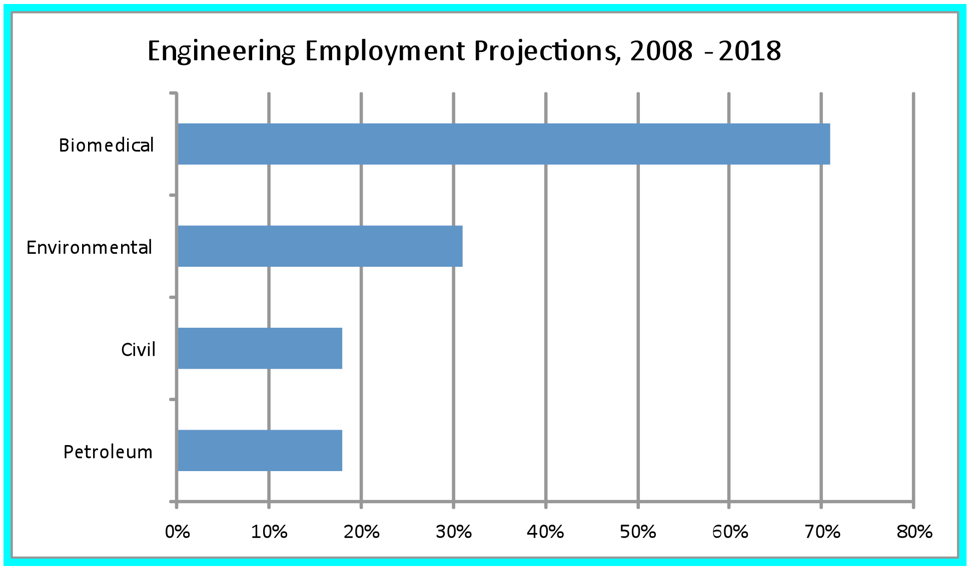
Engineering Specializations	
Aerospace Engineering	the application of physics to air and space travel, ranging from conception to operation of all technologies involved
Agricultural Engineering	the application of biological and engineering principles to the design of agricultural equipment or processes to improve food production and processing as well as manage resources
Biomedical Engineering	the application of biology and biochemistry in a new and growing field to address health and medically-related problems
Chemical Engineering	the application of molecular information to design or improve the production or use of chemicals in a variety of industries
Civil Engineering	the application of fundamental science, math, and engineering knowledge to the design, construction, and maintenance of public works such as bridges, roads, buildings, and dams
Computer Hardware Engineering	related to electrical engineering, the application of knowledge to resolve challenges associated with the design, production, and management of computer components and/or systems
Electrical Engineering	the application of the study of electricity and physical science to the generation and supply of power
Electronics Engineering (except computer)	the application of the knowledge of electricity to the design and management of systems of control, communications, and signal processing
Environmental Engineering	the application of biology and chemistry to solve environmental problems and concerns at local, regional, and global levels
Health and Safety Engineering (except mining safety engineers/inspectors)	the application of knowledge about mechanical, chemical, and human performance systems to prevent harm to humans and the environment
Industrial Engineering	the application of problem solving and analysis to increase productivity through efficient management of resources and technology
Marine Engineering and Naval Architecture	the application of a wide variety of sciences, including physics and electronics, to the design, construction, and maintenance of marine vessels
Materials Science and Engineering	the application of the knowledge of organic and inorganic matter to the analysis, design, or processing of materials
Mechanical Engineering	the broad application of physical science to the design, development, and operation or management of mechanical devices or systems
Mining and Geologic Engineering	the application of geology, physics, and technical knowledge to identify and extract mineral resources while providing for safe operations of the extraction process
Nuclear Science and Engineering	the application of the knowledge of nuclear reactions and radiation to fields such as energy production and medicine
Petroleum Engineering	the application of geology, physics, and technical knowledge to the extraction of petroleum resources within Earth

Source: Bureau of Labor Statistics

Figure 1-3: Engineers apply knowledge of mathematics, fundamental engineering concepts, and scientific principles to develop solutions to technical challenges.

biochemistry and molecular biology as well as engineering. Environmental engineers apply environmental science to solve problems. Engineers apply scientific knowledge to provide practical solutions to complex problems.

TRENDS IN ENGINEERING CAREERS



Source: Bureau of Labor Statistics

Figure 1-4: Projected Changes in Engineering Employment, 2008–2018

Engineering is a growing profession, with growth varying by specialty. From 2008 to 2018, the Bureau of Labor Statistics expects overall engineering employment to grow by 11%. However, certain specializations are expected to grow much faster, and include biomedical engineering (72%), environmental engineering (31%), civil engineering (24%), petroleum engineering (18%), mining and geological engineering (15%), and industrial engineering (14%) (Figure 1-4).

GRAND CHALLENGES OF THE 21ST CENTURY

Students trained as engineers in the 21st century will be tasked with advancing civilization in many exciting ways. If successful, their contributions will provide cheaper energy, improve health care and education, and decrease human impact on the natural environment. The National Academy of Engineering (NAE) has identified fourteen grand challenges society will face in the coming decades. To address these challenges we need more highly trained engineers. The ability to overcome these challenges will "make the world not only a more technologically advanced and connected place, but also a more sustainable, safe, healthy, and joyous—in other words, better—place" (NAE, 2008).

The NAE summarizes the challenges as follows:

- Make solar energy economical
- Provide energy from fusion
- Capture carbon dioxide from burning fossil fuels
- Manage the nitrogen cycle
- Provide access to clean water
- Restore and improve urban infrastructure
- Advance health informatics, the science of information and information processing
- Develop new medicines
- Reverse-engineer the brain to determine how it operates
- Counter the violence of terrorists and natural disasters
- Secure cyberspace
- Enhance virtual reality
- Improve methods of instruction and learning
- Engineer the tools of scientific discovery
  (NAE, 2008)

Given the challenges we face, it is paramount that educators, administrators, and policymakers actively encourage and recruit students to pursue careers in engineering and prepare them for advanced studies in engineering.

Sources: Getty Images; Getty Images; Ingram Publishing

BECOMING AN ENGINEER

To become an engineer, a student must complete an accredited undergraduate program in engineering. Undergraduate engineering programs emphasize the rigorous study of mathematics, expertise in a field of science, and fundamental engineering concepts and practices. Many programs include opportunities for undergraduates to intern with research institutes and/or corporations where they apply their education to real-world challenges.

Most state and many private universities have a college of engineering, and employers select applicants who have graduated from schools accredited by the Accreditation Board for Engineering and Technology (ABET). Completion of a four-year program earns the candidate a Bachelor of Science degree from the college of engineering, with a specialization in a specific field of engineering if applicable.

Much of the work done in engineering is supported by engineering technicians and engineering technologists. Both technicians and technologists focus on the application rather than the theoretical aspects of engineering. Whereas engineers conceptualize, design, and plan, engineering technologists and technicians apply engineering principles to carry out plans. Technology degrees differ from engineering degrees in that they focus more on application of principles rather than concepts and theory. They also require less math and science than engineering degrees.

Much of the work done in engineering is supported by engineering technicians and technologists.

Engineering technicians and engineering technologists perform similar functions but differ in required education. An engineering technologist must a have a four-year B.S. in Engineering Technology in order to be certified. An engineering technician can work having completed a two-year A.A. degree and, in some cases, without any post-secondary degree. Engineering careers do not require advanced degrees, although many engineers engage in professional development to advance within their field or organization. Common paths include the pursuit of master's or doctoral degrees, professional certifications, or a master's degree in business administration.

Engineers who complete programs and find work are also rewarded with a good starting salary. A degree in engineering opens doors to a vast array of professional opportunities, most of which are very well-paid, with starting salaries ranging from $50,000 to more than $80,000, according to a July 2009 survey by the National Association of Colleges and Employers (Figure 1-5). Not only do they engage in useful, important, and interesting work, engineers can support themselves in a comfortable fashion. Knowledge of starting salaries alone may motivate more high school students to consider and pursue a degree in engineering.

Average Starting Salaries of Engineers with a 4-year Undergraduate Degree

Petroleum	$83,121
Chemical	64,902
Mining and Mineral	64,404
Computer	61,738
Nuclear	61,610
Electrical/electronics and communications	60,125
Mechanical	58,766
Industrial/manufacturing	58,358
Materials	57,349
Aerospace/aeronautical/astronautical	56,311
Agricultural	54,352
Bioengineering and biomedical	54,158
Civil	52,048

Source: Bureau of Labor Statistics

Figure 1-5

ENGINEERING EDUCATION FOR THE 21ST CENTURY

Awareness of the need for a clear and consistent strand of 6–12 engineering education grows daily as part of the overall effort to improve STEM (science, technology, engineering, and mathematics) education in the United States. The increased attention to providing quality STEM education comes from the recognition that leadership in scientific and technological innovation is key to the nation's economic vitality. Engineering education is of particular interest as it not only widens the pipeline of future engineers, but also provides important opportunities to interest and engage students in creative applications of fundamental knowledge and skills, improving comprehension and retention of science and mathematics: (See Section III Teaching Engineering in Secondary Schools for a detailed description of the new McGraw-Hill Pre-Engineering program.)

Twenty-first century 6–12 engineering courses endeavor to

- engage students in the processes and products of engineering.
- prepare students to tackle the grand challenges of engineering.
- prepare students academically for the rigors of university-level engineering curricula.
- ensure that all students, not only future engineers, but also future lawmakers and voters, understand and appreciate the vital role that engineers play in their personal lives and the future of the country as a whole.

Existing curricula engage students in developmentally appropriate engineering problem-solving. Students have designed, built, and tested such things as insulated clothing for survival in alpine environments, gliding toys for young children, external heat-resistant materials for the next generation of spacecraft, models of improved urban environments, gravity wheels, electromagnets, simple bridges and structures, and many more exciting devices. Courses will continue to provide students the opportunity to apply science and math and employ the engineering design process to respond to a variety of carefully crafted design challenges.

Source: McGraw-Hill Companies

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