CHAPTER 1

What Is Engineering?

Objectives

In this chapter, you will learn about:

- The numerous fields of engineering
- Engineering as a career
- The relationship between engineers and other professionals
- Engineering professional organizations
- The foundations of engineering design: knowledge, experience, and intuition

If you're reading this book, you are probably enrolled in an introductory course in engineering. You may have chosen engineering because of your strong skills in science and mathematics. Perhaps you like to take things apart or play in cyberspace. You may have an interest in engineering as a way to help people. Maybe you simply followed the advice of your high school guidance counselor. Whatever your reason for studying engineering, you are entering a career filled with discovery, creativity, and excitement. Imagine yourself several years from now, after you've finished your college studies. What will life be like as an engineer? How will your college classes relate to your work and career? This book will help provide you with a vision of the future while teaching you some important engineering skills.

As an aspiring engineer, you have much to learn. You must master the basic foundations of engineering: math, physics, chemistry, and biology. You must study the specialized subjects of your chosen discipline—for example, circuits, mechanics, structures, materials, or computation. You must also learn how to stay on top of technological advances by embracing a program of lifelong learning. This latter need is crucial because the world embraces new technologies on a daily basis. The wise engineer keeps abreast of them all. Your college courses will provide you with the knowledge and mathematical skills that you will need to function in the engineering world. But you must also learn about the important practice of design. The ability to build real things is the hallmark of the engineer. Design sets engineers apart from professionals in the basic sciences. While physicists, chemists, or biologists draw general conclusions by observing specific phenomena, engineers move from the *general* to the *specific*. Engineers harness the laws of nature and utilize them to produce devices, systems, and structures that perform tasks, meet human needs, or solve problems. The design process defines the essence of the engineering profession, and you must become proficient at it on your path to success. This book will introduce you to the basic principles of design and will help you to apply them to your class assignments, design projects, and future job responsibilities.

Table 1-1 Some Traditional Engineering Disciplines

Aeronautical	Computer	Mechanical
Agricultural	Electrical	Naval
Architectural	Environmental	Nuclear
Biomedical	Food	Ocean
Chemical	Industrial	Petroleum
Civil	Materials	Systems

1.1 ENGINEERING HAS MANY FIELDS

The fields of engineering are numerous. A perusal of the websites of engineering colleges around the world, for example, will reveal an almost endless variety of engineering programs of study. Although the names may vary from school to school, most engineers are trained in one of the traditional engineering disciplines listed in Table 1-1. (These disciplines are listed alphabetically with no preference implied.)

The National Academy of Engineering (NAE), in celebration of the accomplishments of engineers during the 20th century, publicized the following statement at the turn of the millennium:

> "The impact of engineers on society has been immense. One hundred years ago, life was a constant struggle against disease, pollution, deforestation, treacherous working conditions, and enormous cultural divides unbreachable with current communications technologies. By the end of the 20th century, the world had become a healthier, safer, and more productive place, primarily because of engineering achievements."[1]

The NAE noted, for example, that the increase in human life expectancy, from about 45 years in 1900 to over 75 years in many countries as of 2010, could be attributed more to engineering accomplishments than to all the advances in medical knowledge combined.

As part of its recognition of engineers, the NAE released a list, replicated here as Table 1-2, of the top 20 engineering accomplishments of the past century. The primary discipline represented by the accomplishment has been added in parentheses.[2]

This list is notable because of the large number of engineering disciplines represented. What is also evident is the cross-disciplinary nature of almost all the citations on the list. Engineers from many fields were needed in order to make each of these milestone accomplishments possible. In fact, each field of engineering embraced by this list has its own important role in the technological progress of the world. It has been, and will continue to be, the job of colleges and universities to train today's students to become tomorrow's engineers.

From reading Tables 1-1 and 1-2, one might conclude that engineers are highly specialized professionals who have little interaction with people from other fields.

---

[1] National Academy of Engineering press release, February 22, 2000.

[2] *National Engineers Week* statement by former astronaut Neil Armstrong, February 2000.

Table 1-2 List of the Top 20 Engineering Accomplishments of the 20th Century (Published by the National Academy of Engineering in 2000)

1. Electrification (Electrical)
2. Automobiles (Mechanical)
3. Airplanes (Aerospace)
4. Water Supply and Distribution (Civil)
5. Electronics (Electrical)
6. Radio and Television (Electrical)
7. Agricultural Mechanization (Mechanical)
8. Computers (Computer)
9. Telephones (Systems)
10. Air Conditioning and Refrigeration (Mechanical)
11. Highways (Civil)
12. Spacecraft (Aerospace)
13. Internet (Computer)
14. Imaging (Electrical)
15. Household Appliances (EE and ME)
16. Health Technologies (Biomedical)
17. Petroleum and Petrochemical Technologies (Petroleum)
18. Laser and Fiber Optics (Electrical)
19. Nuclear Technologies (Nuclear)
20. High-performance Materials (Materials)

In reality, the opposite is true. The best engineers are multidisciplinary individuals who are familiar with many different fields and specialties. The key to successful engineering is a broad multidisciplinary education. Gone are the days where engineers can be content to rest in narrow cubbyholes of training. Many of the great engineering accomplishments of the past century were made possible by interactive teams of engineers from a multitude of disciplines. Although engineers are multidisciplinary by nature, most are indeed trained at the college level in a specific degree program and spend much time utilizing their specialized training. For this reason, we'll begin our study of engineering and design by reviewing the characteristic features of some of the more popular branches of engineering. These fields are presented in alphabetical order.

1.1.1 Aeronautical Engineering

Aeronautical (or aerospace) engineers use their knowledge of aerodynamics, fluid mechanics, structures, control systems, heat transfer, and hydraulics to design everything from rockets, airplanes, and space vehicles to high-speed bullet trains, low-drag fuel-efficient cars, and helium-filled dirigibles. Since the days of the Wright brothers, aeronautical engineers, working in teams with scientists and other types of engineers, have made human flight and space exploration possible. Aeronautical engineers find employment in many industries, but they typically work for big companies on large-scale projects. Some of the more noticeable accomplishments of the aerospace industry have included the Apollo moon landings of the 1960s, NASA Space Shuttle missions, deep space exploration, the International Space Station, the jumbo jet, and a new generation of fuel-sipping aircraft. Commercial ventures into space have even come to fruition. Figure 1.1, for example, shows SpaceShipOne, a manned space ship designed and built by Scaled Composites, a private aerospace company. On October 4, 2004, SpaceShipOne propelled itself into history, becoming the first private manned spacecraft to exceed an altitude of 328,000 feet (twice within 14 days) to claim the $10 million Ansari X-Prize.

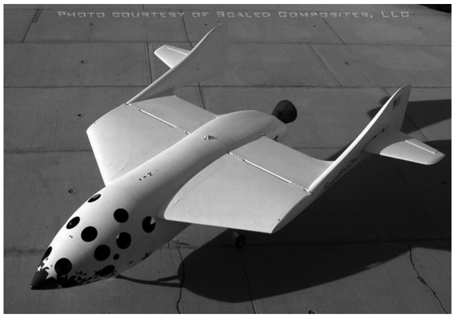


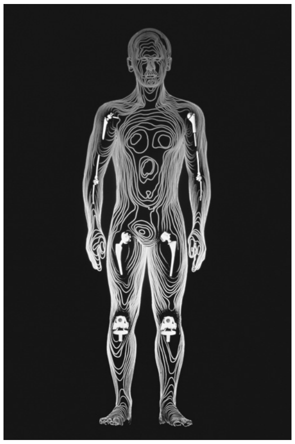
Figure 1.1
SpaceShipOne—The first privately funded commercial manned space flight. (*Photo courtesy of Scaled Composites, LLC.*)

1.1.2 Agricultural Engineering

Agricultural engineers apply the principles of hydrology, soil mechanics, fluid mechanics, heat transfer, combustion, optimization theory, statistics, climatology, chemistry, and biology to the production of food on a large scale. This discipline is popular at colleges and universities located in heavily agricultural areas. Feeding the world's population is one of the most formidable challenges of the 21st century. The amount of arable land on the planet is fixed, but the demand for food must keep pace with the world's steeply rising population. Agricultural engineers will play an important role in this endeavor by applying technology and engineering know-how to improve crop yields, increase food output, improve farming of minimally productive land, and develop cost-effective and environmentally sound pest control and farming methods. Agricultural engineers work with ecologists, biologists, chemists, and natural scientists to understand the impact of human agriculture on the earth's ecosystem.

1.1.3 Biomedical Engineering

The biomedical engineer (or bioengineer) works closely with physicians and biologists to apply modern engineering methods to medicine and human health, and to obtain a better understanding of the human body. Engineering skills are combined with a knowledge of biology, physiology, and chemistry to produce medical instrumentation, prostheses, assistive appliances, implants, and neuromuscular diagnostics. Biomedical engineers have participated in designing numerous devices that



have helped improve medical care over the past half-century. Many biomedical engineers enter medical school upon graduation, but others go to graduate school or seek employment in a health or medical-related industry. The rapidly emerging world of biotechnology, which bridges the gap between engineering and molecular genetics, is also the province of the biomedical engineer. This discipline examines the fundamental functions of cells and organisms from an engineering point of view. Many of the secrets of future medicine lie at the genetic level, and the biomedical engineer will help lead the way to new medical discoveries. Nanotechnology also plays a central role, because cells exist on the nanoscale. The human genome project, for example, has relied heavily on the expertise of bioengineers working in concert with biologists, chemists, and experts, and has created a newly emerging area of technology called *bioinformatics*. The latter field spans the disciplines of bioengineering and computer science. The biomedical engineer is also involved in the emerging areas of microfluidics and nanomaterials. In microfluidic, tiny bioprocessing systems are built on small chips of silicon or other materials. This technology, which is part of the field of micro- and nano-electromechanical systems (MEMS and NEMS), is sometimes referred to as “lab on a chip.” In nanomaterial technology, artificially engineered materials provide an interface between human tissues and everything from bone and skin grafts to *in-vivo* drug delivery systems. The discipline of biomedical engineering also encompasses the field of *bionics*—a technology that attempts to merge biological organisms with manufactured components as one integral whole.

1.1.4 Chemical Engineering

The chemical engineer applies the principles of chemistry to the design of manufacturing and production systems. Whenever a chemical reaction or process must be brought from the laboratory to manufacturing on a large scale, teams of chemical engineers are needed to make it happen. Chemical engineers design the reaction vessels, transport mechanisms, mixing chambers, and measuring devices that allow the process to proceed on a large scale in a cost-effective way. Chemical engineers are employed in many industries, including construction, microelectronics, biotechnology, food processing, and environmental analysis, as well as industries that manufacture petroleum products, petrochemicals, plastics, cosmetics, and pharmaceuticals. Because of the widespread use of such materials, much of our global economy relies on the work of chemical engineers for its success. Their skills are needed wherever a manufacturing process involves organic or inorganic chemical reactions on a production scale. Chemical engineers must rely on their knowledge of mathematics and science—particularly chemistry—to overcome technical problems in a safe and economical manner. Chemical engineers are typically employed by large companies that produce products for worldwide distribution.

1.1.5 Civil Engineering

Civil engineers are responsible for the infrastructure of our society. The civil engineer is concerned with the design and construction of the world’s infrastructure. Civil engineers design transportation systems, roads, bridges, buildings, and airports, as well as other large structures such as water treatment plants, aquifers, and waste management facilities. One classic example of civil engineering on a grand scale, shown in Figure 1.2, is the Hoover Dam in Black Canyon on the Colorado River, about 30 miles southeast of Las Vegas, Nevada. Designing such large structures

Figure 1.2
The Hoover Dam on the Colorado River near Las Vegas, Nevada. (*Photo courtesy of the Bureau of Reclamation.*)

requires knowledge of soil mechanics, hydraulics, strength of materials, concrete engineering, and construction practices. Civil engineers may also be involved in designing smaller structures such as houses, landscapes, and recreational parks. Over the coming decades, civil engineers will play a vital role in revitalizing aging infrastructures worldwide and in dealing with environmental issues such as water resources, air quality, global warming, and refuse disposal. More than any other professional, the civil engineer has to rely heavily on physical scale models, calculations, computer modeling, and past experience to determine the performance of designed structures. This limitation exists because it's seldom possible to build a trial test structure on the scale of most civil engineering products. The civil engineer seldom tests a full-scale, initial prototype, but instead must show via modeling and simulation during the design process that a design will meet its specifications upon final construction. For example, it's not feasible to intentionally collapse a bridge just to verify its weight-bearing capability.

The civil engineer works closely with construction personnel and may spend much time at job sites reviewing the progress of construction tasks. Civil engineers are often employed in the public sector, but may also find work in large or small construction companies and private development firms. One renowned example of a large, public-sector civil engineering effort, shown in Figure 1.3, is the famed "Big Dig" in Boston, Massachusetts. This multibillion-dollar, 10-year effort, the most expensive and extensive single transportation infrastructure project in U.S. history (over $21 billion), is formally known as the Central Artery/Tunnel Project. This

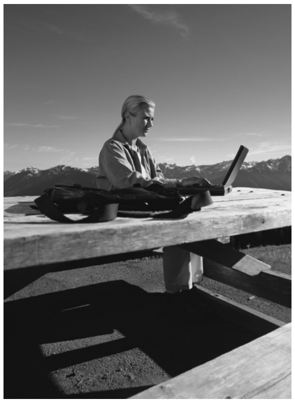
Figure 1.3
Boston's Central Artery/Tunnel Project (the "Big Dig"), one of the largest public works projects in U.S. history. (*Photo courtesy of the Central Artery/Tunnel Project.*)

project has spawned numerous issues of interest to the engineering profession, from structural to ethical.

1.1.6 Computer Engineering

Computer engineering encompasses the broad categories of hardware, software, and digital communication. A computer engineer applies the basic principles of engineering and computer science to the design of computer networks, software systems, communication systems, embedded processors, and computer-controlled devices. The computer engineer also is responsible for designing and building interconnections between computers and their components, including distributed computers, wireless and local area networks (LAN), and Internet servers. For example, a hardware-oriented computer engineer might combine microprocessors, flash memory, disk drives, display devices, LAN cards, and drivers to produce high capacity servers. Graphical-user interfaces and embedded computer systems might be the province of the software-oriented computer engineer. The discipline also includes such areas as sensor networks, crash-resistant hardware and software systems, wireless interfaces, sensor networks, operating systems, and assembly language programming. Computer scientists are traditionally more mathematically oriented than computer engineers, and they have also become involved in the writing of computer software, including Web interfaces, database management systems, and client applications. Unlike the computer scientist, however, the computer engineer is fluent in both the hardware and software aspects of modern computer systems. Examples in which both hardware and software share equally important roles include processor design, network interfaces, desktop and laptop PC design, cell-phone networks, global positioning systems, microcomputer or Internet-controlled appliances, automated manufacturing, and medical instrumentation. Some of the more notable accomplishments of the computer industry include the invention of the microprocessor (Intel, 1971), the explosion of personal computing that began with the first desktops (Apple I, 1976; Apple II, 1978; IBM-PC, 1984; McIntosh, 1984), and the advances in data communication networks that began with the U.S. Department of Defense's Arpanet and grew into the Internet and World Wide Web.

New horizons in computing will present exciting challenges to computer engineers in the 21st century. While not yet realities, quantum computing, nanocomputing, sentient artificial intelligence (e.g., the android Data from *Star Trek: The Next Generation*; numerous machines from *I, Robot*), and direct interfacing between computers and the human brain no longer lie in the realm of pure science fiction.



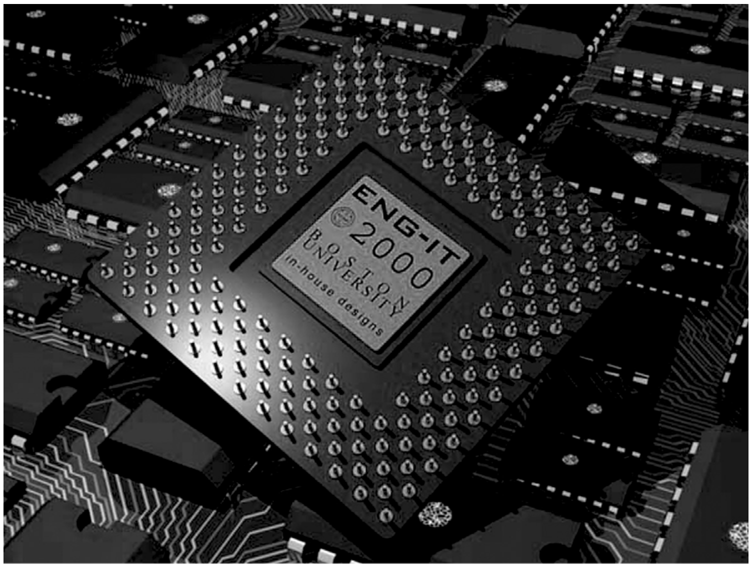
1.1.7 Electrical Engineering

Electrical engineering is an extremely broad discipline that encompasses all forms and uses of electricity. Because information can be expressed in electronic form, the science of information theory often falls within the realm of the electrical engineer. Likewise, because many uses of electricity involve its manipulation and control, the discipline of control theory is often within the province of the electrical engineer. Whether on a large or small scale, electrical engineers are responsible for numerous areas of technology, including microelectronics, data communication, radio, television, lasers, fiber optics, video, audio, computer networks, speech processing, imaging systems, electric power systems, and alternative energy sources such as solar, tidal, and wind power. Many electrical engineers also work in the area of materials science because of the dependence of electronic and photonic devices on advanced semiconductor materials. The electrical engineer also designs transportation systems based on electric power, including mass transit, electric cars, and hybrid vehicles.

The typical electrical engineer has a strong background in the physical sciences, mathematics, and computational methods and also has a knowledge of circuits and electronics, semiconductor devices, analog and digital signal processing, digital systems, electromagnetics, and control systems. The electrical engineer is also fluent in many areas of computer engineering. Some of the more recent accomplishments that have involved electrical engineers include the microelectronic revolution (the microprocessor and large-scale integration on a chip), nano-devices, wireless communication (cellular telephones, data links, iPhones™), photonics (lightwave technology, lasers, and fiber-optic communication), and the so-called laboratory-on-a-chip.

1.1.8 Environmental Engineering

Environmental engineers rely on the principles of biology and chemistry to solve problems related to the environment. A myriad of job opportunities, which are important to communities and society worldwide, await the individual who is proficient in this growing discipline, similar in its core curriculum to civil engineering. In fact, the two programs are housed within the same department at many colleges and universities.



Environmental engineers may be involved in water- and air-pollution control, recycling, waste disposal, and public health issues such as acid rain, global warming, automobile emissions, wildlife protection, and ozone depletion. They may design municipal water supply and industrial wastewater treatment systems, conduct hazardous-waste management studies, or help develop regulations to prevent environmental disasters.

1.1.9 Industrial Engineering

An industrial engineer (sometimes called a manufacturing engineer) is concerned with the total life cycle of a product, from the moment of its inception to its eventual disposal and the recycling of its raw materials. Industrial engineers have the unique challenge of incorporating the latest technological advances in computing and machinery into production and manufacturing facilities. Industrial engineers are intimate with all aspects of the corporate environment, because much of what motivates the field of industrial engineering is the need to maximize output while controlling cost and environmental impact. Skills required for this discipline include knowledge of product development, materials properties, optimization, queuing theory, production techniques, machining, fabrication methods, and engineering economy. Industrial engineers also become fluent in the techniques of computer-aided design (CAD) and computer-aided manufacturing (CAM). Global manufacturing, in which products are developed for a worldwide economy, has become one of the most important aspects of industrial engineering.

A critical area in the province of the industrial engineer is the use of robotics in manufacturing. Building, moving, and controlling robots requires some knowledge of mechanical, electrical, and computer engineering. Most programs in industrial engineering include courses in these additional areas. Another important area of industrial engineering is the field of "green manufacturing," in which an understanding of the environmental impact of a product over its life cycle is considered a central part of the design process.

1.1.10 Materials Engineering

Materials engineering (sometimes called materials science) is one of the oldest engineering disciplines. It concerns the development and use of all forms of physical matter to solve problems on both the macroscopic and microscopic scale. The materials engineer applies knowledge of the basic properties of materials of all types to the solution of engineering problems. In today's high-tech society, an understanding of materials is crucial to almost all engineering endeavors. From such applications as thermal protection of reentering space vehicles to advanced battery concepts for fuel cells, lightweight composite materials for fuel-thrifty vehicles, and even the development of lighter and more efficient laptop computers, the materials engineer plays a key role. An engineer trained in this discipline—one who understands the relationship between materials properties and the performance and durability of ensuing products—is uniquely prepared to contribute to the efforts of a multidisciplinary design team.

Decades ago, the materials engineer dealt almost exclusively in metallurgy and ceramics. The traditional materials engineer was concerned with extracting ores, converting them into useful form, and understanding their properties. Advances in the development of new materials—for example, the proliferation of polymers into society during the latter half of the 20th century—greatly expanded the domain of the materials engineer and led to the creation of new products and entirely new industries. College curricula in the discipline now include elements of chemical, mechanical, civil, and electrical engineering. Modern materials engineering deals with a host of materials, including engineered polymers, high-tech ceramics, composites, liquid/solid state fluids, semiconductors, biomaterials, and nano-materials. The science of *forensics*, concerned with the analysis of materials failure and crime investigation, constitutes an additional application of this field.

1.1.11 Mechanical Engineering

The mechanical engineer is responsible for designing and building physical structures of all kinds. Any device that involves mechanical motion, be it an automobile, bicycle, engine, disk drive, keyboard, fluid valve, jet-engine turbine, wind turbine, or flight structure, requires the expertise of mechanical engineers. Mechanical engineers are fluent in statics, dynamics, materials, structural and solid mechanics, fluid mechanics, thermodynamics, heat transfer, and energy conversion. They apply these principles to a wide variety of engineering problems, including precision machining, environmental engineering, water resources, acoustics, combustion, power sources, robotics, transportation, and manufacturing systems. Mechanical engineers interface most easily with all other types of engineers because their discipline requires such a broad educational background. In addition, our most prevalent interaction with the physical world is via our sense of touch, that is, through mechanical things. The field that best complements a mechanical engineering education is electrical engineering, because so many mechanical things now interface with the world via electrical and electronic interfaces.

One of the newest areas of study related to mechanical engineering is the emerging field of nanotechnology which deals with tiny, microscopic machines fabricated on an atomic scale. “Nanotech” is also closely related to biotechnology. Nano-mechanical systems (NEMS) represents the next great step forward following the micro-electromechanical systems (MEMS) revolution of the late 1990s. The joint fields of MEMS and NEMS have the potential to do for mechanics what the integrated circuit did for electronics, namely, to permit large-scale integration of entire systems on a single semiconductor chip.

1.1.12 Mechatronics Engineering

The mechatronic engineer is fluent in mechanical engineering, electrical engineering, and robotics. As its name implies, the field of mechatronics involves the fusion of mechanical engineering, electronics, and computing toward the design of robotic

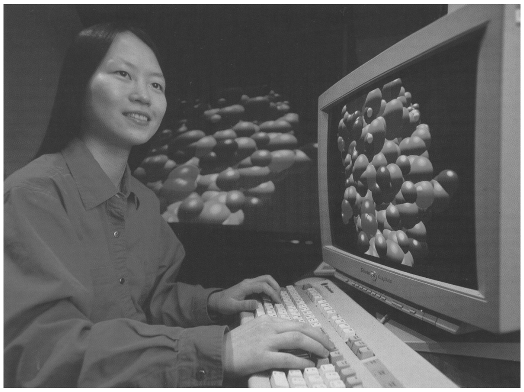


Figure 1.4
An engineer simulates nano-particles. (*Photo courtesy of Boston University Photo Services.*)

products and manufacturing systems. Engineers who work in this field require cross-disciplinary training that can best be approached by majoring in either mechanical or electrical engineering and acquiring skills in the other needed disciplines through extra courses or technical electives. Mechatronic engineers are responsible for the innovation, design, and development of machines and systems that can automate production tasks, reduce production costs, reduce plant maintenance costs, improve product flexibility, and increase production performance. The typical mechatronics engineer solves design problems for which solely mechanical or electrical solutions are not possible. Sensing and actuation are important elements of mechatronics.

1.1.13 Naval Engineering

The naval engineer (or naval architect) designs surface watercraft, submarines, barges, and other seagoing vessels, and is also involved in the design of oil platforms, shipping docks, seaports, and coastal navigation facilities. As a rule, naval architects and engineers have a broad background because many branches of engineering are involved in the design of marine vessels. Naval engineers, for example, are fluent in several of the subjects studied by mechanical engineers, including fluid mechanics, materials, structures, statics, dynamics, water propulsion, and heat transfer. In addition, naval engineers take courses on the design of ships and the history of sea travel. Many naval engineers are employed by the armed forces, but some work for companies that design and build large ships. Steeped in tradition and forever at the cutting edge of technology, naval engineering can be a rewarding career to those interested in the sea.

1.1.14 Nuclear Engineering

Nuclear engineers use their knowledge about atomic physics to solve engineering problems. They are concerned with the design and operation of nuclear reactors for use in naval vessels and electric power plants. From the sole point of view of natural resources, atomic-based power represents one alternative to our dwindling supply of fossil fuels. Nuclear engineers understand the physics of radiation and the radioactive atoms produced in nuclear reactions. Most work in private or governmental research and development laboratories. Some work at construction sites for new nuclear power plants. Nuclear engineers also may supervise fuel loading operations or the critical steps related to storage of nuclear waste.

For the second half of the 20th century, the field of nuclear engineering enjoyed widespread growth as part of efforts to find peaceful uses for atomic energy.

(U.S. Navy imagery used in illustration without endorsement expressed or implied.)

Following two severe accidents[3] and mounting concern over hazardous waste disposal, nuclear power found itself in disfavor at the turn of the millennium. As we approach the second decade of the 21st century, severe demands for energy by an ever-increasing population have renewed interest in nuclear power. Despite major global efforts, the demand for power has vastly outstripped the emergence of alternative, renewable energy source. New insights into possible ways for safe waste disposal, and a better understanding of the hazards of nuclear reactions, have fostered a new demand for nuclear engineers.

1.1.15 Petroleum Engineering

Over 70% of the world's current energy needs are derived from petroleum products, and this situation is unlikely to change for at least the next half-century. The principal challenge of the petroleum engineer is to produce oil, gas, and other energy forms from the earth's natural resources. In order to harvest these resources in an economical and environmentally safe way, the petroleum engineer must have a wide knowledge base that includes mathematics, physics, geology, and chemistry, as well as aspects of most other engineering disciplines. Elements of mechanical, chemical, electrical, civil, and industrial engineering are found in most programs in petroleum engineering. Also, because computers are used with ever-increasing frequency in geological exploration, oil-field production, and drilling operations, computer engineering has become an important specialty within petroleum engineering. Many of the world's supercomputers are owned by petroleum companies.

In addition to conventional oil and gas recovery, petroleum engineers apply new technology to the enhanced recovery of hydrocarbons from oil shale, tar sands, offshore oil deposits, and fields of natural gas. They also design new techniques for recovering residual ground oil that has been left by traditional pumping methods. Examples include the use of underground combustion, steam injection, and chemical water treatment to release oil trapped in the pores of rock. These techniques will likely be used in the future for other geological operations, including uranium leaching, geothermal energy production, and coal gasification. Petroleum engineers also work in the related areas of pollution reduction, underground waste disposal, and hydrology. Because many petroleum companies operate on a worldwide scale, the petroleum engineer has the opportunity to work in numerous foreign countries.

1.1.16 Systems Engineering

In the computer industry, the designation "systems engineer" has come to mean someone who deals exclusively with large-scale software systems. The traditional systems engineer, however, can be anyone who designs and implements complex engineering systems. As the complexity of such entities has increased, so has the demand for systems engineers. These professionals understand how complex engineering projects must be designed and managed and deal not only with initial design, but also with logistics, team coordination, and project supervision. Design efforts bearing the stamp of the systems engineer include communication networks, information systems, transportation infrastructure, large-scale manufacturing systems, power distribution networks, and avionics. Other focal areas include automation, robotics and control, computational biology, information science, and

---

[3] Three Mile Island, PA (1979); Chernobyl, Ukraine (1986)

supply-chain management. Systems engineers also help define the needs and function of consumer products early on in the development cycle. Programs of study in this diverse field include courses in applied mathematics, computer simulation, software, electronics, communications, and automatic control. Because of their broad educational background, systems engineers are comfortable working with most other types of engineers.

1.2 SOME ENGINEERING PROFESSIONAL ORGANIZATIONS

Most branches of engineering are represented by professional societies that bring together members of similar background, training, and professional expertise. These societies operate on a worldwide scale and publish numerous journals for which engineers write papers and articles of interest to the field. Each organization offers its members technical and informational services, post-college training, industry standards, workshops, and conferences. In some cases, other professional services are offered as well, including job networks, advertising, e-mail accounts, product information, web page hosting, and even life and health insurance. All provide student membership at a discount, and student chapters at colleges and universities are common. This section provides information about some of the principal professional organizations. The text provided here has been excerpted from each organization's web page.

1.2.1 American Institute of Aeronautics and Astronautics (*www.aiaa.org*)

> "AIAA advances the state of aerospace science, engineering, and technological leadership. For more than 70 years, AIAA has been the principal society of the aerospace engineer and scientist. In 1963, the American Rocket Society and the Institute of Aerospace Science joined to become AIAA. Both brought long and eventful histories to the relationship – histories that stretched back to 1930 and 1932 respectively, a time when rocketry was the stuff of science fiction and the aviation business was still in its infancy.
>
> "Each society left its distinct mark on AIAA. The merger combined the imaginative, risk-taking, shoot-for-the-moon outlook of Project Mercury-era rocket, missile, and space professionals with the more established, well-recognized, industry-building achievers of the aviation community. The resulting synergy has benefited aerospace ever since.
>
> "Today, with more than 31,000 members, AIAA is the world's largest professional society devoted to the progress of engineering and science in aviation, space, and defense. The Institute continues to be the principal voice, information resource, and publisher for aerospace engineers, scientists, managers, policymakers, students, and educators. AIAA is also the go-to resource for stimulating professional accomplishment and standards-driven excellence in all areas of aerospace for prominent corporations and government organizations worldwide."

Key Publications: *Aerospace America, AIAA Bulletin, Journal of Aircraft, Journal of Spacecraft and Rockets, Journal of Energy, Journal of Aerospace Computing, Information, and Communication.*

1.2.2 Biomedical Engineering Society (*www.bmes.org*)

> "In response to a manifest need to provide a society that gave equal status to representatives of both biomedical and engineering interests, the Biomedical Engineering Society was incorporated in Illinois on February 1, 1968. As stated in the Articles of Incorporation, and modified by approval of the Board of Directors in October, 2006, the purpose of the Society is to promote and enhance biomedical engineering knowledge worldwide and its utilization for the health and well being of humankind.
>
> "Initially, the membership of the Society consisted of 171 Founding members and 89 Charter members. With the cooperation of the Federation of American Societies for Experimental Biology, the first Open Meeting of the Biomedical Engineering Society was held at the Ritz-Carlton Hotel in Atlantic City on April 17, 1968.
>
> "The first Annual Meeting of the Biomedical Engineering Society was held in Houston, November 18-20, 1968, in conjunction with the 21st Annual Conference on Engineering in Medicine and Biology."

Key Publications: *BMES Bulletin*, and *Annals of Biomedical Engineering*, *Cellular and Molecular Bioengineering Journal*

1.2.3 American Institute of Chemical Engineers *(www.aiche.org)*

> "AIChE is the world's leading organization for chemical engineering professionals, with more than 40,000 members from 93 countries. AIChE has the breadth of resources and expertise you need whether you are in core process industries or emerging areas, such as nanobiotechnology.
>
> "As a member, you can access information on recognized and promising chemical engineering processes and methods. Connect with a global network of intelligent, resourceful colleagues and their shared wisdom. Find learning opportunities from recognized authorities—all of which can help you move forward professionally and enrich the world we live in.
>
> "AIChE's vision is to provide value as the global leader of the chemical engineering profession, the lifetime center for professional and personal growth, and security of chemical engineers, and the foremost catalyst in applying chemical engineering expertise in meeting societal needs."

Key Publications: *Chemical Engineering Progress, AIChE Journal, Environmental Progress, Process Safety Progress*, and *Biotechnology Progress*.

1.2.4 American Society of Civil Engineers *(www.asce.org)*

> "Founded in 1852, the American Society of Civil Engineers (ASCE) represents more than 123,000 members of the civil engineering profession worldwide, and is America's oldest national engineering society. ASCE's vision is to position engineers as global leaders building a better quality of life."

> "ASCE's mission is to provide essential value to our members, their careers, our partners and the public by developing leadership, advancing technology, advocating lifelong learning and promoting the profession. From the building of the Parthenon in 432 B.C. to the building of the Petronas Towers today, the civil engineering profession has proven its sustainability. Withstanding the passage of time, civil engineers have built cultural landmarks that stand in tribute to the profession's creative spirit and ingenuity."
>
> "Civil engineers are trained to plan, build, and improve the water, sewer, and transportation systems that you depend on everyday. They build dams able to withstand the crushing pressure of a lake full of water. They build bridges able to resist the forces of wind and traffic. They develop environmentally friendly materials and methods, and they build things to last. So skilled is their work that we rarely stop to wonder how they design the mammoth skyscrapers we work in, the tunnels we drive in, and the stadium domes we sit beneath."

Key Publications: *ASCE News, Civil Engineering Magazine*, plus numerous journals on specialized topics in civil engineering.

1.2.5 Association for Computing Machinery *(www.acm.org)*

> "The Association for Computing Machinery is an educational and scientific society uniting the world's computing educators, researchers, and professionals to inspire dialogue, share resources, and address the field's challenges. ACM strengthens the profession's collective voice through strong leadership, promotion of the highest standards, and recognition of technical excellence. ACM supports the professional growth of its members by providing opportunities for life-long learning, career development, and professional networking.
>
> "The ACM is widely recognized as the premier membership organization for computing professionals, delivering resources that advance computing as a science and a profession; enable professional development; and promote policies and research that benefit society.
>
> "ACM hosts the computing industry's leading Digital Library and Guide to Computing Literature, and serves its global members and the computing profession with journals and magazines, conferences, workshops, electronic forums, and Online Books and Courses."

Key Publications: *Communications of the ACM*, *The ACM Digital Library* (a collection of online publications), plus numerous technical transactions including *Computer–Human Interaction, Computer Systems, Database Systems, Modeling and Computer Simulation, Networking,* and *Software Engineering and Methodology*.

1.2.6 Institute of Electrical and Electronic Engineers (*www.ieee.org*)

> "IEEE's core purpose is to foster technological innovation and excellence for the benefit of humanity. IEEE will be essential to the global technical community and to technical professionals everywhere, and be universally recognized for the contributions of technology and of technical professionals in improving global conditions.

> "A nonprofit organization, IEEE is the world's leading professional association for the advancement of technology. The IEEE name was originally an acronym for the Institute of Electrical and Electronics Engineers, Inc. Today, the organization's scope of interest has expanded into so many related fields that it is simply referred to by the letters I-E-E-E (pronounced Eye-triple-E). Through its global membership, IEEE is a leading authority on areas ranging from aerospace systems, computers, and telecommunications to biomedical engineering, electric power, and consumer electronics, among others. Members rely on IEEE as a source of technical and professional information, resources, and services.
>
> "To foster an interest in the engineering profession, IEEE also serves student members in colleges and universities around the world. Other important constituencies include prospective members and organizations that purchase IEEE products and participate in conferences or other IEEE programs."

Key Publications: *IEEE Spectrum, Proceedings of the IEEE,* plus over 40 specialized *IEEE Transactions* from its various societies including: Aerospace and Electronic Systems; Automatic Control; Biomedical Engineering; Circuits and Devices; Communications; Control Systems; Dielectrics and Electrical Insulation; Electromagnetic Compatibility; Energy Conversion; Engineering Management; Image Processing; Industry Applications; Lasers and Electro-Optics; Mechatronics; Micro-Electromechanical Systems; Neural Networks; Parallel and Distributed Systems; Photonics; Power Electronics; Quantum Electronics; Robotics and Automation; Signal Processing; Software Engineering; Solid-State Circuits; Vehicular Technology; and Visualization and Computer Graphics.

1.2.7 IEEE Computer Engineering Society (*www.computer.org*)

> The IEEE Computer Engineering Society (CS), a subset of the IEEE, "is the world's leading organization of computing professionals. Founded in 1946, the CS is dedicated to advancing the theory and application of computer and information-processing technology.
>
> "The CS serves the information and career-development needs of today's computing researchers and practitioners with technical journals, magazines, conferences, books, conference publications, and online courses. Its Certified Software Development Professional (CSDP) program for mid-career professionals and Certified Software Development Associate (CSDA) credential for recent college graduates confirm the skill and knowledge of those working in the field. Known worldwide for its computer-standards activities, the CS promotes an active exchange of ideas and technological innovation among its members.
>
> "With about 40 percent of its members living and working outside the United States, the CS fosters international communication, cooperation, and information exchange. It monitors and evaluates curriculum accreditation guidelines through its ties with the US Computing Sciences Accreditation Board and the Accreditation Board for Engineering and Technology."

Key Publications: *Computing in Science and Engineering, IEEE Transactions on Computers, IEEE Transactions on Software Engineering,* plus a host of additional transactions and technical journals.

1.2.8 Institute of Industrial Engineers (*www.iienet.org*)

> "The Institute of Industrial Engineers (IIE) is the world's largest professional society dedicated solely to the support of the industrial engineering profession and individuals involved with improving quality and productivity. Founded in 1948, IIE is an international nonprofit association that provides leadership for the application, education, training, research, and development of industrial engineering.
>
> "With approximately 15,000 members and 280 chapters worldwide, IIE's primary mission is to meet the ever-changing needs of industrial engineers, which includes undergraduate and graduate students, engineering practitioners and consultants in all industries, engineering managers, and engineers in education, research, and government. IIE is recognized internationally as the leading provider of cutting-edge continuing education in industrial engineering, and an association that supports the profession of industrial engineering and promotes an increased awareness of the value of industrial engineers.
>
> "IIE provides leadership in developing industrial engineering; in representing the industrial engineering profession; and in enhancing the capabilities of those who are involved in or manage the application, education, training, research or development of industrial engineering."

Key Publications: *Industrial Engineer, Industrial Management, IIE Transactions, The Engineering Economist.*

1.2.9 American Society of Mechanical Engineers *(www.asme.org)*

> "Founded in 1880 as the American Society of Mechanical Engineers, ASME is a not-for-profit professional organization promoting the art, science, and practice of mechanical and multidisciplinary engineering and allied sciences. ASME develops codes and standards that enhance public safety, and provides lifelong learning and technical exchange opportunities benefiting the global engineering and technology community. ASME has more than 127,000 members worldwide.
>
> "The vision of ASME is to be the premier organization for promoting the art, science and practice of mechanical and multidisciplinary engineering and allied sciences to our diverse communities throughout the world.
>
> "Our mission is to promote and enhance the technical competency and professional well-being of our members, and through quality programs and activities in mechanical engineering, better enable its practitioners to contribute to the well-being of humankind."

Key Publications: *Mechanical Engineering, Journal of Applied Mechanics, Journal of Applied Mechanics Reviews*, plus journals in numerous specialty areas, including applied mechanics, Arctic engineering, biomechanical engineering, computing and information science, dynamic systems, electronic packaging, energy turbines and power engineering, materials technology fluids, heat transfer, manufacturing science, mechanical design, mechatronics, measurement and control, offshore mechanics, pressure vessel technology, solar energy, tribology, turbomachinery, and vibration and acoustics.

1.2.10 Society of Petroleum Engineers (*www.spe.org*)

> "The mission of the Society of Petroleum Engineers is to collect, disseminate, and exchange technical knowledge concerning the exploration, development, and production of oil and gas resources, and related technologies for the public benefit; and to provide opportunities for professionals to enhance their technical and professional competence, and to be a society of professional excellence, providing its members the highest quality lifelong learning, and continuous personal and professional growth.
>
> "Total professional and student membership in the Society of Petroleum Engineers grew 8 percent to a record 79,300 members worldwide in 2007, including an increase in members under age 35. SPE membership includes engineers, scientists, technicians, managers, operators, educators and other professionals who work in the global upstream oil and gas industry, as well as students who are studying petroleum engineering or a related field.

Key Publication: *Journal of Petroleum Technology*

1.2.11 American Society of Agricultural and Biological Engineers (*www.asabe.org*)

> "The American Society of Agricultural and Biological Engineers is an educational and scientific organization dedicated to the advancement of engineering applicable to agricultural, food, and biological systems. Founded in 1907 and headquartered in St Joseph, Michigan, ASABE comprises 9,000 members in more than 100 countries. Agricultural, food and biological engineers develop efficient and environmentally sensitive methods of producing food, fiber, timber, and renewable energy sources for an ever-increasing world population.
>
> "The ASABE represents technical specialties in areas of biological engineering, education, food and process engineering, information and electrical technologies, power and machinery, soil and water, structures and environment, ergonomics, safety and health, forest engineering, and aquaculture engineering. Society activities are also conducted through geographic sections, affiliated communities, and special programs, including an active preprofessional (student) group for individuals contemplating or preparing for a career in agricultural, food, and biological engineering. ASABE membership is open to all (engineers as well as nonengineers) who are interested in the knowledge and application of engineering in agricultural, food, and biological systems."

Key Publications: *Biological Engineering, Applied Engineering in Agriculture, Transactions of the ASABE, Journal of Agricultural Safety & Health*

1.2.12 American Society of Naval Engineers (*www.navalengineers.org*)

> The purpose of the Society of Naval Engineers is, "to advance the knowledge and practice of naval engineering in public and private applications and operations, to enhance the professionalism and well-being of members, and to promote naval engineering as a career field.

Society membership is drawn from a broad spectrum of military and civilian professionals and students, engaged in or associated with the many facets of naval engineering. An ASNE headquarters is maintained in Alexandria, Virginia.

"Naval engineering includes all arts and sciences as applied in the research, development, design, construction, operation, maintenance and logistic support of surface and subsurface ships and marine craft, naval maritime auxiliaries, ship-related aviation and space systems, combat systems, command control, electronics and ordnance systems, ocean structures and fixed and mobile shore facilities which are used by the naval and other military forces and civilian maritime organizations for the defense and well-being of the Nation."

Key Publication: *Naval Engineers Journal*

Professional Success: Choosing A Field of Engineering

If you are a first-year student of engineering, you may already have decided upon a major field. After taking several required courses, however, you may not be sure if you've chosen the right type of engineering. Conversely, you may have entered school without committing yourself to any one field of engineering. If you find yourself in either of these situations, you're probably wondering how to choose a career direction in engineering.

One way to find out more about the different branches of engineering is to attend technical talks and seminars hosted by the engineering departments in your college or university. Such talks are usually aimed at graduate students and faculty, so much of the material will be over your head. Simply *exposing* yourself to these technical talks, however, will give you a feeling for the various branches of engineering and help you find one that most closely matches your skills and interests.

Most schools host workshops on career advising. Be sure to attend one. Talk with the experts in career planning and job placement. Most college campuses host student chapters of professional organizations. These groups often organize tours of engineering companies. Attending such a tour can provide a valuable perspective about the activities of a particular branch of engineering and give you an idea about what life as an engineer will be like.

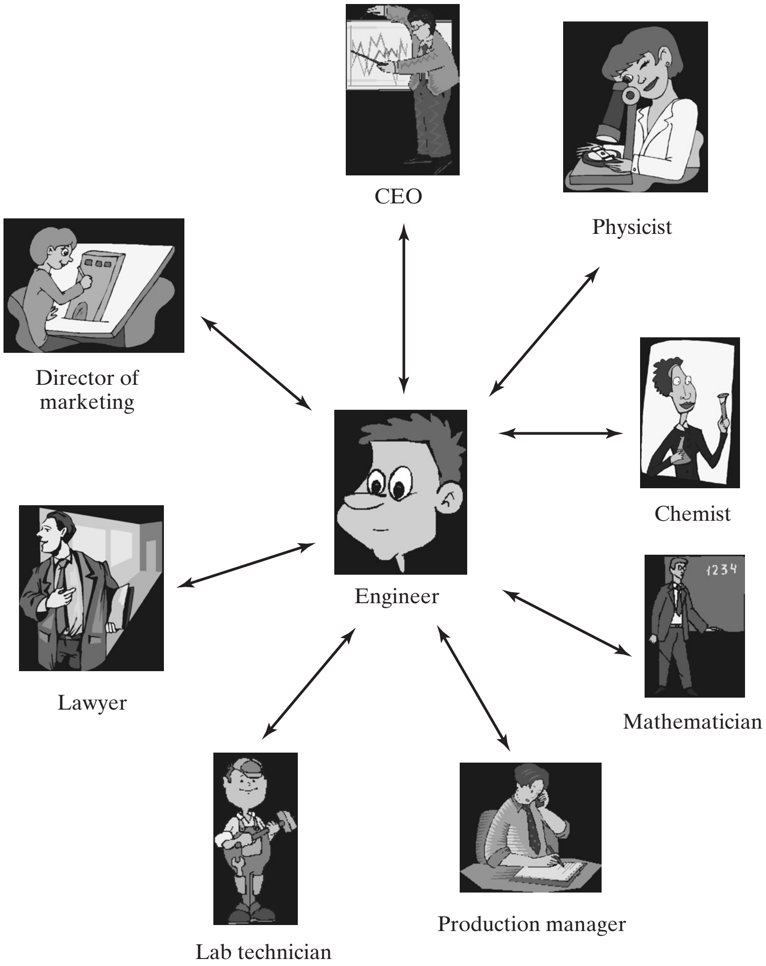
One of the most valuable resources for career advice is your own college faculty. Get advice from your advisor about which major is right for you. Most professors love to talk about their work. Invite a professor to your dormitory or living unit to speak to students about choosing an engineering career. Speak to your department about hosting a career night in which a panel of professors will answer questions about engineering jobs. Learn to make use of all available resources for help in choosing your college major.

1.3 THE ENGINEER: CENTRAL TO PROJECT MANAGEMENT

The word "engineer" may conjure visions of a lone individual sitting in a cubicle at a computer terminal, or perhaps in a workshop, crafting some marvelous piece of technical wizardry. As a student, you may be eager to pursue this notion of the rugged individual—the genius entrepreneur who single-handedly changes the face of technology, perhaps the next Bill Gates or Dean Kamin. You might ask, "Why do I have to take all of these *other* courses? Why can't I just take courses that are of interest to me?" The answer lies in the multidisciplinary nature of engineering. At times, an engineer does work alone, but most of the time engineers must interact with individuals who come from very different educational backgrounds. Engineering projects are often complex undertakings that require teamwork and the coordination of many people possessing different skills and personality traits. An engineer must learn the language of physicists, mathematicians, chemists, managers, fabricators, technicians, lawyers, marketers, and secretaries. It's been said that good engineers are the glue that ties a project together, because they have learned to communicate with specialists from each of these varied fields. Learning to communicate across a variety of occupations requires the engineer to have a broad education and the ability to apply a full range of skills and knowledge to the design process.

To illustrate the breadth of communication skills required of an engineer, imagine that you work for the fictitious company depicted in Figure 1.5. Each person shown in the outer circle possesses a different professional expertise, while you, a design engineer, lie in the center of the organizational circle. Other engineers on

Figure 1.5
The professional circle has the design engineer in the center.



your design team may join you in the center, and each of you can easily communicate with each other due to your similar training. But each of you can also communicate with each of the specialists in the outer ring. As engineers, you've taken courses or have been exposed to each of their various disciplines. This unique feature of your educational background enables you to communicate with anyone in the professional circle and positions you as one of the individuals most likely to act as central coordinator.

The Physicist

The physicist of the company is responsible for understanding the basic physical principles that underlie the company's product line. She spends her time in the laboratory exploring new materials and analyzing their interactions with heat, light, and electromagnetic radiation. She may discover a previously unknown quantum interaction that will lead to a new semiconductor device, or perhaps she will explore the potential for using superconductors in a company product. Or she may simply perform the physical analysis for a new micro-accelerometer. Because you've taken two or more semesters of basic physics and have learned some mechanics, thermodynamics, and electromagnetics, you can easily converse with the physicist and discuss how her basic discoveries relate to the practical interests of the company.

The Chemist

The chemist analyzes materials and substances used in producing company products. She ensures that raw materials used for manufacturing meet purity specifications so that quality control can be maintained. In her laboratory, she directs a team of experimentalists who seek to discover improved materials that are stronger and more durable than those currently being used. She may perform research on complex organic compounds or perhaps work on molecular-based nanotechnology. As an engineer, you've taken one or more courses in chemistry and can speak her language. You understand such concepts as reaction rates, chemical equilibrium, molarity, reduction and oxidation, acids and bases, and electrochemical potential. Perhaps you're a software engineer writing a program that will control a chemical-analysis instrument. Maybe you are a chemical engineer charged with translating a chemical reaction into a manufactured product. Whatever your role, you are an individual very well suited to bringing the contributions of the chemist to the design process.

The Mathematician

The mathematician of the company, who might also be a computer scientist, worries about such things as modeling, statistics, databases, and forecasting. He may be involved in an intriguing new database algorithm or mathematical method for modeling an engineering system. Perhaps he uses mathematics to analyze the company's production line or to forecast trends in marketing. You converse easily with the mathematician, because you have taken numerous math courses as part of your engineering program. Although your emphasis has been on applied, rather than pure, mathematics, you're familiar with calculus, differential equations, linear algebra, statistics, probability, vector algebra, and complex variables. You can easily apply the concepts of mathematics to problems in engineering design.

The Production Manager

Like the army officer in command, the production manager is responsible for mobilizing materials, supplies, and personnel to manufacture company products. He may consider such things as job scheduling, quality control, materials allocation, quality assurance testing, and yield. As the engineer who designs products, you work closely with the production manager to make sure that your design approach is compatible with the company's manufacturing capabilities. Your training as an engineer and your exposure to machining, welding, circuit fabrication, and automation have given you the ability to understand the job of the production manager and have provided you with the vocabulary needed to communicate with him.

The Lab Technician

The lab technician is an indispensable member of the design team. A habitual tinkerer and experimenter, the lab technician helps bring your design product to fruition. He is adept at using tools and has much knowledge about the practical aspects of engineering. The lab technician is masterful at fabricating prototypes and is likely to be the individual who sets up and tests them. The typical lab technician has a degree in engineering technology; hence, you may have taken many of the same courses as he has taken, although your courses probably included more formal theory and mathematics than his. You communicate easily with the lab technician and include him in each phase of your design project.

The Lawyer

The lawyer is concerned with the legal aspects of the company's products. Should we apply for a patent on the XYZ widget? Are we exposing ourselves to a liability suit if we market a particular product? Is our new deal with Apex, Inc. fair to both companies from a legal perspective? To help the lawyer answer these questions, you must be able to communicate with him and share your engineering knowledge. The logical thought that forms the basis of law is similar to the methods you've used to solve countless engineering problems. As an engineer, you easily engage in discourse with the lawyer and can apply his legal concerns about safety, ethics, and liability to the design process.

The Director of Marketing

The director of marketing is a master of imagery and style. She has the job of selling the company's products to the public and convincing people that your products are better than those of your competitors. The marketing manager has excellent communication skills, some knowledge of economics, and an understanding of what makes people want to buy. You interface easily with the marketing manager because you've dealt with all aspects of design as part of your training as an engineer. Through this training, you have focused not only on technical issues, but also on such things as product appearance, the human–machine interface, durability, safety, and ease of use. Your familiarity with these important issues has prepared you to help the director of marketing understand your product and how it works. You are able to respond to her concerns regarding what the public needs from the products that you design.

The President/Chief Executive Officer

The CEO of the company probably has an MBA (Master's of Business Administration) or higher degree and a long history working at corporate financial affairs. The CEO worries about the economy and what future markets the company should pursue or whether to open a new plant in a foreign country. It's the CEO who determines how your current project will be financed, and he needs to be kept up to date about its progress. The CEO also may ask you to assess the feasibility of a new technology or product concept. As an engineer, you have no difficulty conversing with the CEO, because the economic principles of profit and loss, cost derivatives, statistics, and forecasting are closely tied to concepts you learned in calculus, statistics, and economics. You've learned to use spreadsheets in one or more engineering classes and have no trouble interpreting or providing the information that is part of the CEO's world. Likewise, your training as an engineer prepares you to communicate with the CEO about the impact of your projects on the economic health of the company.

1.4 ENGINEERING: A SET OF SKILLS

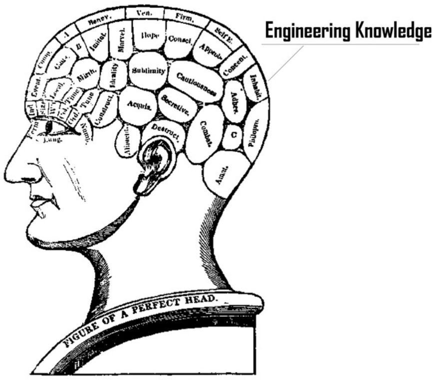
To be successful, an engineer must acquire technical, theoretical, and practical competence and must also be good at organization, communication, and documentation. Three especially important skills that lie at the foundation of engineering are *knowledge, experience*, and *intuition*. These talents do not form an exhaustive set, but they are crucial to the well-rounded engineer.

1.4.1 Knowledge

Knowledge describes the body of facts, scientific principles, and mathematical tools that an engineer uses to form strategies, analyze systems, and predict results. An engineer's acquired knowledge can provide a deeper understanding of how something works. The natural sciences (for example physics, chemistry and biology) help an engineer understand the physical world. Mathematics provides a universal technical language that bridges different disciplines and can be understood by anyone regardless of spoken language or cultural background. Each field of engineering has its own traditional body of knowledge, but an engineer in one field also learns subjects from other fields. Areas of knowledge that are common to all engineers include mechanics, circuits, materials science, and computer programming.

As a student of engineering, you may ask why you are required to take subjects that seem irrelevant to your career aspirations. Any experienced engineer will tell you the answer: Engineers work in a multidisciplinary world where a basic knowledge of many different subject areas is an absolute necessity. Examples abound: mechanical and computer engineers use electrical circuits. Electrical engineers build physical structures design biomedical electronics. Aeronautical engineers rely on software systems and need to know about materials. Software engineers design civil infrastructure systems. Understanding the field of another engineer is critical to cross-disciplinary communication and design proficiency.

Although formal education is an important part of any engineer's training, the prudent engineer also acquires knowledge through on-the-job training and a lifetime of study and exploration. Tinkering, fixing, experimenting, and taking things



Knowledge is an important part of engineering. (graphic courtesy of Fermi National Laboratory) apart to see how they work also are important sources of engineering knowledge. As a young person, did you disassemble your toys, put together models, write your own computer games, create Web pages, or play with building sets, jewelry construction kits, hammers, nails, glue guns, picture hangers, radios, bicycles, or cars? Without knowing it, you began the path toward acquiring engineering knowledge. The professional engineer engages in these same practices. By becoming involved in all aspects of a design project, by keeping up to date with the latest technology, by taking professional development courses and solving real world problems, the practicing engineer remains current and competent.

1.4.2 Experience

Experience refers to the body of methods, procedures, techniques, and rules of thumb that an engineer uses to solve problems. For the engineer, accumulating experience is just as important as acquiring knowledge. As a student, you will have several opportunities to gain engineering experience. Cooperative assignments, assistantships in labs, capstone design projects, summer jobs, and research work in a professor's laboratory provide important sources of engineering experience. On-the-job training is also a good way to gain valuable professional experience. Many engineering companies recognize this need and provide entry-level engineers with initial training as a way of infusing additional experience not acquired in college. Developing experience requires "seasoning," the process by which a novice engineer gradually learns the "tricks of the trade" from other, more experienced engineers. Company lore about methods, procedures, and history is often passed orally, from one engineer to another, and a new engineer learns this information by working with other engineers. The history of what *hasn't* worked in the past is an important part of this oral tradition.

An engineer also gains valuable experience by enduring design *failure*. When the first attempt at a project fails in the testing phase, the wise engineer views it as a learning experience and uses the information to make needed changes and alterations. Experience is acquired by testing prototypes, studying failures, and observing the results of design decisions.

Engineers also must consider the issues of reliability, cost, manufacturability, ergonomics, and marketability when making design decisions. Only by confronting these constraints in real-world situations can an engineer truly gain experience.

Photo courtesy of NASA

1.4.3 Intuition

Intuition is a characteristic normally associated with fortune-tellers, stockbrokers, and baseball players. Successful engineers, however, also employ intuition from time to time. To the engineer, intuition refers to a basic instinct about what will or will not work as a problem solution. In the age of the calculator, it's easy to let the results of key punching (*the calculated volume of my cup is 1.7694 cubic meters*) assume the role of a correct answer over an intuitive feeling for what might actually be reasonable (*a cup can't be as big as my desk*!). Although intuition can never replace careful analysis and meticulous design work, it can help an engineer decide which approach to follow when faced with many choices and no obvious answer. An intuitive feeling for what will work, as well as what will *not* work, grounded in extensive experience and knowledge, can save time by helping an engineer choose the path that will eventually lead to success rather than failure. When intuition is at work, you may hear an engineer using such phrases as "That seems reasonable" or "That answer is plausible."

Intuition is a direct byproduct of design experience and is acquired only through practice, practice, and more practice. In the information age, where much of engineering focuses on the computer, engineers are tempted to solve everything by simulation and computer modeling. While computers have dramatically accelerated the design cycle and have changed the practice of engineering, they make it easy to forget that a product ultimately must obey the idiosyncrasies of the real physical world. Developing intuition about that world is an important part of your engineering education. The difference between a good engineer and an excellent one is often just an instinct for how the laws of nature will manifest themselves in the design process. Will too much power overheat that circuit? Will friction rob that engine of too much power? How much oil can we reliably extract from that shale? How big should the vessel be for a production run of that new cosmetic? Will this ship float? Will this spacecraft fly? Developing intuition should be a key goal of your engineering education.

Examine your own experiences to date to see if you have already acquired some intuition. Do you alter computer settings just to see what happens? Have you opened the hood of the family car just to see what lies beneath it? Have you adjusted the gears on your bicycle? Have you put together a kit or built your science project from raw materials? Have you built a birdhouse? Each of these tasks helps you acquire intuition. Observing the way in which other engineers have laid out the boards of a computer will acquaint you with the techniques of hardware design. Adjusting the gear and brake settings of your bicycle will help you to understand design tradeoffs, such as the conflict between strength and durability versus lightweight construction. Building a birdhouse will acquaint you with the geometrical principles that lie at the core many fields of structural engineering. Becoming knowledgeable in the use of tools will help you to better understand the impact of

your design decisions on manufacturing. Repetition, testing, careful attention to detail, working with more experienced engineers, and dedication to your discipline are the keys to developing design intuition. Design intuition is best acquired by "doing design," that is, by playing with real things.

Professional Success: How to Gain Experience as a Student

This chapter stresses the importance of experience in the life of an engineer. You can begin to acquire design experience even while you are a student. A cooperative education program, if your school has one, is an excellent way to gain experience as an engineer. The typical program places you as an intern in an engineering company for six to twelve months. You'll typically be assigned to a senior engineer to assist in such tasks as computer-aided design, software development, product prototyping, testing, laboratory evaluation, or other work. You'll get to see how the company works, and the company will get to evaluate you as a possible future hire. In addition, you'll be paid for the time you spend at the company.

Students can also gain valuable experience by working in research labs at school. Most professors are delighted to take eager undergraduates into their research laboratories. Most schools list the research interests of the faculty on departmental Web pages. Learn about the research activities of a professor whose class you have enjoyed. Don't be afraid to simply ask if the professor needs help in the lab. Many professors receive industry or government funding for their research, so you may even be paid an hourly wage or a small stipend for your time. You'll be assigned such tasks as fabricating experiments, wiring circuits, writing programs, taking data, preparing test samples, or assisting graduate students.

KEY TERMS

Career
Engineering
Intuition
Knowledge
Management
Profession