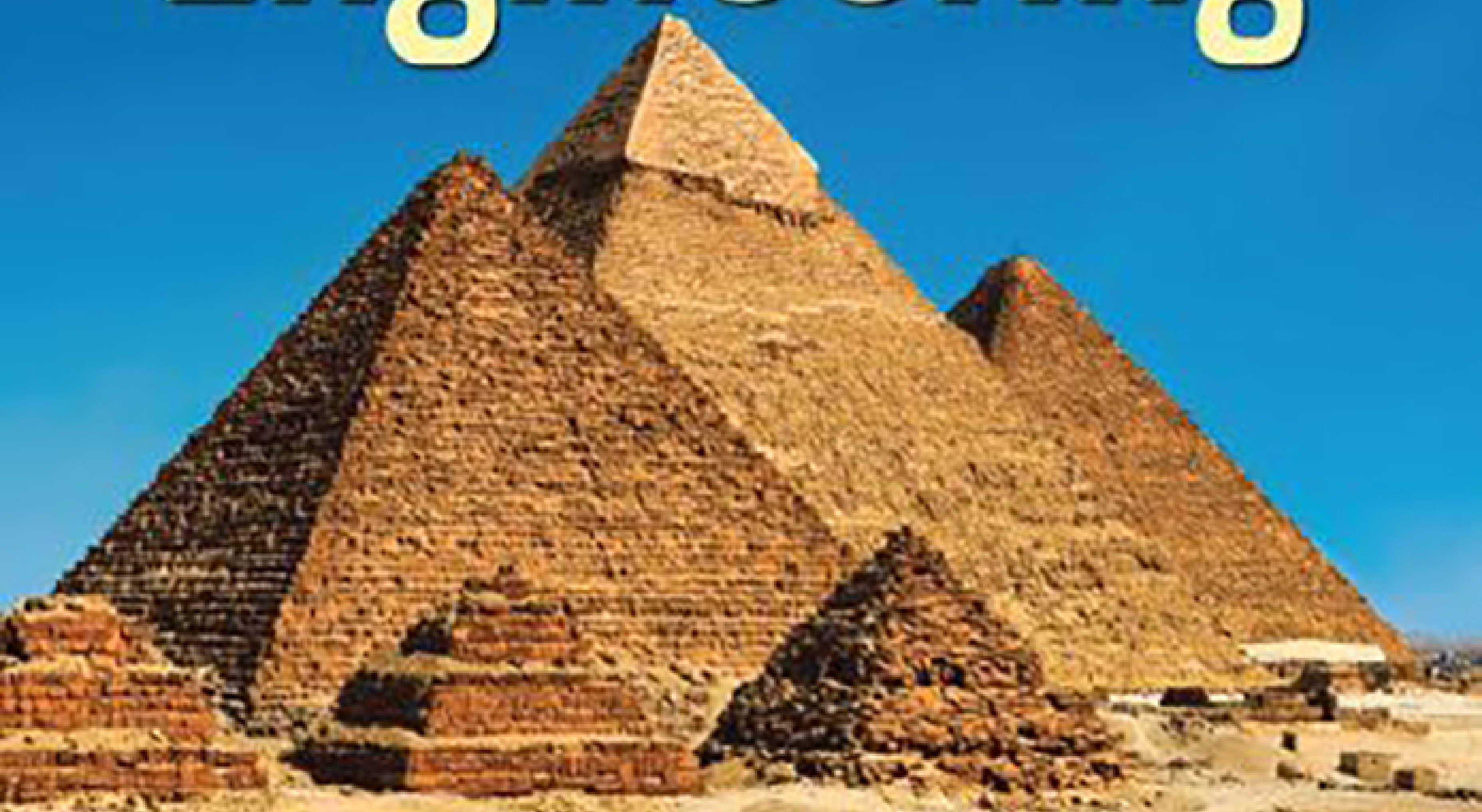
THIRD EDITION

Foundations of Engineering



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Mark Holtzapple
Dan Reece

Foundations of ENGINEERING

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THIRD EDITION

Mark T. Holtzapple
W. Dan Reece
Texas A&M University

McGraw Hill

FOUNDATIONS OF ENGINEERING

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TO THE PROFESSOR

Traditional engineering courses—such as courses on heat transfer, circuits, and fluids—are fairly well defined. In contrast, there is no general agreement on the content of freshman engineering courses. Current freshman engineering texts choose from a range of topics including professionalism, creativity, ethics, design, technical writing, graphing, systems of units, engineering science, and problem solving. All of these topics are important aspects of the freshman engineering experience, but we found no one text that adequately encompassed them all. Therefore, we decided to write our own text to fill the void.

Many freshman engineering texts describe specific engineering disciplines, such as mechanical or electrical engineering, and give sample problems involving statics or electrical circuits. Given the increasing number of new engineering disciplines (e.g., biochemical engineering) and the increasingly interdisciplinary nature of engineering (e.g., mechatronics), we feel this discipline-specific approach is inadequate. Instead, we feel a more unified approach is required, with less emphasis on traditional disciplines. The goals of our text are listed here:

- *Excite the student about engineering.* Most practicing engineers find their work to be very exciting and creative. However, freshmen must struggle with the rigors of their science and mathematics classes, so they may be unaware of the pleasures that await them. We hope to stimulate the students' interest in engineering by describing engineering history, challenging them with "brain teaser" problems, and explaining the creative process.

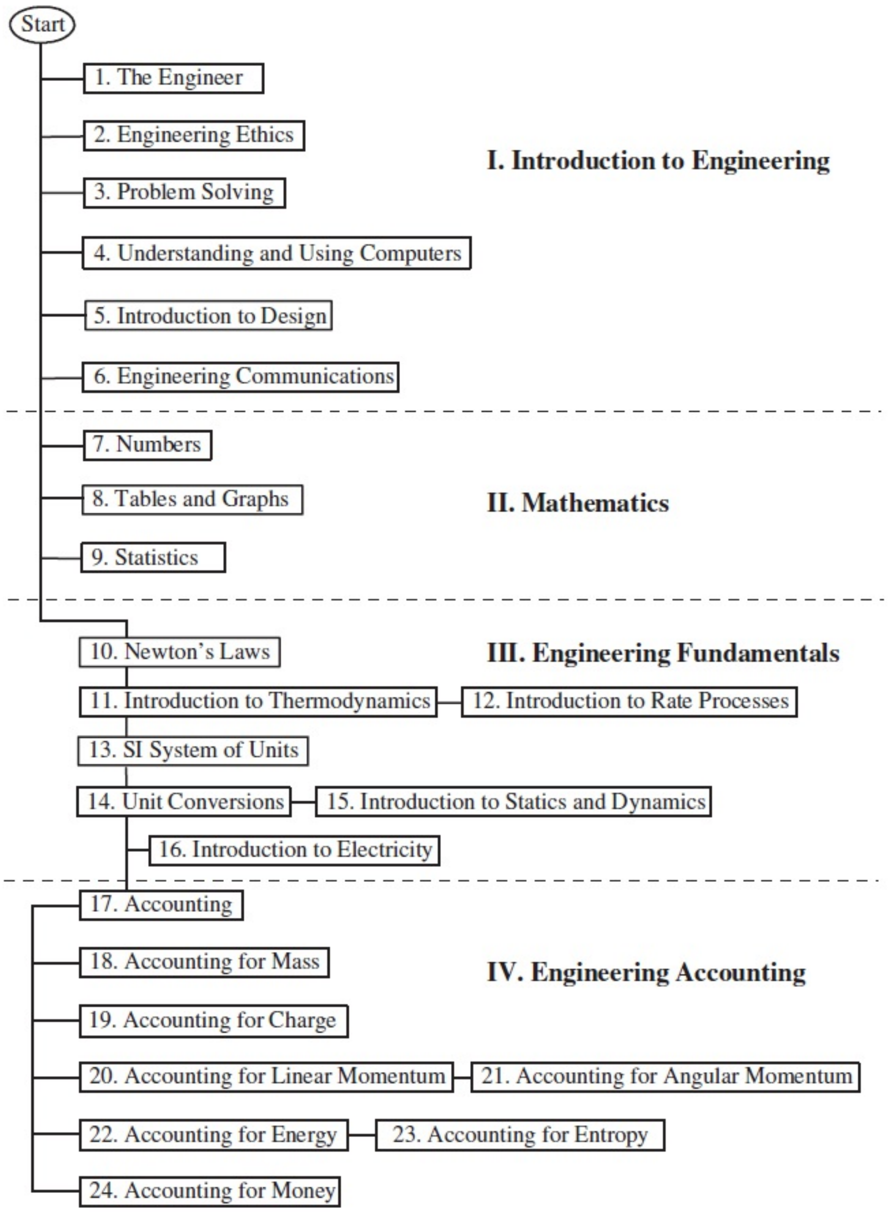
- *Provide a strong foundation in engineering fundamentals.* Engineering has grown beyond the traditional disciplines (e.g., civil, mechanical, and electrical engineering) and now includes nontraditional disciplines (e.g., biomedical, environmental, and nuclear engineering). The common threads through all these disciplines are fundamental physical and mathematical laws.
- *Cultivate problem-solving skills.* The most important engineering skill is the ability to solve problems. We describe many heuristic approaches to creative problem solving as well as a systematic approach to solving well-defined engineering problems.
- *Challenge advanced students.* Students who have good high school backgrounds will have been exposed to calculus and physics. To stimulate their interest in engineering, advanced topics are sprinkled throughout the book.
- *Integrate computing with other engineering topics.* This book contains numerous sample computer programs illustrating a variety of engineering applications. This will help the student realize that computing is not a separate topic, but is a tool used by engineers to solve problems.
- *Provide reference material.* Most students will not purchase handbooks until later in their engineering careers. This book provides unit conversion factors and material properties so that students have the resources to solve real-world problems.
- *Provide information the student is unlikely to encounter elsewhere.* Often, important engineering information that does not fit neatly into advanced courses is put into a freshman engineering course. Thus, this text includes information such as statistics, grammatical rules for the SI system, and graphing rules.
- *Connect with their high school experience.* Many students may be concerned about possible gaps between their actual knowledge and the knowledge college professors expect of them. Touching upon topics with which they are already familiar will ease their anxiety and improve their confidence.
- *Review high school mathematics.* Most freshman engineering students no longer have their high school mathematics textbooks, nor is high school mathematics discussed in college calculus textbooks. For students who need to refresh their mathematics skills, the book's website, http://www.mhhe.com/holtzapple, offers a mathematics supplement

complete with practice problems.

- *Connect with their freshman science and mathematics courses.* Some students may perceive that their freshman science and mathematics classes are a hazing process, and may not understand that these courses form the backbone of engineering. We purposely incorporate topics they see in other courses to show the connection with engineering.
- *Provide "soak time" for difficult topics.* Learning is a process that requires repetition. A few difficult topics that students will encounter in later engineering courses (e.g., thermodynamics, rate processes) are introduced here at a very simple level. This allows them to become acquainted with the ideas, so their next detailed exposure is easier.
- *Introduce the design process.* To help freshmen experience the joy of engineering, we think it is necessary to assign a design problem during their first semester. To support this notion, early in the text, we introduce design.
- *Emphasize the importance of communication skills.* Too often, engineers are criticized for lacking communication skills. To help overcome this problem, we provide information on both oral and written communication that will be immediately useful to freshmen during their design project.

The topics in *Foundations of Engineering* are presented in a sequential manner, so it can be read from front cover to back cover with each new topic building on previously presented topics. Although the book is designed so that it **can** be read from cover to cover, this does not imply that it **must** be read from cover to cover. The accompanying figure indicates how the chapters fit together.

The "road map" in the accompanying figure shows that Chapters 1 through 9 are independent; if you decide to skip these chapters, it will not seriously affect the students' understanding of later chapters. In contrast, Chapters 10, 11, 13, and 14 are interdependent and must be covered in sequence. Chapters 12 and 15 are optional, but if covered, they must be after Chapters 11 and 14, respectively. Chapter 17 sets the stage for all the later chapters and therefore must be covered if the later chapters are taught. Chapters 18, 19, 20, 22, and 24 are independent. If Chapters 21 and 23 are covered, they must be done after Chapters 20 and 22, respectively.



Relationship of book chapters.

In our experience, many students who have the potential to make excellent engineers have a poor command of high school mathematics. Whether they have forgotten it or never learned it, the information is lost to them because they no longer have their high school mathematics texts. To overcome this problem, the book's website includes a review of high school mathematics. At Texas A&M University, we require students to do mathematics homework problems, but do not take class time to discuss these topics because they review high school material. Each chapter with mathematical content informs students of the mathematical prerequisites needed to fully understand the chapter, and directs them to the appropriate section on the website.

If your freshman engineering course is taught in two semesters, it is possible to use the entire book. However, if you are teaching a one-semester course, it is unlikely you will be able to cover all the material. In this case, we suggest that you give the students a “guide map” through the book, indicating which sections you consider to be core testable material and which sections are offered for enrichment purposes only. All the sections are conveniently numbered, so it is possible to be very explicit about what you expect the students to read.

This book is designed to be used in conjunction with a computer programming text. There are computer problems in almost every chapter that can be used to integrate students’ computing knowledge with other engineering topics. Also, this book may be used in conjunction with an engineering graphics text. Obviously one of the most important tools for practicing engineers is the ability to read and create engineering drawings. We mention the importance of graphics several places in our text, but provide no real examples because this subject is very broad and is covered very well by other texts.

McGraw Hill maintains a website at www.mhhe.com/holtzapple that provides supplemental teaching materials. Please visit the site; we’re sure you’ll find it useful.

We hope that you and your students enjoy using this book. We will happily receive suggestions for improvements that may be incorporated into future editions.

Mark T. Holtzapple W. Dan Reece

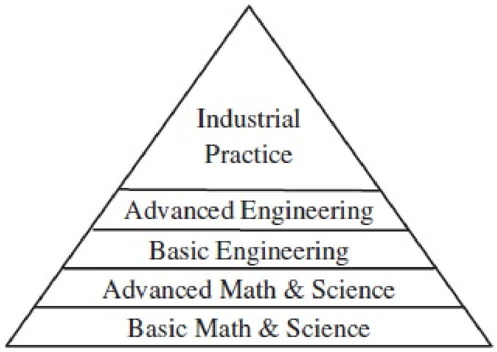
TO THE STUDENT

The engineering profession blossomed in Egypt with the construction of irrigation systems, roads, and pyramids by the first civil engineers. Regardless of the engineering discipline you decide to follow, you can visualize your engineering studies as a construction project in which you are building your knowledge.

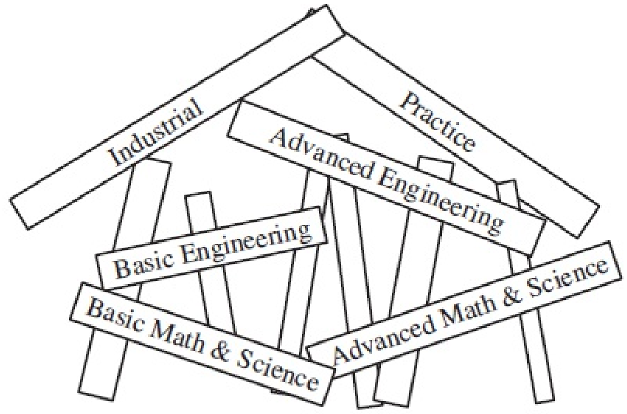
If you are wise, you will construct a pyramid, a well-proven structure that can withstand millennia of weathering. A pyramid is strong because it has a wide foundation. Your wide foundation requires a firm grasp of mathematics and science, which cannot be achieved by memorizing formulas or learning rote procedures. Instead, your objective should be to become “educated” and to *understand*.

Unfortunately, some students take the “plug-and-chug” approach to their engineering studies. They mistakenly believe that real-world engineers mindlessly plug numbers into handbook formulas with little understanding of the underlying principles. They view the required science and mathematics courses as a hazing process to separate the weak from the strong. Students with this attitude are constructing a rickety shack that will blow down in the first strong wind. They will be incapable of solving difficult problems and probably will make no significant engineering contributions to society.

In writing this text, our purpose is to begin your engineering education by providing a firm foundation for your later studies. This is a huge task, so our book is necessarily long and detailed. In fact, it is unlikely that you will be able to cover the entire book in a single semester. Your professor will decide which of the many topics will be covered in your particular course. However, your professor’s decisions should not preclude you from reading on your own. All of the topics in this text should be covered at some point in your studies.



The Educated Engineer



The “Plug-and-Chug” Engineer

We have divided the book into four sections:

- *Introduction to Engineering:* This is an overview of the engineering professions and the skills required to become a good engineer.
- *Mathematics:* We touch on a few mathematical concepts that you are not likely to encounter in your calculus class.
- *Engineering Fundamentals:* We feel the topics discussed here are absolutely fundamental to engineering education. You will be introduced to topics such as thermodynamics, rate processes (e.g., heat transfer, electricity), and Newton’s laws. Unit conversions are given particular attention because this topic is so important.
- *Engineering Accounting:* We have cast the basic conservation laws (e.g., conservation of energy or mass) as a simple “accounting” procedure. We feel that accounting is a unifying concept that transcends the individual engineering disciplines. Here, you have the opportunity to apply your new skills to a variety of problems. The fundamental accounting principles are applied to such quantities as mass, energy, linear momentum, and angular momentum.

In case your high school mathematics is rusty, the book’s website, at http://www.mhhe.com/holtzapple includes a mathematics supplement which reviews topics such as algebra, mathematical notation, probability, geometry, trigonometry, logarithms, polynomials, zeros of equations, and calculus. Each chapter with mathematical content informs you of the mathematical prerequisites needed to fully understand the chapter, and directs you to the appropriate section on the website.

The website also contains useful supplemental learning materials. Please visit the site; we're sure you'll find it useful.

We think of our book as a smorgasbord of delightful delicacies. There are so many delicacies, it is impossible for you to eat them all in a single sitting. However, with many sittings, it is possible for you to enjoy them all.

As many topics as we cover in this book, we still do not attempt to cover everything you will need to know. For several topics of major importance to engineers, particularly engineering graphics and the details of computing, we expect that you are receiving training from other texts. Both topics are essential to the practicing engineer. Even a simple engineering drawing passes more information than several volumes of words alone. Computers have revolutionized engineering. What took hours of drudgery just 20 years ago can now be done in seconds by using personal computers and software.

As shown in the "pyramid of learning" depicted earlier, all engineering disciplines use knowledge gained in mathematics and science courses. In addition, an important foundation of engineering is communications. One of the most important functions of engineers is to present their findings clearly and succinctly, both orally or in writing. It is no accident that English and technical writing are included in your engineering studies! The ability to convey ideas well comes only with hard work, practice, and constructive feedback; this may be the most important skill you have to learn.

We recommend that you hold onto this book. It has many useful charts, tables, conversion factors, and formulas that you will find invaluable in your later studies. Also, the topics are covered in a friendly, unified approach. If you are having troubles grasping a concept in your later studies, we hope you will take this book off your shelf and read—or reread—the appropriate chapters.

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Mark T. Holtzapple is Professor of Chemical Engineering at Texas A&M University. In 1978, he received his BS in chemical engineering from Cornell University. In 1981, he received his PhD from the University of Pennsylvania. His PhD research focused on developing a process to convert fast-growing poplar trees into ethanol fuel.

After completing his formal education, in 1981 Mark joined the U.S. Army and helped develop a portable backpack cooling device to alleviate heat stress in soldiers wearing chemical protective clothing.

After completing his military service, in 1986 Mark joined the Department of Chemical Engineering at Texas A&M University. It quickly became apparent that he had a passion for teaching: within a 2-year period he won nearly every major teaching award offered at Texas A&M, including Tenneco Meritorious Teaching Award, General Dynamics Excellence in Teaching Award, Dow Excellence in Teaching Award, and two awards offered by the Texas A&M Association of Former Students. Mark particularly has a passion for teaching freshman engineering students. He wrote this book to excite students about engineering and to help lay a solid foundation for their future studies.

In addition to his role as an educator, Mark is a prolific inventor. He is developing technologies that desalinate water, store electricity, capture carbon dioxide from flue gas, and store carbon dioxide in building materials. For fun, he is developing a novel flying car. He is also developing a high-efficiency, low-pollution Brayton cycle engine suitable for automotive use. In addition, he is developing technologies for converting waste biomass into useful products, such as animal feeds, industrial chemicals, and fuels. To recognize his contributions in biomass conversion, in 1996 he received the

Presidential Green Chemistry Challenge Award offered by the president and vice president of the United States.

W. Dan Reece

Dr. Reece is a retired professor from the Nuclear Engineering Department and is the former Director of the Nuclear Science Center at Texas A&M University. He received his Bachelor of Chemical Engineering, Master of Science in Nuclear Engineering, and PhD in Mechanical Engineering all at the Georgia Institute of Technology. He has worked as an analytical chemist, a chemical engineer, and a staff scientist at the Pacific Northwest National Laboratory, before his current positions at Texas A&M.

Much of Dr. Reece's research is in the area of radiation monitoring, novel uses of radiation in medicine, and the health effects of radiation. Like Dr. Holtzapple, he has a passion for teaching and has won a Distinguished Teaching Award from the Texas A&M Association of Former Students. Dr. Reece taught many topical courses in dosimetry and health physics, has an active consulting business, and, whenever his schedule allows him free time, enjoys backpacking, playing tennis, and running. His greatest enjoyment comes from his children, his students, and the advances in medicine and worker protection he has helped to make.

SECTION ONE

INTRODUCTION TO ENGINEERING

This book is divided into four sections. This first section addresses the question of what exactly are engineers, and what do they do? In this section we will explore the various disciplines within engineering, some history of engineering, and what characteristics are usually present in good engineers. Next, we examine engineering professionalism and engineering ethics. Lastly, we will look at the most basic activities of engineering: solving problems, using computers, designing things, and communicating findings.

CHAPTER 1

The Engineer

Mathematical Prerequisite

- Geometry (Appendix I, Mathematics Supplement)

Nearly all the manmade objects that surround you result from the efforts of engineers. Just think of all that went into making the chair upon which you sit. Its metal components came from ores extracted from mines designed by mining engineers. The metal ores were refined by metallurgical engineers in mills that civil and mechanical engineers helped build. Mechanical engineers designed the chair components as well as the machines that fabricated them. The polymers and fabrics in the chair were probably derived from oil that was produced by petroleum engineers and refined by chemical engineers. The assembled chair was delivered to you in a truck that was designed by mechanical, aerospace, and electrical engineers, in plants that industrial engineers optimized to make best use of space, capital, and labor. The roads on which the truck traveled were designed and constructed by civil engineers.

Obviously, engineers play an important role in bringing ordinary objects to market. In addition, engineers are key players in some of the most exciting ventures of humankind. For example, the Apollo program was a wonderful enterprise in which humankind was freed from the confinement of earth and landed on the moon. It was an engineering achievement that captivated the United States and the world. Some pundits say the astronauts never should have gone to the moon, simply because all other achievements pale in comparison; however, we say that even more exciting challenges await you and your generation.

1.1 WHAT IS AN ENGINEER?

Engineers are individuals who combine knowledge of science, mathematics, and economics to solve technical problems that confront society. It is our practical knowledge that distinguishes engineers from scientists, for they too are masters of science and mathematics. Our emphasis on the practical was eloquently stated by the engineer A. M. Wellington (1847–1895), who described engineering as “the art of doing . . . well with one dollar, which any bungler can do with two.”

Although engineers must be very cost-conscious when making ordinary objects for consumer use, some engineering projects are not governed strictly by cost considerations. President Kennedy promised the world that the Apollo program would place a man on the moon prior to 1970. Our national reputation was at stake and we were trying to prove our technical prowess to the Soviet Union in space, rather than on the battlefield. Cost was a secondary consideration; landing on the moon was the primary consideration. Thus, engineers can be viewed as problem solvers who assemble the necessary resources to achieve a clearly defined technical objective.

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Engineer: Origins of the Word

The root of the word *engineer* derives from *engine* and *ingenious*, both of which come from the Latin root *in generare*, meaning “to create.” In early English, the verb *engine* meant “to contrive” or “to create.”

The word *engineer* traces to around A.D. 200, when the Christian author Tertullian described a Roman attack on the Carthaginians using a battering ram described by him as an *ingenium*, an ingenious invention. Later, around A.D. 1200, a person responsible for developing such ingenious engines of war (battering rams, floating bridges, assault towers, catapults, etc.) was dubbed an *ingeniator*. In the 1500s, as the meaning of “engines” was broadened, an engineer was a person who made engines. Today, we would classify a builder of engines as a mechanical engineer, because an engineer, in the more general sense, is “a person who applies science, mathematics, and economics to meet the needs of humankind.”

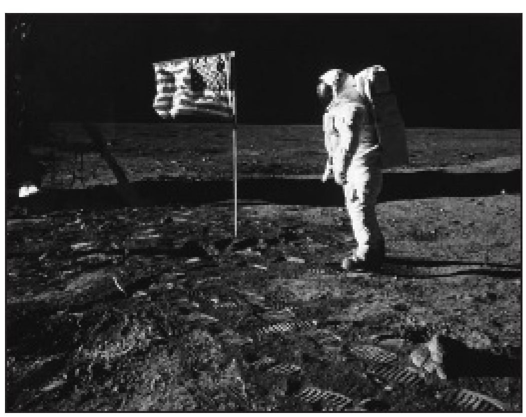
1.2 THE ENGINEER AS PROBLEM SOLVER

Engineers are problem solvers. Given the historical roots of the word engineer (see box above), we can expand this to say that engineers are *ingenious* problem solvers.

In a sense, all humans are engineers. A child playing with building blocks who learns how to construct a taller structure is doing engineering. A secretary who stabilizes a wobbly desk by inserting a piece of cardboard under the short leg has engineered a solution to the problem.

Early in human history, there were no formal schools to teach engineering. Engineering was performed by those who had a gift for manipulating the physical world to achieve a practical goal. Often, it would be learned through apprenticeship with experienced practitioners. This approach resulted in some remarkable accomplishments. Appendix D summarizes some outstanding engineering feats of the past.

Current engineering education emphasizes mathematics, science, and economics, making engineering an "applied science." Historically, this was not true; rather, engineers were largely guided by intuition and experience gained either personally or vicariously. For example, many great buildings, aqueducts, tunnels, mines, and bridges were constructed prior to the early 1700s, when the first scientific foundations were laid for engineering. Engineers often must solve problems without even understanding the underlying theory. Certainly, engineers benefit from scientific theory, but sometimes the solution is required before the theory can catch up to the practice. For example, theorists are still trying to fully explain high-temperature superconductors while engineers are busy forming flexible wires out of these new materials that may be used in future generations of electrical devices.



Fulfilling President Kennedy's promise, the United States landed on the moon in 1969.

1.3 THE NEED FOR ENGINEERING

Appendix D describes how humankind's needs have been met by engineering throughout history. As you prepare for a career in engineering, you should be aware of the problems you will face. Here, we look briefly at some of the challenges in our future.

1.3.1 Resource Stewardship and Utilization

The history of engineering can be viewed as "humans versus nature." Humans made progress when they overcame some of nature's terrors by redirecting rivers, paving land, felling trees, and mining the earth. In view of our large population (about 8 billion), we can claim victory.

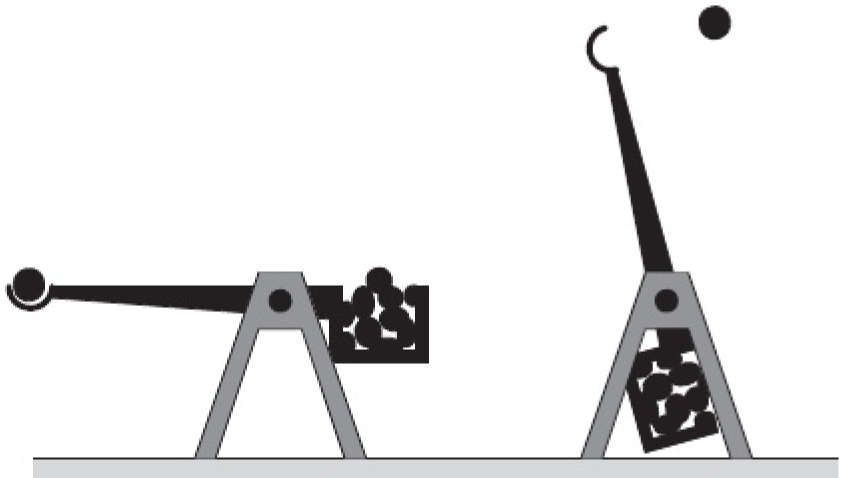
The Trebuchet: An Engine of War

page 4

The trebuchet (pronounced *tray-boo-shay*) pictured below is an ancient "engine" of war. It consists of a long beam that rotates about a fixed fulcrum. One end of the beam has a cup or sling into which the projectile is placed. At the other end is a counterweight that, when released, causes the beam to rotate and throw the projectile into the air.

The trebuchet was invented in China about 2200 years ago and reached the Mediterranean about 1400 years ago. It could throw objects weighing up to 1 ton great distances; in fact, it was used even after the invention of the cannon, because its range was greater than that of early artillery. A modern trebuchet constructed in England could throw a 476-kg car (without engine) 80 meters using a 30,000-kg counterweight. Ancient machines threw stones, dead horses, and even diseased human corpses as a form of biological warfare.

As is often the case, practice preceded theory; trebuchets were constructed and used long before their theory was understood. Many modern concepts, such as force vectors and work (a force exerted over a distance), are thought to have been developed by engineers seeking to improve trebuchet performance. The trebuchet is an example of military necessity causing advances in scientific understanding, a process that is still occurring.



Adapted from: P. E. Chevedden, L. Eigenbrod, V. Foley, and W. Soedel, “The Trebuchet,” *Scientific American*, July 1995, pp. 66–71.

The rising wave of environmentalism results from our recognition that a fundamental change is now required. We can no longer be nature’s adversary, but must become its caretaker. We have become so powerful, we literally can eliminate whole ecosystems either deliberately (e.g., by felling rain forests) or inadvertently (e.g., by releasing pollution into the water and air). Many scientists are also concerned that human activity may result in changing weather patterns due to the release of “greenhouse gases” such as carbon dioxide, methane, chlorofluorocarbons, and nitrogen oxides. Some chlorine-containing gases are implicated in the destruction of the ozone layer, which protects plants and animals from damaging ultraviolet light.

Although we humans have become extremely powerful, we still depend upon nature to provide the basics of life, such as food and oxygen. These basics do not come easily. NASA has spent millions of dollars to develop regenerative life support systems for use on the moon or Mars that allow people to live independently of earth’s life support system. The research continues because the problem is so challenging.

“Sustainable development” is a recent economic philosophy that recognizes humans’ right to live and improve their standard of living, while simultaneously protecting the environment. This philosophy attempts to reshape our economy to achieve sustainability. For example, basing our energy sources on fossil fuels is not sustainable. Eventually they will run out, or the pollution resulting from their use will make the planet uninhabitable. Sustainable development would require the use of renewable energy sources such as solar, wind, and biomass fuels, or “infinite” energy sources such as fission (with breeder reactors) or fusion. Resource conserving, recycling, and nonpolluting technologies are also essential to sustainable development.

page 5

In modern times, many resources are used once and then thrown away. This “one-pass” approach is increasingly unacceptable, because of the finite nature of our resources and because discarded resources cause pollution. Instead, engineers must develop a cyclical approach in which resources are reused. Some products are now designed to be dismantled when their useful life is completed. They are constructed of metals and polymers that can be reformed into new products.

All processes, including the cyclical processes developed by future engineers, are driven by energy. Because energy production expends resources and causes pollution, it is incumbent upon engineers to develop energy-efficient processes. Many of our current processes use energy inefficiently and can be greatly improved by future engineers.

Unavoidably, all processes produce waste. In the future, many engineers will be required to design processes that minimize wastes, produce wastes that can be converted to useful products, or convert the wastes to forms that can be safely stored.

1.3.2 Global Economy

During World War II, while much of the world economy was destroyed, the U.S. economy remained intact. For a few decades immediately following the war, the U.S. economy was very strong with high export levels. Foreign nations wanted our goods—not because they were of superior quality, but because there were few alternatives. In fact, the quality of many U.S. goods actually deteriorated due to sloppy manufacturing practices, adopted because our industry was not challenged by competition.

Today, the world economy is completely different. The economies of the world have long since recovered from the war. Many nations are capable of producing goods that are equal or superior to the quality of U.S. goods. After the war, a product labeled “Made in Japan” was assumed to be of poor quality; today, this label is an indication that the product is well made and affordable.

In a free market, consumers are able to buy products from all over the world. When they select products made in other countries, it represents a loss of jobs for the United States. American industry is meeting this challenge by instituting “quality” into the corporate culture. A company that is committed to quality must identify their customers, learn their requirements, and transform its manufacturing and management practices to create products that meet the customers’ needs and expectations.

Because labor is generally less expensive overseas, many labor-intensive products cannot be economically manufactured in the United States using current technology. However, if engineers develop manufacturing methods that use machines to replace labor, then many of these products can be made in the United States.

Another way for the United States to compete is by developing high-technology products. A major U.S. competitive advantage is our very strong science base. We have a very healthy scientific enterprise in this nation. By translating the latest scientific research into consumer products, we can maintain a competitive edge.

1.4 THE TECHNOLOGY TEAM

Modern technical challenges are seldom met by the lone engineer. Technology development is a complex process involving the coordinated efforts of a technology team consisting of:

A Few Words on Diversity

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To fully describe a person, the list of traits might include intellectual ability, personality, creativity, educational level, hobbies, hair color, skin color, body weight, height, age, physical strength, gender, religion, ethnic background, sexual orientation, nationality, language, parental upbringing, and so forth. The list is long, and there are so many variations within each trait that certainly every person is unique.

Because humanity is so diverse, you can be assured that the teammates on your technology team will be different from you. This diversity will be a source of either strength or weakness, depending upon how you respond to it.

Diversity is a source of strength when people with various backgrounds and abilities all work together on the technical problem. The benefits of diversity have long been recognized; hence the expression “two heads are better than one.” This simple statement recognizes the fact that a single person may not have all the skills necessary to solve a complex problem, but collectively, the needed skills are there. Also, a diverse team has a useful variety of viewpoints. For example, although traditional automobile design teams have been strictly male, women have recently joined these teams. The female teammates have introduced a new perspective to automobile design, making the cars safer and more appealing to women, who constitute about 50% of the car-buying public.

Diversity is a source of weakness if teammates are so different that they cannot communicate, or they mistrust each other and cannot work together toward a common end. This potential weakness results from two common human tendencies: tribalism and overgeneralization. *Tribalism* refers to the fact that during most of human history, people have lived in tribes composed of similar members. When outsiders entered the tribal land, they were often treated with suspicion because they were potential enemies. *Overgeneralization* refers to the fact that in their attempt to understand the world, humans make generalizations from specific observations—but sometimes the generalizations go too far. For example, if Laura were watching a basketball game, she would observe that the team is composed primarily of tall people. After the game, if Laura were to meet Greg, who happens to be seven feet tall, she might assume that Greg plays basketball, when, in fact, he has no interest in the game. Tribalism and overgeneralization prevent people from dealing with each other as individuals; instead, perceived attributes of a group are automatically assigned to an individual. Not acknowledging the true character of a co-worker makes a working relationship impossible.

To gain strength from diversity and avoid potential pitfalls, it is important that the technology team share a common set of core values that allow it to work together. Some sample core values are shown below:

- Teammates are rewarded on the basis of hard work, not politics.
- Teammates are treated with respect.
- Teammates are treated as unique persons with their own skills, talents, abilities, and perspectives.

Adopting these core values, and others, will allow the team to function in harmony and gain strength from diversity.

- *Scientists*, who study nature in order to advance human knowledge. Although some scientists work in industry on practical problems, others have successful careers publishing results that may not have immediate practical applications. Typical degree requirement: BS, MS, PhD.

- *Engineers,* who apply their knowledge of science, mathematics, and economics to develop useful devices, structures, and processes. Typical degree requirement: BS, MS, PhD.
- *Technologists,* who apply science and mathematics to well-defined problems that generally do not require the depth of knowledge possessed by engineers and scientists. Typical degree requirement: BS.
- *Technicians,* who are generally supervised by engineers and scientists to accomplish specific tasks such as drafting, laboratory procedures, and model building. Typical degree requirement: two-year associate's degree.
- *Artisans,* who have the manual skills (welding, machining, carpentry) to construct devices specified by scientists, engineers, technologists, and technicians. Typical degree requirement: high school diploma plus experience.

Elijah McCoy: Mechanical Engineer and Inventor

page 7

Elijah McCoy was born in the early 1840s in Colchester, Ontario, Canada. His parents were former slaves who escaped from Kentucky via the Underground Railroad, a network of individuals who helped slaves reach freedom.

At that time, educational opportunities for blacks were limited, so at age 15, McCoy's parents sent him to study in Scotland, where he achieved the title "master mechanic and engineer." He returned to North America and settled in Detroit, Michigan. During the 1860s, it was difficult for blacks to obtain jobs in the professions, so his first job was a fireman/oilman on the Michigan Central Railroad. As a fireman, he shoveled coal into the firebox. As an oilman, he lubricated the machinery, which had to be stopped for that purpose, causing delays and reducing efficiency. This experience inspired his first patent (U.S. Patent 129,843, issued July 12, 1872), for a device that lubricated machinery while in motion. This lubricating device was so superior to the competition that some engineers would ask if machinery was equipped with *the real McCoy,* a popular American expression meaning *the real thing.* Interestingly, this expression originated in an 1856 advertising slogan *the real MacKay,* used to promote a Scottish brand of whiskey.

During his life, McCoy developed 57 patents. They were issued in the United States, Great Britain, Canada, France, Germany, Austria, and Russia. Among them were an ironing board and a lawn sprinkler.

In 1920, he established the Elijah McCoy Manufacturing Company to manufacture and sell his numerous inventions. He died nine years later in 1929. To honor his achievements as an inventor, he was inducted into the National Inventors Hall of Fame in 2001.

Adapted from the following websites:

www.princeton.edu/~mcbrown/display/mccoy.html
web.mit.edu/www/inventorsI-Q/mccoy.html
www.inventorsmuseum.com/elijahmccoy.htm
www.invent.org/book/book-text/mccoy.htm
www.uselessknowledge.com/word/mccoy.shtml

Successful teamwork results in accomplishments larger than can be produced by individual team members. There is a magic when a team coalesces and each member builds off of the ideas and enthusiasm of teammates. For this magic to occur and to produce output that surpasses individual efforts, several characteristics must be present:

- Mutual respect for the ideas of fellow team members.
- The ability of team members to transmit and receive the ideas of the team.
- The ability to lay aside criticism of an idea during early formulation of solutions to a problem.
- The ability to build on initial or weakly formed ideas.
- The skill to accurately criticize a proposed solution and analyze for both strengths and weaknesses.
- The patience to try again when an idea fails or a solution is incomplete.

1.5 ENGINEERING DISCIPLINES AND RELATED FIELDS

At this point in your engineering career, you may not have selected a major. Does your future lie in mechanical engineering, chemical engineering, electrical engineering, or other engineering fields? Once you have made your selection, you will have decided upon your engineering *discipline.* To help in this decision, we briefly describe the major engineering disciplines and some related fields.

Josephine Garis Cochrane: Inventor of the Dishwasher

In 1839, Josephine Garis was born into an industrious family. Her father, John Garis, was a civil engineer who supervised mills along the Ohio River and drained swamps to develop Chicago during the 1850s. Her great-grandfather, John Fitch, built a steamboat of his own design that served Philadelphia in 1786.

In 1853, at age 19, Josephine Garis married William Cochran, a handsome 27-year-old man who became wealthy in the dry goods business. Josephine was an independent woman—although she took her husband's name, she insisted on ending it with an *e*.

The young socialite couple was popular and had many friends, whom they entertained frequently with elaborate dinner parties using family heirloom china. The servants who washed the china were careless and broke too many plates, so Josephine decided to wash and dry the dishes herself. She soon concluded that this activity wasted her precious time, so she resolved to design a machine that would wash the dishes for her. Within a half hour, she decided that the machine should hold the dishes in a rack and high-pressure water would scrub them clean.

Shortly thereafter, in 1883, Josephine's husband died. Although he was a wealthy man, he had spent more than he earned, leaving her destitute. Nonetheless, with the help of mechanic George Butters, she built the first dishwasher in the shed behind her home, a site now marked with a historical marker. Powered by a hand pump, it cleaned dishes using streams of soapy water. Friends and neighbors came to see the contraption. They were delighted and encouraged her to pursue it further. On December 28, 1886, Mrs. Cochrane received her first patent on the dishwasher.

Because it was expensive, she decided to market her dishwasher to institutions, rather than homes. The Palmer House, a famous Chicago hotel, was her first customer. Her dishwasher could wash and dry 240 dishes within 2 minutes.

Because she had no capital, she hired a contractor to build the units. Relations were strained; the contractor would often ignore her ideas because she had no formal mechanical training and because she was a woman. Further, the contractor took most of the profits, even though she had the brains, patents, entrepreneurial talent, and sales orders. She was not able to raise capital from investors because they refused to invest in a company headed by a woman.

In 1893, nine of her Garis-Cochran dishwashers cleaned dirty dishes at the World's Columbian Exposition, a large fair held in Chicago. Judges awarded her machine the highest prize, stating it had the "best mechanical construction, durability and adaptation to its line of work." The resulting publicity generated more orders. By 1898, Mrs. Cochrane had saved enough money to open her own manufacturing facility and no longer depend on a contractor to build her machines. George Butters became the foreman and oversaw the three employees. Finally, she could work with people who respected her and did not challenge her ideas. Her dishwashers were acclaimed by hotels and other institutions because they saved labor, reduced breakage, and sanitized the dishes. Josephine had succeeded and lived to see her business thrive.

After her death in 1913, the company continued to manufacture dishwashers of her design. In 1926, the company was purchased by Hobart, a manufacturer of well-engineered appliances. Hobart changed the name of the dishwasher subsidiary to KitchenAid, which finally introduced a home dishwasher in the 1940s. Later, KitchenAid was acquired by Whirlpool, a major home appliance manufacturer.

Adapted from: J. M. Fenster, "The Woman Who Invented the Dishwasher," *American Heritage of Invention & Technology,* vol. 15, no. 2, pp. 54–61, Fall 1999.

Figure 1.1 shows when the major engineering disciplines were born. Nearly all disciplines are thought to have evolved from civil engineering. Note that all engineering disciplines require extensive knowledge of physics, whereas chemical and materials engineering require extensive knowledge of physics and chemistry. Some recent disciplines (biochemical and biomedical) require extensive knowledge of physics, chemistry, and biology.

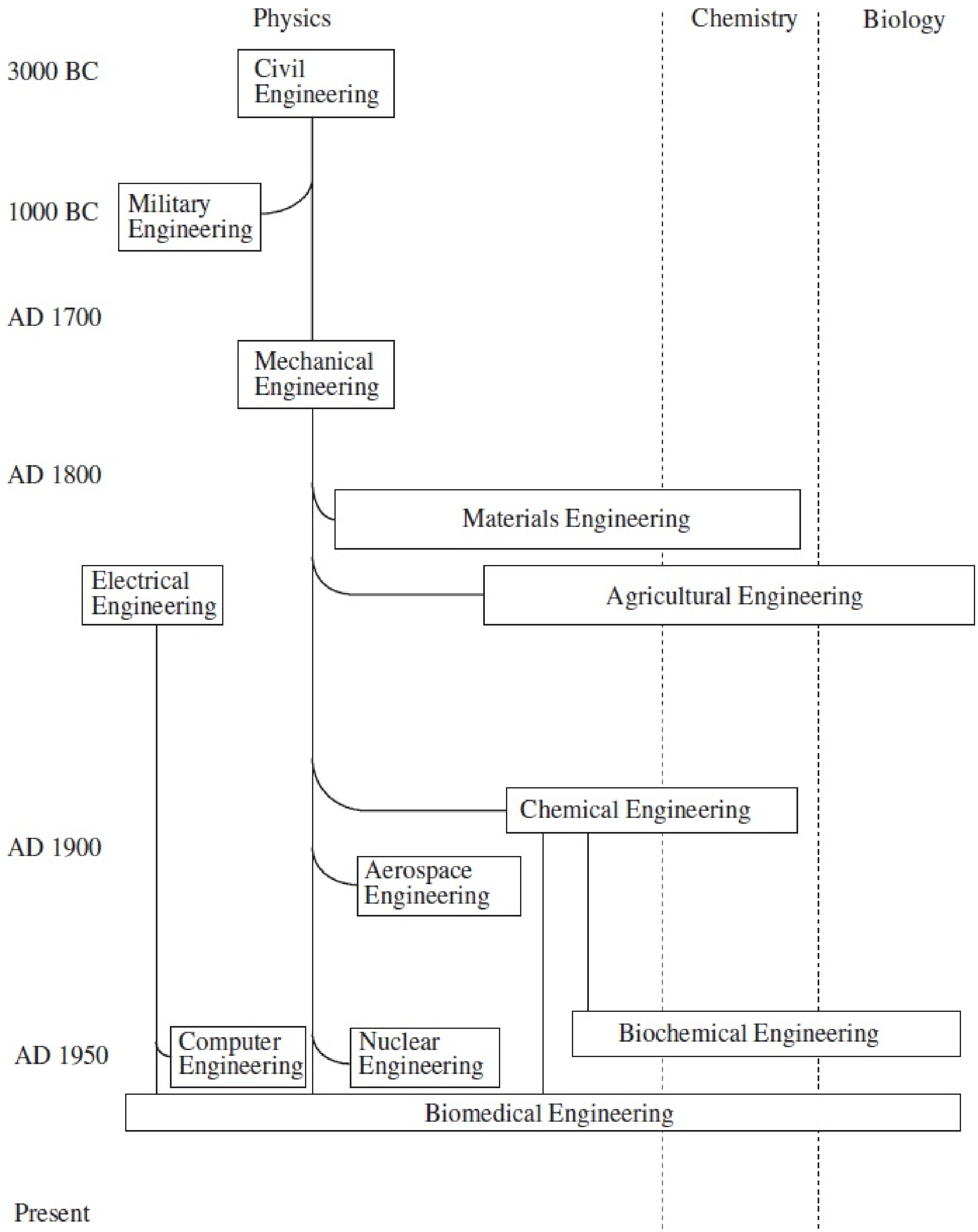

FIGURE 1.1
Birth of engineering disciplines (birth dates are approximate).

1.5.1 Civil Engineering

Civil engineering is generally considered the oldest engineering discipline—its works trace back to the Egyptian pyramids and before. Many of the skills possessed by civil engineers (e.g., building walls, bridges, roads) are extremely useful in warfare, so these engineers worked on both military and civilian projects. To distinguish those engineers who work on civilian projects from those who work on military projects, the British engineer John Smeaton coined the term *civil engineer* in about 1750.

Civil engineers are responsible for constructing large-scale projects such as roads, buildings, airports, dams, bridges, harbors, canals, water systems, and sewage systems.

Ancient Egypt: From Engineer to God

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Egyptian civilization ascended from the Late Stone Age, around 3400 B.C., with vigorous advancements in several engineering fields. While we can still see the spectacular construction feats of the Pyramid Age (3000–2500 B.C.), the ancient Egyptians also pioneered other engineering fields. As hydraulic engineers, they manipulated the Nile River for agricultural and commercial purposes; as chemical engineers, they produced dyes, cement, glass, beer, and wine; as mining engineers, they extracted copper from the Sinai Peninsula for use in the bronze tools that built the pyramids.

One of the key players of this period was Imhotep, known today as "The Father of Stone Masonry Construction." Imhotep served the pharaoh Zoser as chief priest, magician, physician, and head engineer. Most archaeologists credit Imhotep with designing and building the first pyramid, a stepped tomb for Zoser at Sakkara, around 2980 B.C. This pyramid consists of six stages, each 30 feet high, built from local limestone, and hewn with copper chisels. While only 200 feet high (the height of an 18-story building), this unique structure served as a prototype for the Great Pyramid at Giza, constructed 70 years later, which covers four city blocks in area and originally stood 480 feet high.

Imhotep acquired an extensive reputation as a sage, and in later centuries was recognized as the Egyptian god of healing. Although Egyptian civilization saw great engineering progress during the Pyramid Age, 2000 years of stagnation and decline followed.

Hypostyle Hall of Karnak Temple in Luxor, Egypt.
Tatiana-GV/iStock/Getty Images

Courtesy of Seth Adelson, graduate student.

1.5.2 Mechanical Engineering

Mechanical engineering was practiced concurrently with civil engineering because many of the devices needed to construct great civil engineering projects were mechanical in nature. During the Industrial Revolution (1750–1850), wonderful machines were developed: steam engines, internal combustion engines, mechanical looms, sewing machines, and more. Here we saw the birth of mechanical engineering as a discipline distinct from civil engineering.

Mechanical engineers make engines, vehicles (automobiles, trains, planes), machine tools (lathes, mills), heat exchangers, industrial process equipment, power plants, consumer items (typewriters, pens), and systems for heating, refrigeration, air conditioning, and ventilation. Mechanical engineers must know structures, heat transfer, fluid mechanics, materials, and thermodynamics, among many other things.

1.5.3 Electrical Engineering

Soon after physicists began to understand electricity, the electrical engineering profession was born. Electricity has served two main functions in society: the transmission of power and of information. Those electrical engineers who specialize in power transmission design and build electric generators, transformers, electric motors, and other high-power equipment. Those who specialize in information transmission design and build radios, televisions, computers, antennae, instrumentation, controllers, and communications equipment.

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Electronic equipment can be **analog** (meaning the voltages and currents in the device are *continuous* values) or **digital** (meaning only *discrete* voltages and currents can be attained by the device). As analog equipment is more susceptible to noise and interference than digital equipment, many electrical engineers specialize in digital circuits.

Modern life is largely characterized by electronic equipment. Daily, we rely on many electronic devices—televisions, telephones, computers, calculators, and so on. In the future, the number and variety of these devices can only increase.

1.5.4 Chemical Engineering

By 1880, the chemical industry was becoming important in the U.S. economy. At that time, the chemical industry hired two types of technical persons: mechanical engineers and industrial chemists. The chemical engineer combined these two persons into one. The first chemical engineering degree was offered at the Massachusetts Institute of Technology (MIT) in 1888.

Chemical engineering is characterized by a concept called *unit operations.* A unit operation is an individual piece of process equipment (chemical reactor, heat exchanger, pump, compressor, distillation column). Just as electrical engineers assemble complex circuits from component parts (resistors, capacitors, inductors, batteries), chemical engineers assemble chemical plants by combining unit operations together.

Chemical engineers process raw materials (petroleum, coal, ores, corn, trees) into refined products (gasoline, heating oil, plastics, pharmaceuticals, paper). Biochemical engineering is a growing subdiscipline of chemical engineering. Biochemical engineers combine biological processes with traditional chemical engineering to produce food and pharmaceuticals and to treat wastes.

1.5.5 Industrial Engineering

In the late 1800s, industries began to use "scientific management" techniques to improve efficiency. Early pioneers in this field did time-motion studies on workers to reduce the amount of labor required to produce a product. Today, industrial engineers develop, design, install, and operate integrated systems of people, machinery, and information to produce either goods or services. Industrial engineers bridge engineering and management.

Industrial engineers are famous for designing and operating assembly lines that optimally combine machinery and people. However, they can also optimize train or plane schedules, hospital operations, banks, or overnight package delivery services. Industrial engineers who specialize in human factors design products (e.g., hand tools, airplane cockpits) with the human user in mind.

1.5.6 Aerospace Engineering

Aerospace engineers design vehicles that operate in the atmosphere and in space. It is a diverse and rapidly changing field that includes four major technology areas: aerodynamics, structures and materials, flight and orbital mechanics and control, and propulsion. Aerospace engineers help design and build high-performance flight vehicles (e.g., aircraft, missiles, and spacecraft) as well as automobiles. Also, aerospace engineers confront problems associated with wind effects on buildings, air pollution, and other atmospheric phenomena.

1.5.7 Materials Engineering

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Materials engineers are concerned with obtaining the materials required by modern society. Materials engineers may be further classified as:

- *Geological engineers,* who study rocks, soils, and geological formations to find valuable ores and petroleum reserves.
- *Mining engineers,* who extract ores such as coal, iron, and tin.
- *Petroleum engineers,* who find, produce, and transport oil and natural gas.
- *Ceramic engineers,* who produce ceramic (i.e., nonmetallic mineral) products.
- *Plastics engineers,* who produce plastic products.
- *Metallurgical engineers,* who produce metal products from ores or create

metal alloys with superior properties.

- *Materials science engineers*, who study the fundamental science behind the properties (e.g., strength, corrosion resistance, conductivity) of materials.

1.5.8 Agricultural Engineering

Agricultural engineers help farmers efficiently produce food and fiber. This discipline was born with the McCormick reaper. Since then, agricultural engineers have developed many other farm implements (tractors, plows, choppers, etc.) to reduce farm labor requirements. Modern agricultural engineers apply knowledge of mechanics, hydrology, computers, electronics, chemistry, and biology to solve agricultural problems. Agricultural engineers may specialize in food and biochemical engineering; water and environmental quality; machine and energy systems; and food, feed, and fiber processing.

1.5.9 Nuclear Engineering

Nuclear engineers design systems that employ nuclear energy, such as nuclear power plants, nuclear ships (e.g., submarines and aircraft carriers), and nuclear spacecraft. Some nuclear engineers are involved with nuclear medicine; others are working on the design of fusion reactors that potentially will generate limitless energy with minimal environmental damage.

1.5.10 Architectural Engineering

Architectural engineers combine the engineer’s knowledge of structures, materials, and acoustics with the architect’s knowledge of building esthetics and functionality.

1.5.11 Biomedical Engineering

Biomedical engineers combine traditional engineering fields (mechanical, electrical, chemical, industrial) with medicine and human physiology. They develop prosthetic devices (e.g., artificial limbs), artificial kidneys, pacemakers, and artificial hearts. Recent developments will enable some deaf people to hear and some blind people to see. Biomedical engineers can work in hospitals as clinical engineers, in medical centers as medical researchers, in medical industries designing clinical devices, in the FDA evaluating medical devices, or as physicians providing health care.

1.5.12 Computer Science and Engineering

Computer science and engineering evolved from electrical engineering. Computer scientists understand both computer software and hardware, but they emphasize software. In contrast, computer engineers understand both computer software and hardware but emphasize hardware. Computer scientists and engineers design and build computers ranging from supercomputers to personal computers, network computers together, write operating system software that regulates computer functions, or write applications software such as word processors and spreadsheets. Given the increasingly important role of computers in modern society, computer science and engineering are rapidly growing professions.

1.5.13 Engineering Technology

Engineering technologists bridge the gap between engineers and technicians. Engineering technologists typically receive a 4-year BS degree and share many courses with their engineering cousins. Their course work evenly emphasizes both theory and hands-on applications, whereas the engineering disciplines described above primarily emphasize theory with less emphasis on hands-on applications. Engineering technologists can acquire specialties such as general electronics, computers, and mechanics. With their skills, engineering technologists perform such functions as designing and building electronic circuits, repairing faulty circuits, maintaining computers, and programming numerically controlled machine shop equipment.

1.5.14 Engineering Technicians

Engineering technicians typically receive a 2-year associate’s degree. Their education primarily emphasizes hands-on applications with less emphasis on theory. They are involved in product design, testing, troubleshooting, and manufacturing. Their specialties include the following: electronics, drafting, automated manufacturing, robotics, and semiconductor manufacturing.

1.5.15 Artisans

Artisans often receive no formal schooling beyond high school. Typically, they learn their skills by apprenticing with experienced artisans who show them the “tricks of the trade.” Artisans have a variety of manual skills such as machining, welding, carpentry, and equipment operation. Artisans are generally responsible for transforming engineering ideas into reality; therefore, engineers often must work closely with them. Wise engineers highly value the opinions of artisans, because artisans frequently have many years of practical experience.

1.5.16 Engineering Employment Statistics

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Table 1.1 shows the number of engineers employed in the United States. Approximately 1.7 percent of all employees are engineers.

TABLE 1.1

Number of engineers and other professions in the United States

Engineering	Total	Men	Women
Civil	296,415	260,835	35,580
Mechanical	235,040	218,615	16,425
Electrical	181,095	166,735	14,360
Industrial	176,575	140,375	36,200
Aerospace	111,435	99,810	11,625
Chemical	53,875	44,190	9,680
Computer hardware	47,555	41,925	5,630
Materials	33,025	30,260	2,765
Environmental	25,495	18,525	6,970
Petroleum	22,045	18,925	3,120
Biomedical	12,910	10,900	2,010
Marine	10,185	9,115	1,070
Mining	7,925	7,015	915
Nuclear	6,180	5,075	1,105
Agricultural	1,780	—	—
Others	457,085	400,170	56,915
Total	1,678,620	1,472,470	204,370
Computers and Mathematics			
Software developers	1,085,705	886,910	198,800
Computer systems analysts	431,495	258,025	173,470
Computer programmers	358,785	283,500	75,285
Web developers	129,610	87,215	42,395
Information security analysts	72,830	58,875	13,955
Computer scientists	15,920	12,770	3,150
Mathematicians	1,290	1,035	255
Other Professionals			
Lawyers	890,650	568,465	322,185
Physicians	743,005	489,670	253,335
Pharmacists	213,205	96,765	116,435
Architects	154,410	117,970	36,440
Dentists	93,295	66,000	27,295
Scientists			
Chemists	73,010	46,920	26,095
Biologists	61,515	33,630	27,885
Physicists	9,735	7,670	2,070
Total Workers (full-time, >25 years old)	99,399,500	56,659,885	42,739,615
Total Population	322,941,311	158,887,125	164,054,186

Source: U.S. Census (2016)

1.6 ENGINEERING FUNCTIONS

Regardless of their discipline, engineers can be classified by the functions they perform:

- *Research engineers* search for new knowledge to solve difficult problems that do not have readily apparent solutions. They require the greatest training, generally an MS or PhD degree.
- *Development engineers* apply existing and new knowledge to develop prototypes of new devices, structures, and processes.
- *Design engineers* apply the results of research and development engineers to produce detailed designs of devices, structures, and processes that will be used by the public.
- *Production engineers* are concerned with specifying production schedules, determining raw materials availability, and optimizing assembly lines to mass produce the devices conceived by design engineers.
- *Testing engineers* perform tests on engineered products to determine their reliability and suitability for particular applications.
- *Construction engineers* build large structures.
- *Operations engineers* run and maintain production facilities such as factories and chemical plants.
- *Sales engineers* have the technical background required to sell technical products.
- *Managing engineers* are needed in industry to coordinate the activities of the technology team.
- *Consulting engineers* are specialists who are called upon by companies to supplement their in-house engineering talent.
- *Teaching engineers* educate other engineers in the fundamentals of each engineering discipline.

To illustrate the roles of engineering disciplines and functions, consider all the steps required to produce a new battery suitable for automotive propulsion. (The probable engineering discipline is in parentheses and the engineering function is in italics.) A *research engineer* (chemical engineer) performs fundamental laboratory studies on new materials that are possible candidates for a rechargeable battery that is lightweight but stores much energy. The *development engineer* (chemical or electrical engineer) reviews the results of the research engineer and selects a few candidates for further development. She constructs some battery prototypes and tests them for such properties as maximum number of recharge cycles, voltage output at various temperatures, effect of discharge rate on battery life, and corrosion. If the development engineer lacks expertise in corrosion, the company would temporarily hire a *consulting engineer* (chemical, mechanical, or materials engineer) to solve a corrosion problem. When the development engineer has finally amassed sufficient information, the *design engineer* (mechanical engineer) designs each battery model that will be produced by the company. He must specify the exact composition and dimension of each component and how each component will be manufactured. A *construction engineer* (civil engineer) erects the building in which the batteries will be manufactured and a *production engineer* (industrial engineer) designs the production line (e.g., machine tools, assembly areas) to mass produce the new battery. *Operations engineers* (mechanical or industrial engineers) operate the production line and ensure that it is properly maintained. Once the production line is operating, *testing engineers* (industrial or electrical engineers) randomly select batteries and test them to ensure that they meet company specifications. *Sales engineers* (electrical or mechanical engineers) meet with automotive companies to explain the advantages of their company's battery and answer technical questions. *Managing engineers* (any discipline) make decisions about financing plant expansions, product pricing, hiring new personnel, and setting company goals. All of these engineers were trained by *teaching engineers* (many disciplines) in college.

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In this example, the engineering disciplines that satisfy each function are unique to the project. Other projects would require the coordinated efforts of other engineering disciplines. Also, the disciplines selected for this project are an idealization. A company might not have the ideal mix of engineers required by a project and would expect its existing engineering staff to adapt to the needs of the project. After many years, engineers become cross trained in other disciplines, so it becomes difficult to classify them by the disciplines they studied in college. An engineer who wishes to stay employed must be adaptable, which means being well acquainted with the fundamentals of other engineering disciplines.

1.7 HOW MUCH FORMAL EDUCATION IS RIGHT FOR YOU?

Knowledge is expanding at an exponential rate. It is impossible to fully grasp engineering in a 4-year BS degree. Although you will continue learning on the job, your experience there will tend to be narrowly focused on the needs of the company.

As you proceed through your engineering studies, you should ask yourself, How much more formal education do I need? The answer depends upon your ultimate career objectives. Many of the job functions described above can be performed adequately with a BS degree. However, others—like the research engineer and the development engineer—generally require an MS or a PhD. These individuals are engaged in the early stages of product development. More education is required because they must solve more challenging technical problems.

If you think that you would enjoy the technical challenges met by advanced-degree engineers, do not let the educational costs dissuade you. Most graduate schools provide financial assistance to their students in the form of a stipend. Although the stipend does not equal the pay received in industry, it is usually enough to live a comfortable life. Because people with advanced degrees generally earn higher salaries (Figure 1.2), the short-term financial loss may eventually be recouped. Financial gain should not be your primary motivation for obtaining an advanced degree, however. You should consider it only if you would enjoy a job with greater technical challenges.