CONCEPTS IN ENGINEERING

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Mark T. Holtzapple
W. Dan Reece

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TO THE PROFESSOR

Concepts in Engineering introduces fundamental engineering concepts to freshman engineering students. It can be the primary text for a 1- or 2-credit introductory course that focuses on engineering fundamentals common to all engineering disciplines. Alternatively, it can be a supporting text in a 2- or 3-credit course that teaches introductory engineering concepts and other relevant topics, such as engineering computation or graphics. The specific goals of the text follow:

- *Excite students about engineering.* We hope to stimulate students' interest in engineering by describing engineering history, challenging them with "brain teaser" problems, and explaining the creative process.
- *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.
- *Cultivate professionalism.* Students are introduced to various engineering disciplines as well as other members of the technology team. They learn about the traits of successful and creative engineers. Information is provided about the advantages of obtaining advanced degrees and becoming a professional engineer. Also, students are introduced to the important topic of engineering ethics.
- *Provide information students are unlikely to find elsewhere.* This text includes basic information—such as grammatical rules for the SI system and graphing rules—that does not fit neatly into advanced courses.
- *Introduce the design process.* To help freshmen experience the joy of engineering, we think it is necessary for them to work on a design project. To help support this activity, we introduce the design process.
- *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.

Because it uses only high school mathematics, *Concepts in Engineering* can be used by students who are not calculus-ready. For students who need to review their high school mathematics, a mathematics supplement is available in printed form or at the following website: http://www.mhhe.com/holtzapple. It briefly describes algebra, mathematical notation, probability, geometry, trigonometry, logarithms, polynomials, zeros of equations, and calculus. Each chapter in *Concepts in Engineering* that has mathematical content informs students of the prerequisites needed to fully understand the chapter, and directs them to the appropriate chapters in the mathematics supplement.

Concepts in Engineering has a sister text called *Foundations of Engineering* which provides an introduction to the following engineering science topics: computers, statistics, Newton's laws, thermodynamics, rate processes (i.e., heat transfer, fluid flow, electricity, and diffusion), statics and dynamics, and electronics. It also introduces "engineering accounting," a conceptual framework that supports engineers in all disciplines as they count the following: mass, charge, linear momentum, angular momentum, energy, entropy, and money. If you wish to include some of these topics in your course, selected chapters are available from McGraw-Hill Custom Publishing.

McGraw-Hill maintains a website at www.mhhe.com/holtzapple that provides supplemental teaching materials. Please visit the site; we're sure you will 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

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TO THE STUDENT

In a track and field race, those who are well prepared place well, and those who are poorly prepared place poorly. The purpose of *Concepts in Engineering* is to ensure that you are well prepared, so that you will place well in the "race" you are about to begin. *Concepts in Engineering* introduces you to fundamental engineering concepts that are relevant to all engineering disciplines. The specific goals of our text follow:

- *Excite you about engineering.* Both of us are very happy that we studied engineering and enjoy using it to solve real-world problems. We hope to stimulate your interest in engineering by describing engineering history and challenging you with "brain teaser" problems. Also, we want to help develop your creativity, which is a vital part of engineering.
- *Cultivate your problem-solving skills.* Engineers are hired to solve problems. To help you become a skilled problem solver, we describe several approaches to creative problem solving as well as a systematic approach to solving well-defined engineering problems.
- *Cultivate professionalism.* To help you choose your engineering major, we describe various engineering disciplines and how they relate to other members of the technology team, such as scientists and technicians. We also introduce you to engineering ethics and how engineers impact society.
- *Introduce the design process.* The most creative aspect of engineering is design, where we create technologies that address societal needs. To help you get started, we introduce the design process.
- *Emphasize the importance of communication skills.* Too often, engineers are criticized for lacking communication skills. To overcome this problem, we provide information on both oral and written communication that will be useful throughout your career.

Engineers must master mathematics. If you need to review your high school mathematics, a mathematics supplement is available in printed form or at the following website: http://www.mhhe.com/holtzapple. It briefly describes algebra, mathematical notation, probability, geometry, trigonometry, logarithms, polynomials, zeros of equations, and calculus. Each chapter in *Concepts in Engineering* that has mathematical content informs you of the prerequisites needed to fully understand the chapter, and directs you to the appropriate chapters in the mathematics supplement.

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

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Mark T. Holtzapple

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.

In addition to his role as an educator, Mark is a prolific inventor. He is developing an energy-efficient, ecologically friendly air-conditioning system that uses water instead of Freons as the working fluid. 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 Professor in the Nuclear Engineering Department and 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 teaches 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.

CONTENTS

CHAPTER 2
ENGINEERING ETHICS

CHAPTER 3
PROBLEM SOLVING

CHAPTER 4
INTRODUCTION TO DESIGN

CHAPTER 5
ENGINEERING COMMUNICATIONS

CHAPTER 6

NUMBERS

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Concepts in ENGINEERING

Mathematical Prerequisite

- Geometry (Appendix I, Mathematics Supplement)

CHAPTER 1

The Engineer

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.

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.

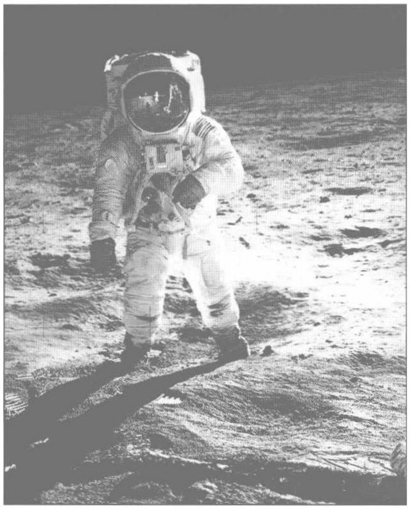


Photo courtesy of NASA/NASA Media Services.

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

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 C 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.

1.3 THE NEED FOR ENGINEERING

Appendix C 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

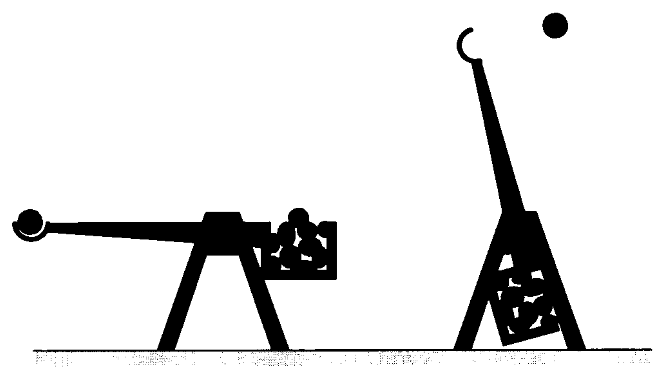
The history of engineering can be viewed as "humans versus nature." Humans made progress when they overcame some of nature's terrors by redirecting rivers, paving land, felling trees, and mining the earth. In view of our large population (about 6 billion), we can claim victory.

The Trebuchet: An Engine of War

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.

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:

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