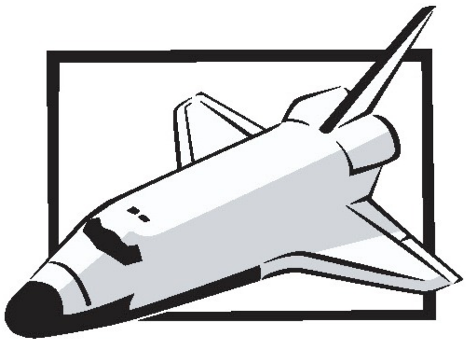


CHAPTER 2
The Engineering Profession

Scientists investigate that which already is;
Engineers create that which never has been.

Theodore Von Karman

INTRODUCTION

This chapter will introduce you to the engineering profession. Look at it as a discussion of "everything you ever wanted to know about engineering"—and then some. Hopefully, when you are finished reading the chapter, you will have a comprehensive understanding of the engineering profession and perhaps have found the engineering niche that attracts you most. This information, coupled with knowledge of the personal benefits you will reap from the profession, is intended to strengthen your commitment to completing your engineering degree.

First, we'll answer the question, "What is engineering?" Through several standard definitions, you'll learn that engineering is essentially the application of mathematics and science to develop useful products or processes. We'll then discuss the engineering design process, which we will demonstrate through a case study of an actual student design project.

To expand your understanding of engineering, we will take stock of the Greatest Engineering Achievements of the 20th Century, selected by the National Academy of Engineering and announced during National Engineers Week 2000. These achievements will show you the critical role engineering plays in making the quality of our life possible.

Next, we will discuss the rewards and opportunities that will come to you when achieve your B.S. degree in engineering. Having a clear picture of the many payoffs will be a key factor in motivating you to make the personal choices and put forth the effort required to succeed in such a challenging and demanding field of study.

We will then examine the various engineering disciplines, the job functions performed by engineers, and the major industry sectors that employ engineers. At the same time, we will open your horizons to the future by describing those fields showing the greatest promise for growth.

The last section of the chapter will focus on engineering as a profession, including the role of professional societies and the importance of professional registration.

2.1 WHAT IS ENGINEERING?

I'm sure you have been asked, ***"What is engineering?"*** I remember my grandmother asking me that question when I was in college. At the time, I didn't have much of an answer. Yet, when you think about it, it is a fundamental question, especially for new engineering students like yourself. So, just what is engineering?

A good starting point for answering this question is the theme for many years of *National Engineers Week*, held each February in honor of George Washington, considered our nation's first engineer. That theme depicts engineering according to its function:

Turning ideas into reality

To reflect the global nature of engineering, starting in 2006, the theme of National Engineers Week was changed to:

Engineers make a world of difference

Both themes are helpful in understanding engineering. The earlier theme suggests what engineers do. The more recent theme underscores the impact what engineers do has on the world.

Over the years, many definitions of engineering have been put forth, from that of the famous scientist Count Rumford over 200 years ago:

Engineering is the application of science
to the common purpose of life

to the current standard definition of engineering provided by the Accreditation Board for Engineering and Technology (ABET) [1]:

> "Engineering is the profession in which a knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of [hu]mankind. "

Harry T. Roman, a well-known New Jersey inventor and electrical engineer, compiled 21 notable definitions of engineering. These are presented in Appendix A.

EXER CISE

Study the 21 definitions of engineering presented in Appendix A. Then compose your own definition of engineering. Write it down and commit it to memory. This may seem like an unnecessary exercise, but I assure you it isn't. Aside from impressing others with a quick informed answer to the question "What is engineering?" this exercise will help clarify your personal understanding of the field.

ONE LAST POINT. The question is often asked: How is engineering different from science? An excellent answer was provided by Astronaut Neil Armstrong in the forward of *A Century of Innovation: Twenty Engineering Achievements That Changed Our Lives* [2]:

> ***Engineering*** is often associated with science and understandably so. Both make extensive use of mathematics, and engineering requires a solid scientific basis. Yet as any scientist or engineer will tell you, they are quite different. Science is a quest for "truth for its own sake," for an ever more exact understanding of the natural world. It explains the change in the viscosity of a liquid as its temperature is varied, the release of heat when water vapor condenses, and the reproductive process of plants. It determines the speed of light. Engineering turns those explanations and understandings into new or improved machines, technologies, and processes—to bring reality to ideas and to provide solutions to societal needs.

LEARNING MORE ABOUT ENGINEERING

As you learn more about the field of engineering, you will find there is no simple answer to the question, "What is engineering?" Because engineers do so many different things and perform so many different functions, learning about engineering is a lifelong process. Still, there are a variety of ways to start this process of learning about and understanding engineering, one being the tremendous amount of information you can access through the Internet.

One helpful web site you should check out is the one connected to National Engineers Week:

http://www.eweek.org

At that web site you can learn much about both engineering and National Engineers Week at the same time. And while at the web site, click on "New Faces in Engineering" and you'll have the opportunity to check out the accomplishments of young engineers (two to five years out of school) who are doing particularly interesting and unique work. Their e-mail addresses are included and you are invited to send your questions to them.

Additional web sites published by other professional engineering societies and the Federal government, such as those listed below, will help further your understanding of the field. The addresses of these sites are:

http://www.engineeringk12.org
http://www.discoverengineering.org
http://www.careercornerstone.org
http://www.jets.org
http://dedicatedengineers.org
http://www.bls.gov/oco/ocos027.htm

I would encourage you to research these web sites to broaden your understanding of engineering. As indicated in Chapter 1, Section 1.4, increasing your knowledge about engineering will strengthen your commitment to engineering study and your motivation to succeed.

2.2 THE ENGINEERING PROCESS

At the heart of engineering is the *engineering process*, sometimes called the *engineering design process*. The engineering design process is a step-by-step method to produce a device, structure, or system that satisfies a need.

Sometimes this need comes from an external source. For example, the U.S. Air Force might need a missile system to launch a 1,000-pound communications satellite into synchronous orbit around the earth. Other times, the need arises from ideas identified within a company. For example, consumers did not initiate the need for various sizes of little rectangular yellow papers that would stick onto almost anything yet be removed easily when 3M invented "Post-its" [3].

Whatever the source, the need is generally translated into a set of specifications ("specs"). These can include performance specifications (e.g., weight, size, speed, safety, reliability), economic specifications (e.g., cost), and scheduling specifications (e.g., production and delivery dates).

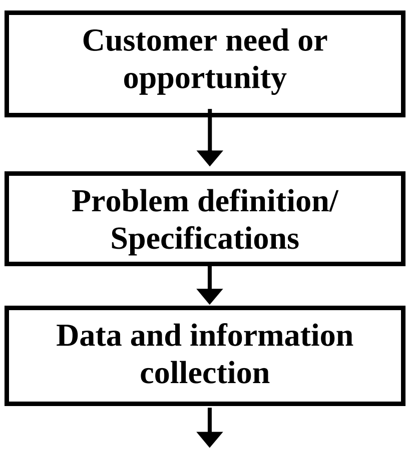
YOUR ALARM CLOCK IS AN EXAMPLE

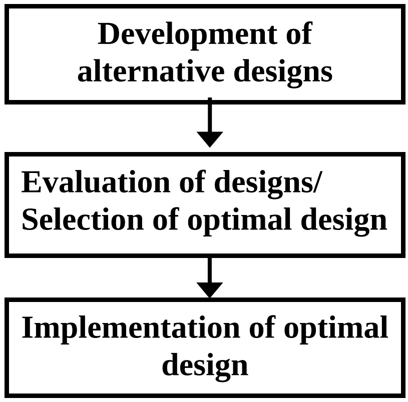
Virtually everything around you was designed by engineers to meet certain specifications. Take the start of your day, for example. You probably wake up to a battery-powered alarm clock. Every design feature of the clock was carefully considered to meet detailed specifications. The alarm was designed to be loud enough to wake you up but not so loud as to startle you. It may even have a feature in which the sound level starts very low and increases progressively until you wake up. The digital display on your clock was designed to be visible day and night. The batteries were designed to meet life, safety, and reliability requirements. Economic considerations dictated material selection and manufacturing processes. The clock also had to look aesthetically pleasing to attract customers, while maintaining its structural integrity under impact loading, such as falling off your night stand.

THE ENGINEERING DESIGN PROCESS

Now that you have been introduced to the first two steps—identifying the need and then drawing up specifications to meet that need—the complete step-by-step design process can be illustrated by the schematic below.

The Engineering Design Process





From this schematic, you can see that each step of the design process reflects a very logical, thorough problem-solving process. The problem definition and specifications (Steps 1 and 2) will need to be supplemented by additional data and information (Step 3) before the development of possible solutions can begin (Step 4). The process of developing and evaluating possible designs (Steps 4 and 5) involves not only creativity but also the use of computer-aided drafting (CAD), stress analysis, computer modeling, material science, and manufacturing processes. Engineers also bring a great deal of common sense and experience to the design process.

During the design process, a number of constraints may be identified. Whatever these constraints may be—e.g., availability of parts and materials, personnel, and/or facilities—the final design must not only meet all design specifications but also satisfy any constraints.

Many iterations through the engineering design process may be required before a final design is selected. Fabrication of some of the designs may be required in order to test how well each meets the performance specifications.

It should be noted that the engineering design process is part of the broader product development cycle that begins with the perception of a market opportunity and ends with the production, sale, and delivery of a product. An excellent resource on this subject is the book *Product Design and Development* by Karl Ulrich and Steven Eppinger [4].

2.3 CASE STUDY: SOLAR-POWERED ELECTRIC VEHICLE

The six steps of the engineering design process make most sense when they are seen in action. We are using an actual case study about the design and construction of a solar-powered vehicle so you can see each step of the process at work.

CUSTOMER NEED OR OPPORTUNITY

In April, 2004, Delft University of Technology in the Netherlands received an invitation from the South Australian Tourism Commission to apply for entry into the 2005 World Solar Challenge. This would be the 8th time since the inception of the race in 1987 that solar-electric vehicles built by teams of engineers at both universities and corporations would race 3,000 km across the Australian continent from Darwin to Adelaide. In this case, the opportunity or need—the first step in the engineering design process—was created by the South Australian Tourism Commission. For information about the World Solar Challenge go to the official web site at:

http://www.wsc.org.au

It was an easy decision for the Delft University team since they were the defending champions, having won both the 2001 and 2003 World Solar Challenge events with their Nuna and Nuna 2 vehicles, respectively. The decision was made to put together an eleven-member Nuna 3 student team to seek an unprecedented "three-peat."

PROBLEM DEFINITION AND SPECIFICATIONS

The primary design specifications, Step 2 of the engineering design process, were established by the race rules. They included the following requirements:

- Maximum vehicle size: Length = 5 meters; Width = 1.8 meters; Height = 1.6 meters
- Minimum height for driver’s eyes: 700 mm
- Solar cell type: No limitation
- Battery type: Commercially available
- Maximum battery capacity: 5.5 Kw-hr
- Safety requirements: Safety belts, helmets, structural roll bar, 15-second unassisted driver egress, brakes, tires, driver vision, steering, electrical systems

For the Delft University Nuna 3 team, these requirements led to additional problem definitions and specifications. Who would lead the team? How much money would the entire project cost? How would it be financed? What facilities would be required? The race rules had specified size and height requirements, but what would be the optimal weight of the vehicle? What materials would be needed to fabricate the vehicle?

DATA AND INFORMATION COLLECTION

Before developing alternative designs that met all the design specifications, the team first had to collect extensive data and information. They needed to learn the technologies associated with electric motor systems, batteries, solar power systems, vehicle aerodynamics, the design and construction of light-weight structures, vehicle suspension and steering systems, mechanical drive systems, and wheels. They also needed to learn about the topography of the race route, expected weather conditions, and solar isolation estimates.

Much of this knowledge built on what had been learned through the Nuna and Nuna 2 projects. However, the challenge of designing an improved vehicle required greater attention to each design issue.

DEVELOPMENT OF ALTERNATIVE DESIGNS

Once they had collected sufficient basic data, the team moved to the next step of the design process: developing alternative designs.

Producing an optimally designed solar-electric vehicle is an excellent example of the type of design tradeoffs that often must be made during this stage of the design process. The Nuna 3 team realized that high performance could be achieved by the following:

- High solar panel power
- Low aerodynamic drag (low drag coefficient; low frontal area)
- Low vehicle weight
- High electrical power system efficiency
- High mechanical drive system efficiency
- Good battery performance
- High overall reliability

However, several of these design parameters conflict. Achieving all of them simultaneously just isn't possible. This is where design tradeoffs enter into the development of alternative designs.

For the Nuna 3 vehicle, the need for certain tradeoffs was immediately apparent. For example, the team knew they could achieve high solar panel power through a large solar panel surface area. They also knew, however, that a large surface area would result in high drag and high vehicle weight.

Low vehicle weight was imperative, but at some point would contribute to poor structural integrity and low overall reliability. Another tradeoff involved the distribution of heavy electrical components (batteries, controllers, etc). Placing them close together would reduce wiring requirements thereby reducing weight and electrical losses. Distributing them optimally would improve vehicle handling and stability. Selection of solar cells required trading off panel power, cost, assembly time, and reliability.

An important step in this stage of the engineering design process is to select performance specifications or design targets for the key design parameters. For example, the Nuna 3 team felt that a top place finish in 2005 World Solar Challenge would be ensured if their vehicle performed to the following specifications:

- Solar panel power (peak) – 2,100 watts
- Aerodynamic drag (Cd x A) - 0.07
- Vehicle weight (exclusive of driver and batteries) – <200 kg
- Electric power system efficiency - >97%
- Battery weight – 30 kg (for 5.5 kw-hr capacity)

And the Nuna 3 team had more than winning in mind. The Nuna 2 vehicle had averaged 97 km/hr in winning the 2003 World Solar Challenge. No solar-powered car had ever topped the 100 km/hr mark in the previous seven races. The Nuna 3 team set its sights on this elusive target.

EVALUATION OF DESIGNS/SELECTION OF OPTIMAL DESIGN

This is one of the most difficult, challenging, and time-consuming steps in the engineering design process. For many engineers, however, it is also the most interesting and rewarding one, for here is where ideas really begin to turn into reality.

For the Nuna 3 team, this step was no different. In evaluating potential designs and selecting the optimal one, they still had numerous hurdles to overcome, and questions to resolve. Although they had faced many of these quandaries in the earlier stages of the design process, they now needed hard answers to such questions as:

- What should the external shape of the vehicle be?
- How can driver comfort be assured without adding to vehicle weight and frontal area?

- What composite materials should be used on specific areas of the vehicle? What fabrication process should be used?
- What fastening techniques (bolting, welding, gluing, riveting) should be used in a multitude of cases?
- What solar cells should be selected?
- What should be the design voltage of the solar panel?
- What motor and motor controller should be used?
- What type of tires and rims should be used?
- What type of brakes should be used?
- What type and how many batteries should be used?
- Which components could be fabricated by the team in-house and which would need to be contracted out?

A number of key questions were answered as follows:

SOLAR CELLS. Three-junction, Gallium Arsenide (GaAs) solar cells having an efficiency of over 26 percent were selected. Since the race was to be conducted in September, a time when the sun is lower in the sky, it was decided to place as many cells as possible on the sides of the vehicle.

AERODYNAMIC DESIGN. An ideal aerodynamic design was developed to minimize frontal area and overall drag coefficient through computer simulations of proposed designs, testing scale models in a small wind tunnel, and finally testing the full scale car in a large wind tunnel.

ELECTRIC MOTOR. The decision was made to refurbish the Drivetek motor used in the Nuna and Nuna 2 vehicles rather than purchase a new slightly more efficient motor. The "wheel motor" was totally encased in the rear wheel to minimize loss through mechanical transmission from the motor to the wheel. Improvements included a 30 percent reduction in weight and higher efficiency (>98%) at the peak power and torque levels.

BATTERIES. The team selected Lithium-polymer batteries made by the South Korean company Kokam. The battery pack considered of six modules of seven cells each, all connected in series. The batteries, the most energy-dense available, had a capacity of 5.5 kw-hr and a total weight of 30 kilograms.

After definitively answering these and other questions, the team settled on their optimal design. A series of drawings of all the parts followed, and the team advanced to the final step of the engineering design process: implementing the optimal design.

IMPLEMENTATION OF OPTIMAL DESIGN

Now began the "real" work, as the title of this last phase of the design process indicates. The Nuna 3 team divided this part of the project into three stages.

The first stage consisted of building the mechanical system, including the overall structure and external body, wheels, steering, and brakes. Once this stage was complete, the vehicle could be pushed around a parking lot or rolled down a hill.

In stage two, they installed the power electronic system—including the motor, motor controls, batteries, and drive system. With this stage finished, the vehicle could be driven around as an actual electric vehicle.

In the third stage, the team installed the solar panels on the body. The panels were prefabricated by Gochermann Solar Technology in Germany according to design details provided by the Nuna 3 team. Needless to say, all of this work required extreme attention to detail, particularly in maintaining the smooth aerodynamic shape of the vehicle.

NUNA 3 TEAM WINS 2005 WORLD SOLAR CHALLENGE

Once the entire design process was completed, on June 21, 2005, the team proudly presented *Nuna 3* at a major media event held at the Circuit Park Zandvoort, a motor speedway near the Dutch beach resort of Zandvoort. The excitement of the entire nation was reflected by the fact that the Dutch band Sonar11 wrote a song "Gone with the Sun" especially for Nuna 3. The team's job was far from over, however. Lots of work remained, such as testing the vehicle's performance, formulating the race strategy, and transporting both the team and vehicle to the World Solar Challenge starting line in Darwin, Australia—a distance of more than 13,000 miles.

Soon the team and Nuna 3 vehicle were in Darwin for several weeks of pre-race activity including test driving and completion of a rigorous scrutineering process. This was the first chance to see the other members of the 21-car field. Front runners included: *Aurora* from Australia, a past winner of the World Solar Challenge; *Momentum* from the University of Michigan, winner of the 2005 North American Solar Challenge; *Tesserac*t from MIT, always a top finisher in solar car racing; and *Sky Ace Tiga* from Ashiya University in Japan, holder of the world speed record for solar powered cars of 165 km/hr.

On the fourth day, the Nuna 3 crossed the finish line at Adelaide, Australia, 3 hours and 24 minutes ahead of second place Aurora. The team accomplished its goal of exceeding an average speed of 100 km/hr, covering the 3,000 kilometer distance in a record 29 hours and 11 minutes, averaging 103 km/hr. For more information on the Nuna 3 project see:

http://www.nuonsolarteam.nl/nuna3/engels/home_eng.php

More information about solar car racing and the design of solar cars can be found in References 5, 6, and 7.

Nuna 3 Solar Powered Vehicle During Test Driving

(Photo by Hans-Peter van Velthoven/Nuon)

THE NEEDS AND OPPORTUNITIES FOR ENGINEERING DESIGN ARE BOUNDLESS

The purpose of chronicling Delft University's solar car project was to illustrate the engineering design process in action. Now that you have seen the logic and demand that each step of the process entails, you should easily be able to come up with a list of the many other problems, needs, and opportunities that would suit its step-by-step approach. Here are just a few ideas that occurred to me. What ideas would you add to this list? Remember, it is entirely possible that, down the road, you will be the engineer who turns one of these needs into reality.

- A device carried by a police officer that would detect a bullet fired at the officer and intercept it.

- A device that would mark the precise location of a football when the referee blows the whistle.
- A system that would not permit an automobile to be stolen.
- A device that would program a VCR to skip the commercials while taping your favorite TV show.
- A machine that would serve ping-pong balls at different speeds and with different spins.
- A device that identifies vehicles that are carrying explosives.
- A car alarm that goes off if the driver falls asleep.
- A device that cuts copper tubing in tight places.
- An in-home composting and recycling system that eliminates the need for sewer or septic systems.
- A device that prevents elderly people from being injured when they fall down.
- An affordable, fuel-cell powered automobile that only emits water vapor.
- A system that continues to tape your favorite morning radio show after you arrive at work so you can listen to it on the way home.
- A high-rise building with an "active suspension system" that responds to ground movement (earthquakes).

2.4 GREATEST ENGINEERING ACHIEVEMENTS OF THE 20^TH^ CENTURY

Although engineering achievements have contributed to the quality of human life for more than 5,000 years [8], the 20th century stands out for its remarkable engineering progress and innovation. In recognition of this, as we entered the 21st century the National Academy of Engineering (NAE) launched a project to select the 20 "Greatest Engineering Achievements of the 20th Century."

The primary selection criterion was the impact of the engineering achievement on the quality of life in the 20th century. William A. Wulf, president of the National Academy of Engineering summed it up well:

> "Engineering is all around us, so people often take it for granted, like air and water. Ask yourself, what do I touch that is not engineered? Engineering develops and delivers consumer goods, builds the networks of highways, air and rail travel, and the Internet, mass produces antibiotics, creates artificial heart valves, builds lasers, and offers such wonders as imaging technology and conveniences like microwave ovens and compact discs. In short, engineers make our quality of life possible."

The following is a listing of the "Greatest Engineering Achievements" presented by Neil Armstrong at the National Press Club in Washington, D.C. on February 22, 2000.

#20 - High Performance Materials
#19 - Nuclear Technologies
#18 - Laser and Fiber Optics
#17 - Petroleum and Gas Technologies
#16 - Health Technologies
#15 - Household Appliances
#14 - Imaging Technologies
#13 - Internet
#12 - Space Exploration
#11 - Interstate Highways
#10 - Air Conditioning and Refrigeration
#9 - Telephone
#8 - Computers
#7 - Agricultural Mechanization
#6 - Radio and Television
#5 - Electronics
#4 - Safe and Abundant Water
#3 - Airplane
#2 - Automobile
#1 - Electrification

Brief descriptions of each is presented in Appendix B. Detailed descriptions of each "great achievement" can be found in an excellent book titled *A Century of Innovation: Twenty Engineering Achievements that Transformed Our Lives* [2] and also on the web at:

http://www.greatachievements.org

2.5 Rewards and Opportunities of an Engineering Career

Engineering is a unique and highly selective profession. Among the 130 million people employed in the United States, only about 1.4 million (1.1 percent) list engineering as their primary occupation [9]. This means the overwhelming majority of people employed in this country do something **other than engineering**.

These employment figures are reflected by national college and university statistics. Engineering typically represents slightly less than five percent of college graduates, as the following table shows [10]:

Major	Number of 2003/04 College Graduates	Percent of Total
Business	307,149	21.9%
Social Sciences	150,357	10.7%
Education	106,278	7.6%
Math and Science	92,819	6.6%
Psychology	82,098	5.9%
Visual and Performing Arts	77,181	5.5%
Health Professions	73,934	5.2%
Engineering	**63,558**	**4.5%**
TOTAL	1,399,542	100.0%

So why choose to study engineering? Why strive to become one of those 4.5 percent of college graduates who receive their B.S. degree in engineering? I'll tell you why.

The benefits of an engineering education and the rewards and opportunities of a career in engineering are numerous. I have frequently led first-year engineering students in a brainstorming exercise to identify these many rewards and benefits. We generally develop a list of 30 to 40 items, which each student then ranks (or deletes) according to personal preferences. For one individual, being well paid may be #1. Someone else may be attracted by the opportunity to do challenging work. Still others may value engineering because it will enable them to make a difference in people's lives.

My personal top ten list is presented on the next page. Although your list may well differ from mine, I am going to discuss each briefly—if only to help you realize more fully the many rewards, benefits, and opportunities an engineering career holds for you.

Ray's Top Ten List

1. **Job Satisfaction**
2. **Varied Opportunities**
3. **Challenging Work**
4. **Intellectual Development**
5. **Social Impact**
6. **Financial Security**
7. **Prestige**
8. **Professional Environment**
9. **Understanding How Things Work**
10. **Creative Thinking**

After studying my list and developing your own, hopefully you will find yourself more determined to complete your engineering studies. You may also find yourself somewhat puzzled by the skewed statistics that opened this section. With so many benefits and job opportunities a career in engineering promises, you'd think that college students would be declaring engineering majors in droves.

I guess engineering really is a unique and highly selective profession. Consider yourself lucky to be one of the "chosen few."

1. JOB SATISFACTION

What would you say is the #1 cause of unhappiness among people in the United States? Health problems? Family problems? Financial problems? No. Studies have shown that, by far, the #1 cause of unhappiness among people in the U.S. is **job dissatisfaction**. And furthermore, Americans are growing increasingly unhappy with their jobs. A study conducted in 2005 for the Conference Board, a leading business membership and research organization, indicated that only half of all Americans are satisfied with their jobs, down from nearly 60 percent in 1995 [11].

Do you know people who dislike their job? People who get up every morning and wish they didn't have to go to work? People who watch the clock all day and can't wait until their workday is over? People who look forward to Fridays and dread Mondays? People who work only to earn an income so they can enjoy their time off? Maybe you have been in one of these situations. Lots of people are.

Throughout my career, it has been very important to me to enjoy my work. After all, I spend eight hours or more a day, five days a week, 50 weeks a year, for 30 or 40 years working. This represents about 40 percent of my waking time. Which would you prefer? Spending 40 percent of your life in a career (or series of jobs) you despise? Or spending that 40 percent in a career you enjoy and love? I'm sure you can see why it is extremely important to find a life's work that is satisfying, work that you want to do.

Engineering could very well be that life's work. It certainly has been for me and for many of my colleagues over the years. But what exactly does "job satisfaction" mean? The remaining items on my "Top Ten List" address this question. Remember, though, these are my preferences; yours may very well be different.

2. VARIED OPPORTUNITIES

While the major purpose of this chapter is to help you understand the engineering profession, you have just skimmed the surface thus far. Your introduction to the engineering field has largely been a "functional" one, starting with the idea that engineering is the process of "turning ideas into reality," followed by a detailed look at the engineering design process—more function.

As you'll learn subsequently, engineering entails much more than just "functions" governed by a rigid six-step design process. In fact, I like to think of engineering as a field that touches almost every aspect of a person's life. I often point out to students that the day you walk up the aisle to receive your B.S. degree in engineering, you have closed no doors. **There is nothing you cannot become from that time forward!** Doctor. Lawyer. Politician. Astronaut. Entrepreneur. Teacher. Manager. Salesperson. Practicing engineer. All these and many others career opportunities are possible.

Here are some examples of people educated as engineers and the professions they ended up in:

ENGINEER	PROFESSION
Neil Armstrong	Astronaut/First Person on Moon
Herbert Hoover	President of the United States
Jimmy Carter	President of the United States
Alfred Hitchcock	Movie Director
Eleanor Baum	Dean of Engineering
Herbie Hancock	Jazz Musician
Paul MacCready	Inventor (Designer GM EV1 Electric Car)
Ellen Ochoa	Space Shuttle Astronaut
Hyman G. Rickover	Father of the Nuclear Navy
Bill Nye	Host of TV Show "Bill Nye The Science Guy"
Boris Yeltsin	Former President of Russia
Alexander Calder	Sculptor
Bill Koch	Yachtsman (Captain of America Cup Team)
W. Edwards Deming	Father of Modern Management Practice
Grace Murray Hopper	U.S. Navy Rear Admiral/Computer Engineer
Ming Tsai	Restaurateur and Star of TV Cooking Show
Montel Williams	Syndicated Talk Show Host
Samuel Bodman	U.S. Secretary of Energy
Michael Bloomberg	Billionaire/Mayor of New York City
A. Scott Crossfield	X-15 Test Pilot
Don Louis A. Ferre'	Governor of Puerto Rico
Yasser Arafat	Palestinian Leader/Nobel Peace Prize Laureate
Tom Landry	Former Dallas Cowboy’s Head Coach
Shiela Widnall	Former Secretary of the Air Force
Robert A. Moog	Father of Synthetic Music
Chester Carlson	Inventor of Xerox Process
John A. McCone	Director of Central Intelligence Agency
Arthur C. Nielsen	Developer of Nielsen TV Ratings

Although none of the above individuals ended up working as a practicing engineer, I expect they would all tell you that their engineering education was a key factor in their subsequent successes. You can learn more about these and other famous "engineers" at:

http://www.engineeringk12.org/students/fun_section/famous_engineers.htm

Personal Story

When I was an engineering student, I had no idea that the career path I have taken even existed. After completing my B.S. and M.S. degrees in Mechanical Engineering at MIT, I worked for five years as a practicing engineer at Rocketdyne, a division of Rockwell International at that time. While doing some part-time teaching to supplement my salary, I developed an interest in an academic career and was able to get a position on the engineering faculty at California State University, Northridge.

Although I enjoyed teaching, my interests shifted more to administration and working with students outside of the classroom. I started the first Minority Engineering Program in California and directed it for ten years. The administrative and management experience I gained led me to the position of Dean of Engineering. My engineering career thus evolved from practicing engineering to teaching it; from teaching it to creating and directing a special program for minority engineering students; and finally from directing a program to managing an entire engineering college.

The field of engineering practice itself offers an enormous diversity of job functions. There are analytical engineers, design engineers, test engineers, development engineers, sales engineers, and field service engineers. The work of analytical engineers most closely resembles the mathematical modeling of physical problems you do in school. But only about ten percent of all engineers fall into this category, pointing to the fact that engineering *study* and engineering *work* can be quite different.

- If you are imaginative and creative, **design engineering** may be for you.
- If you like working in laboratories and conducting experiments, you might consider **test engineering**.

- If you like to organize and expedite projects, look into becoming a **development engineer**.
- If you are persuasive and like working with people, **sales or field service engineering** may be for you.

Later in this chapter, we will examine the wide variety of engineering job functions in more detail. Then, in Chapter 8, we will explore less traditional career paths for which engineering study is excellent preparation, such as medicine, law, and business.

3. CHALLENGING WORK

Do you like intellectual stimulation? Do you enjoy tackling challenging problems? If so, you'll get plenty of both in engineering. Certainly, during your period as an engineering student, you will face many challenging problems. But, as the saying goes, "you ain't seen nothing yet" until you graduate and enter the engineering work world, where there is no shortage of challenging, "open-ended" problems. By "open-ended," I mean there is generally no one "correct" solution, unlike the problems you usually are assigned in school. Open-ended problems typically generate many possible solutions, all of which equally meet the required specifications. Your job is to select the "best" one of these and then convince others that your choice is indeed the optimal one.

It certainly would be helpful if you had more exposure to open-ended problems in school. But such problems are difficult for professors create, take more time for students to solve, and are excessively time-consuming to grade. Regardless, however, of the kind of problem you are assigned (open-ended or single answer; in school or the engineering work-world), they all challenge your knowledge, creativity, and problem-solving skills. If such challenges appeal to you, then engineering could be a very rewarding career.

4. INTELLECTUAL DEVELOPMENT

Engineering education "exercises" your brain much the way weight-lifting or aerobics exercises your body—and the results are remarkably similar. The only difference is that physical exercise improves your body, while mental exercise improves your mind. As your engineering studies progress, therefore, your abilities to solve problems and think critically will increasingly grow stronger.

This connection between mental exercise and growth is by no means "news" to educators. But recent research in the cognitive sciences has uncovered knowledge that explains how and why this process works [12]. We now know, for example, that the brain is made up of as many as 180 billion neuron cells. Each neuron has a very large number of tentacle-like protrusions called dendrites. The dendrites make it possible for each neuron to receive signals (synapses) from thousands of neighboring neurons. The extent of these "neural networks" is determined in large part by the demands we place on our brains—i.e., the "calisthenics" we require of them. So the next time your find yourself reluctant to do a homework assignment or study for a test, just think of all those neural networks you could be building.

One of the things I value most about my engineering education is that it has developed my logical thinking ability. I have a great deal of confidence in my ability to deal effectively with problems. And this is not limited to engineering problems. I am able to use the critical thinking and problem-solving skills I developed through my engineering education to take on such varied tasks as planning a vacation, searching for a job, dealing with my car breaking down in the desert, organizing a banquet to raise money, purchasing a new home, or writing this book. I'm sure you also will come to value the role your engineering education plays in your intellectual growth.

5. Social Impact

I hope you are motivated by a need to do something worthwhile in your career, something to benefit society. Engineering can certainly be an excellent career choice to fulfill such humanitarian goals.

The truth is, just about everything engineers do benefits society in some way. Engineers develop transportation systems that help people and products move about so easily. Engineers design the buildings we live and work in. Engineers devise the systems that deliver our water and electricity, design the machinery that produces our food, and develop the medical equipment that keeps us healthy. Almost everything we use was made possible by engineers.

Depending on your value system, you may not view all engineering work as benefiting people. Some engineers, for example, design military equipment like missiles, tanks, bombs, artillery, and fighter airplanes. Others are involved in the production of pesticides, cigarettes, liquor, fluorocarbons, and asbestos. As an engineer, you will need to weigh the merits of such engineering functions and make your career choices accordingly.

My view is that engineering holds many more beneficial outcomes for society than detrimental ones. For example, opportunities exist for engineers to use their expertise in projects designed to clean up the environment, develop prosthetic aids, develop clean and efficient transportation systems, find new sources of energy, solve the world's hunger problems, and improve the standard of living in underdeveloped countries.

6. FINANCIAL SECURITY

When I ask a class of students to list the rewards and opportunities that success in engineering study will bring them, money is almost always #1. In my "Top Ten List," it's #6. It's not that engineers don't make good money. They do! It's just that money is not a primary motivator of mine.

I've always held the view that if you choose something you like doing, work hard at it, and do it well, the money will take care of itself. In my case, it has. Of course, you may discount my philosophy because of my credentials and career successes. But remember, my engineering career began much the same way yours will—working in industry as a practicing engineer. My subsequent career moves, however, were never motivated by money alone. I hope you too don't make money your primary reason for becoming an engineer. Other reasons, like job satisfaction, challenging work, intellectual development, and opportunities to benefit society hopefully will prove to be more important factors. If they are, you will find the quality of your life enriched tremendously. And I guarantee that "the money will take care of itself," as it has for me.

Let's not lose sight of reality, however! If you do become an engineer, **you will be rewarded financially**. Engineers, even in entry-level positions, are well paid. In fact, engineering graduates receive the highest starting salary of any discipline, as shown in the data below for 2005/06 [13].

Beginning Offers to 2005/06 Graduates

Discipline	Avg. Salary
Engineering	**$51,465**
Computer Sciences	49,680
Engineering Technology	48,514
Nursing	45,347

Business	41,900
Mathematics and Sciences	38,217
Agriculture & Natural Resources	33,716
Education	32,438
Humanities & Social Sciences	31,290
Communications	31,110

You also may be interested to know that of the 20,491 offers reported in this study, 7,964 (38.9 percent) went to business graduates and 5,160 (25.1 percent) went to engineering graduates—disciplines that comprise only 26 percent of all college graduates. The remaining 74 percent received only 36 percent of all job offers. Put another way:

> ***Engineering graduates received almost <u>six</u> times as many job offers as the average number for graduates in all other disciplines.***

If the starting salary data has not convinced you that engineering is a financially rewarding career, perhaps you will be convinced by the fact that many of the world's wealthiest people started their careers with a degree in engineering. You will find a listing of some of these people in Appendix C. As reported by *Forbes Magazine* [14], the personal wealth of these individuals ranges from a high of $30 billion down to $4 billion. I hope this brings the idea home that "the sky is the limit."

EXERCISE

Pick one of the 21 individuals listed in Appendix C among the world's wealthiest *engineers*. Find out as much as you can about the person by conducting an Internet search using a search engine such as Google. What was their major in college? What did they do early in their career? How did they become so wealthy? What lessons can you learn from their success?

7. PRESTIGE

What is *prestige*? The dictionary defines it as "the power to command admiration or esteem," usually derived from one's social status, achievements, or profession. Engineering, as both a field of study and a profession, confers prestige. You may have already experienced the prestige associated with being an engineering major. Perhaps you have stopped on campus to talk with another student and during the conversation, he or she asked, "What's your major?" What reaction did you get when you said, "Engineering"? Probably one of respect, awe, or even envy. To non-engineering majors, engineering students are "the really smart, studious ones." Then, if you reciprocated by asking about that student's major, you may wish you hadn't after getting an apologetic response like, "I'm still undecided."

This hypothetical conversation between an engineering and non-engineering student is not farfetched. In fact, variations of it take place all the time. Everyone knows that engineering study requires hard work, so people assume you must be a serious, highly capable student.

I often ask students to name a profession that is more prestigious than engineering. "Medicine" always comes up first. I tend to agree. Physicians are well paid and highly respected for their knowledge and commitment to helping people live healthier lives. So if you think you want to be a medical doctor and have the ability, arrange to meet with a pre-med advisor as soon as possible and get started on your program. I certainly want to have the most capable people as my doctors.

After medicine, law and accounting are typically cited as more prestigious professions than engineering. Here, however, I disagree, arguing against these and **every other profession** as conferring more prestige than engineering. Anyone who knows anything about engineering would agree that engineers play critical, ubiquitous roles in sustaining our nation's international competitiveness, in maintaining our standard of living, in ensuring a strong national security, in improving our health, and in protecting public safety. I can't think of any other profession that affects our lives in so many vital, significant ways.

Engineers are critical to our:

- **International competitiveness**
- **Standard of living**
- **National security**
- **Personal health**
- **Public safety**

8. PROFESSIONAL ENVIRONMENT

Although engineers can perform a variety of functions and work in many different settings, most new engineering graduates are hired into entry-level positions in "hi-tech" companies. While the nature of your work and status within the company may quickly change, there are certain standard characteristics of all professional engineering work environments.

For one, you will be treated with respect—both by your engineering colleagues and by other professionals. With this respect will come a certain amount of freedom in choosing your work and, increasingly, you will be in a position to influence the directions taken by your organization.

As a professional, you also will be provided with adequate workspace, along with whatever equipment and staff support you need to get your work done.

Another feature of the engineering work environment is the many opportunities you will have to enhance your knowledge, skills, self-confidence, and overall ethos as a professional engineer. Experienced engineers and managers know that new engineering graduates need help in making the transition from college to the "real world." From the outset, then, your immediate supervisor will closely mentor you, giving you the time and guidance to make you feel "at home" in your new environment. She will carefully oversee your work assignments, giving you progressively more challenging tasks and teaming you with experienced engineers who will teach you about engineering and the corporate world.

Once you are acclimated to your new position, your company will see to it that your engineering education and professional development continue. You will frequently be sent to seminars and short courses on a variety of topics, from new engineering methods to interpersonal communications. You may be given a travel allotment so you can attend national conferences of professional engineering societies. You also may discover that your company has an educational reimbursement program that will pay your tuition and fees to take courses at a local university for professional development or to pursue a graduate degree.

You can expect yearly formal assessments of your performance, judged on the merits of your contributions to the company. As a professional, you will not be required to punch a clock, for your superiors will be more concerned about the quantity and quality of your work, not your "time-on-tasks." If you have performed well in these areas, you can usually expect an annual merit salary increase, plus occasional bonuses for a "job particularly well done." Promotions to higher positions are another possibility, although they generally have to be earned over an extended period of time.

Finally, as a professional, you will receive liberal benefits, which typically include a retirement plan, life insurance, medical insurance, dental insurance, sick leave, paid vacation and holidays, and savings or profit-sharing plans.

9. UNDERSTANDING HOW THINGS WORK

Do you know why golf balls have dimples on them? Do you understand how the loads are transmitted to the supports on a suspension bridge? Do you know what nanotechnology is? How optical storage devices work? How fuel cells work? When you drive on a mountain road, do you look at the guard rails and understand why they were designed the way they are? Do you know why split-level houses experience more damage in earthquakes? Do you know why we use alternating current (AC) rather than direct current (DC)? One of the most valuable outcomes of my engineering education is understanding how things around me work.

Furthermore, there are many issues facing our society that depend on an understanding of technology. Why don't we have more zero-emission electric vehicles rather than highly polluting cars powered by internal combustion engines? Should we have stopped building nuclear reactors? What will we use for energy when the earth's supply of oil becomes prohibitively costly or runs out? Can we count on nuclear fusion? Should we have supersonic aircraft, high-speed trains, and automated highways? Is it technically feasible to develop a "Star Wars" defense system that will protect us against nuclear attack? Why are the Japanese building higher quality automobiles than we are building? Can we produce enough food to eliminate world hunger? Do high-voltage power lines cause cancer in people who live or play near them?

Your engineering education will equip you to understand the world around you and to develop informed views regarding important social, political, and economic issues facing our nation and the world. Who knows? Maybe this understanding will lead you into politics.

10. CREATIVE THINKING

Engineering is by its very nature a creative profession. The word "engineer" comes from the same Latin word *ingenium* as the words "genius" and "ingenious." This etymological connection is no accident: engineers have limitless opportunities to be ingenious, inventive, and creative. Do you remember reading about the "Greatest Engineering Achievements of the 20th Century"? You can be sure that creativity played a major role in each of these achievements.

Sometimes new engineering students have difficulty linking "creativity" with "engineering." That's because, at first glance, the terms are likely to invoke their stereotypical connections: "creativity" with art; "engineering" with math, science, and problem solving. The truth, though, is that creativity is practically an essential ingredient of engineering. Consider, for example, the following definition of "creativity," taken from a book entitled *Creative Problem Solving and Engineering Design* [15]:

> ***Playing with imagination and possibilities while interacting with ideas, people, and the environment, thus leading to new and meaningful connections and outcomes.***

This is just what engineers do. In fact, this definition of "creativity" could almost be a definition of "engineering."

To experienced engineers, who regularly engage in solving open-ended, real-world problems, the need for creativity in the engineering process is a given. It would seem particularly important, for example, during Steps 4, 5, and 6 of the engineering design process described in Section 2.2, which involve developing and evaluating alternative possible solutions, followed by the selection of the "best" one. Without an injection of creativity in these steps, the actual "best" solution may be overlooked entirely.

However, these are not the only steps of the engineering design process that involve creativity. Indeed, creativity enters into <u>every</u> step of the process. It would be a good exercise for you to review the six steps of the engineering design process to see how creativity can come into play at each step.

Beyond the engineering process itself, the need for engineers to think creatively is greater now than ever before, because we are in a time when the rate of social and technological changes has greatly accelerated. Only through creativity can we cope with and adapt to these changes. If you like to question, explore, invent, discover, and create, then engineering would be an ideal profession for you.

A wonderful place to explore the way human creativity in art, technology, and ideas has shaped our culture is ***The Engines of Our Ingenuity*** web page:

http://www.uh.edu/engines

There you will find the text of more than 2,150 episodes created and presented on National Public Radio for almost two decades by John Lienhard, professor of mechanical engineering at the University of Houston.

REFLECTION

Review my top ten list of "rewards and opportunities" that will come to you if you are successful in getting your engineering degree. Which one on the list is the most important to you? Money? Prestige? Challenging work? Making a difference in the world? Reflect on the one you chose. Why did you choose it? Why is that one important to you?

2.6 ENGINEERING DISCIPLINES

At this point you should have a general understanding of what engineering is and what engineers do—along, of course, with the many rewards and opportunities that engineering offers. Our goal in the remainder of this chapter is to clarify and broaden that understanding. We'll start by looking at engineering from a new perspective, and that is how engineers can be classified by their academic discipline.

Until recently, engineering has consisted of five major disciplines, which enroll the largest number of students. In rank order, these disciplines are:

- **Mechanical Engineering**
- **Electrical Engineering**
- **Civil Engineering**
- **Chemical Engineering**
- **Industrial Engineering**

A sixth discipline, **Computer Engineering**, has now been added to this list. Initially a subspecialty within electrical engineering (and still organized that way at many institutions), computer engineering has grown so rapidly that universities are increasingly offering separate accredited B.S. degrees in this field. (Given these changes, computer engineering is treated separately in my subsequent discussion of engineering disciplines.)

In addition to the top six disciplines, there are many other more specialized, non-traditional fields of engineering. Aerospace engineering, materials engineering, biomedical engineering, ocean engineering, petroleum engineering, mining engineering, nuclear engineering, and manufacturing engineering are examples of these.

The following table shows the number of programs and the number of degrees awarded in 2004/05 in each engineering discipline. Of the 65,183 B.S. degrees awarded, 80 percent were in the top six disciplines, while 20 percent were in the more specialized, non-traditional fields.

ENGINEERING DISCIPLINES RANKED BY NUMBER OF B.S. DEGREES—2004/05 [16]

Discipline	Number of Accredited Programs	B.S. Degrees Awarded in 2004/05	Percent of Total Degrees
Mechanical Engineering	277	14,947	22.9%
Electrical Engineering	284	12,459	19.1
Civil Engineering	233	8,549	13.1
Computer Engineering	183	8,379	12.9
Chemical Engineering	154	4,521	6.9
Industrial Engineering	97	3,482	5.3
Biomedical Engineering	36	2,410	3.7
Aerospace Engineering	61	2,371	3.6
General Engineering	35	1,179	1.9
Materials Sci/Metallurgical Engr	65	840	1.3
Architectural Engineering	14	722	1.1
Agricultural Engineering	43	635	1.0
Systems Engineering	10	570	0.9
Environmental Engineering	46	522	0.8
Marine/Ocean Engineering	16	477	0.7
Engineering Physics/Engr Sci	32	383	0.6

Petroleum Engineering	16	315	0.5
Engineering Management	11	303	0.5
Nuclear Engineering	18	275	0.4
Mining/Mineral/Geological Engr	32	224	0.3
Manufacturing Engineering	24	165	0.3
Ceramic Engineering	6	81	0.1
Other engineering disciplines	12	1,464	2.2
TOTAL	**1,495**	**65,183**	**100.0%**

To find out which of these engineering programs are offered by the 352 universities in the U.S. that have accredited engineering programs, visit the Accreditation Board for Engineering and Technology (ABET) web site at:

http://www.abet.org/accrediteac.asp

There you can search for listings of accredited engineering programs by discipline (e.g., electrical, mechanical, civil, etc.) and by geographical location (region or state).

What follows is an overview of the engineering disciplines. For each of the top six disciplines, more information and details are provided, while for the smaller disciplines briefer descriptions are given.

ELECTRICAL ENGINEERING

Electrical engineering (including computer engineering) is the largest of all engineering disciplines. According to U.S. Department of Labor statistics, of the 1.4 million engineers working with the occupational title of "engineer" in the U.S. in 2005, 353,000 (26 percent) were electrical and computer engineers [9].

Electrical engineers are concerned with electrical devices and systems and with the use of electrical energy. Virtually every industry utilizes electrical engineers, so employment opportunities are extensive. The work of electrical engineers can be seen in the entertainment systems in our homes, in the automobiles we drive, in the computers used by businesses, in numerically-controlled machines used by manufacturing companies, and in the early warning systems used by the federal government to ensure our national security.

Two outstanding sources of information about electrical engineering careers are the Sloan Career Cornerstone Center web site at:

http://www.careercornerstone.org/eleceng/eleceng.htm

and the Institute of Electrical and Electronic Engineers (IEEE) web site at:

http://www.ieee.org/portal/site

As you will see at the IEEE web site, the IEEE is organized into the following 39 technical societies:

Technical Societies of the IEEE

Aerospace and electronic systems	Antennas and propagation
Broadcast technology	Circuits and systems
Communications	Electromagnetic compatibility
Ultrasonics, ferroelectrics, and frequency control	Components, packaging, and manufacturing technology
Computer	Control systems
Consumer electronics	Education
Computational intelligence	Intelligent transportation systems
Dielectrics and electrical insulation	Electron devices
Engineering management	Industrial electronics
Geoscience and remote sensing	Information theory
Industry applications	Lasers and electro-optics
Instrumentation and measurement	Microwave theory and techniques
Magnetics	Oceanic engineering
Nuclear and plasma sciences	Power engineering
Power electronics	Solid state circuits
Professional communication	Reliability
Robotics and automation	Signal processing
Social implications of technology	Systems, man, and cybernetics
Product safety engineering	Vehicular technology
Engineering in medicine and biology	

The listing of IEEE societies should give you an idea of the scope encompassed by the electrical engineering field. Within electrical engineering programs of study, the above 39 technical areas are generally organized under six primary specialties:

Computer Engineering**
Electronics
Communications
Power
Controls
Instrumentation

[**As explained previously, computer engineering will be discussed later in this section as a separate engineering discipline.]

Electronics deals with the design of circuits and electric devices to produce, process, and detect electrical signals. Electronics is rapidly changing and becoming increasingly important because of new advances in microelectronics. Most notable among these has been the doubling of the number of components that can be placed on a given surface area every two years for the past four decades, which has led to much smaller and more powerful devices. Our standard of living has significantly improved due to the advent of semiconductors and integrated circuits (ICs). Semiconductor products include not just digital ICs but also analog chips, mixed-signal (analog and digital integrated) circuits, and radio-frequency (RF) integrated circuits.

Communications involves a broad spectrum of applications from consumer entertainment to military radar. Recent advances in personal communication systems (e.g., cellular telephones, personal assistants, and GPS systems) and video-conferencing, along with technological advances in lasers and fiber optics, are bringing about a revolution in the communications field, opening up possibilities that were not even dreamed of a few years ago: e.g., on-line video-conferencing, international broadcasting of conferences and tutorials, real-time transfer of huge data files, and transmission of integrated voice/data/video files. Wireless communication allows people to communicate anywhere with anyone by voice, e-mail, text, or instant messaging; to send or receive pictures and data; and to access the Internet.

Power involves the generation, transmission, and distribution of electric power. Power engineers are involved with conventional generation systems such as hydroelectric, steam, and nuclear, as well as alternative generation systems such as solar, wind, ocean tides, and fuel cells. Power engineers are employed wherever electrical energy is used to manufacture or produce a product—petrochemicals, pulp, paper, textiles, metals, and rubber, for example. As such, power engineers must have in-depth knowledge about transmission lines, electric motors, and generators.

Controls engineers design systems that control automated operations and processes. Control systems generally compare a measured quantity to a desired standard and make whatever adjustments are needed to bring the measured quantity as close as possible to the desired standard. Control systems are used in regulating the temperature of our buildings, reducing the emissions from our cars and trucks, ensuring the quality of chemical and industrial processes, maintaining reliable electrical output from our power plants, and ensuring highly efficient and fault tolerant voice and data networks. Unmanned aerial vehicles (UAVs) represent a major new and challenging application of controls engineering.

Instrumentation involves the use of electronic devices, particularly transducers, to measure such parameters as pressure, temperature, flow rate, speed, acceleration, voltage, and current. Instrumentation engineers not only conduct such measurements themselves; they also take part in processing, storing, and transmitting the data they collect.

MECHANICAL ENGINEERING

Mechanical engineering is currently the second largest engineering discipline (behind the combined discipline of electrical and computer engineering) in terms of the number of graduates annually and the third largest in terms of the number of employed engineers. According to the U.S. Department of Labor [9], of the 1.4 million engineers in 2005, 221,000 (15.9 percent) were mechanical engineers. Mechanical engineering is also one of the oldest and broadest engineering disciplines.

Mechanical engineers design tools, engines, machines, and other mechanical equipment. They design and develop power-producing machines such as internal combustion engines, steam and gas turbines, and jet and rocket engines. They also design and develop power-using machines such as refrigeration and air-conditioning equipment, robots, machine tools, materials handling systems, and industrial production equipment.

The work of mechanical engineers varies by industry and function. Specialties include, among others, applied mechanics, design, energy systems, pressure vessels and piping, and heating, refrigeration, and air-conditioning systems. Mechanical engineers also design tools needed by other engineers for their work.

The American Society of Mechanical Engineers (ASME) lists 37 technical divisions.

Technical Divisions of the ASME

Applied mechanics	Internal combustion engines
Bioengineering	Fuels and combustion technologies
Fluids engineering	Nuclear engineering
Heat transfer	Power
Tribology	Advanced energy systems
Aerospace	Fluid power systems and technology
Environmental engineering	Noise control and acoustics
Pipeline systems	Computers and information in engineering
Solid waste processing	Information storage & processing systems
Management	Materials handling engineering
Solar energy	Safety engineering and risk analysis
Process industries	Plant engineering and maintenance
Materials	Technology and society
Petroleum	Nondestructive evaluation engineering
Manufacturing engineering	Ocean, offshore, and artic engineering
Design engineering	Pressure vessels and piping
Rail transportation	Electronic and photonic packaging
Textile engineering	Dynamic systems and control
	Microelectromechanical systems (MEMS)

I'm sure this is an overwhelming list, but it is only the "tip of the iceberg." Each of these technical divisions is divided into a number of technical committees. For example, the Applied Mechanics Division is organized into 17 technical committees, each representing subspecialty within the mechanical engineering field. A partial list of these committees will give you some "flavor" of the applied mechanics area:

Composite materials
Computing in applied mechanics
Dynamics and control of structures and systems
Dynamic response of materials
Fracture and failure mechanics

Elasticity
Experimental mechanics
Geomechanics
Materials processing and manufacturing
Fluid mechanics
Instability in solids and structures
Mechanics in biology and medicine
Integrated structures

Within mechanical engineering study, these numerous technical fields and subspecialties are generally grouped into three broad areas:

Energy

Structures and motion in mechanical systems

Manufacturing

Energy involves the production and transfer of energy, as well as the conversion of energy from one form to another. Mechanical engineers in this area design and operate power plants, study the economical combustion of fuels, design processes to convert heat energy into mechanical energy, and create ways to put that mechanical energy to work. Mechanical engineers in energy-related fields also design heating, ventilation, and air-conditioning systems for our homes, offices, commercial buildings, and industrial plants. Some develop equipment and systems for the refrigeration of food and the operation of cold storage facilities; others design "heat exchange" processes and systems to transfer heat from one object to another. Still others specialize in the production of energy from alternative sources such as solar, geothermal, and wind.

The second major area of mechanical engineering study involves the **design of structures** and the **motion of mechanical systems**. Mechanical engineers in these areas contribute to the design of automobiles, trucks, tractors, trains, airplanes, and even interplanetary space vehicles. They design lathes, milling machines, grinders, and drill presses used in the manufacture of goods. They help design the copying machines, faxes, personal computers, and related products that have become staples in our business and home offices. They are involved in the design of the many medical devices, systems, and equipment that help keep us healthy—and, in some cases, alive. Indeed, every piece of machinery that touches our lives, directly or indirectly, has been designed by a mechanical engineer.

Manufacturing, the third area of mechanical engineering study, is the process of converting raw materials into a final product. To take this process from start to finish, a variety of equipment, machinery, and tools is bound to be needed. Designing and building these requisite equipment and machines are what the manufacturing area of mechanical engineering entails. Put simply, mechanical engineers in this area design and manufacture the machines that make machines. They also design manufacturing processes, including automation and robotics, to help make the production of manufactured goods as efficient, cost-effective, and reliable as possible.

If you are interested in learning more about careers in mechanical engineering, check out the ASME student web site:

http://www.asme.org/Communities/Students

CIVIL ENGINEERING

Civil engineering is the currently the third largest engineering field in terms of graduates annually and the second largest in terms of working engineers. According to the U.S. Department of Labor [9], of the 1.4 million engineers working in the U.S. in 2005, 230,000 (16.4 percent) were civil engineers. Civil engineering is the oldest branch of engineering, with major civil engineering projects dating back more than 5,000 years. Today, civil engineers plan, design, and supervise the construction of facilities essential to modern life. Projects range from high-rise buildings to mass transit systems, from airports to water treatment plants, from space telescopes to off-shore drilling platforms.

The American Society of Civil Engineers (ASCE) is organized into 11 technical divisions and councils that develop and disseminate technical information through conferences, book and journals, and policies and standards:

Technical Divisions of ASCE

Aerospace	Cold regions
Computing	Energy
Engineering mechanics	Forensics
Disaster risk management	Lifelines earthquake engineering
Geomatics	Pipelines
Sustainability	

Within civil engineering study, these 11 technical areas are generally organized into seven academic specialties:

Structural engineering

Transportation engineering

Environmental engineering

Water resources engineering

Geotechnical engineering

Surveying

Construction engineering

Structural engineers design all types of structures: bridges, buildings, dams, tunnels, tanks, power plants, transmission line towers, offshore drilling platforms, and space satellites. Their primary responsibility is to analyze the forces that a structure would encounter and develop a design to withstand those forces. A critical part of this design process involves the selection of structural components, systems, and materials that would provide adequate strength, stability, and durability. Structural dynamics is a specialty within structural engineering that accounts for dynamic forces on structures, such as those resulting from earthquakes.

Transportation engineers are concerned with the safe and efficient movement of both people and goods. They thus play key roles in the design of highways and streets, harbors and ports, mass transit systems, airports, and railroads. They are also involved in the design of systems to transport goods such as gas, oil, and other commodities.

Environmental engineers are responsible for controlling, preventing, and eliminating air, water, and land pollution. To these ends, they are typically involved in the design and operation of water distribution systems, waste water treatment facilities, sewage treatment plants, garbage disposal systems, air quality control programs, recycling and reclamation projects, toxic waste cleanup projects, and pesticide control programs.

Water resources is, by its very title, an engineering specialty focused on water-related problems and issues. The work of engineers in this area includes the operation of water availability and delivery systems, the evaluation of potential new water sources, harbor and river development, flood control, irrigation and drainage projects, coastal protection, and the construction and maintenance of hydroelectric power facilities.

Geotechnical engineers analyze the properties of soil and rocks over which structures and facilities are built. From the information their analyses yield, geotechnical engineers are able to predict how the ground material would support or otherwise affect the structural integrity of the planned facility. Their work is thus vital to the design and construction of earth structures (dams and levees), foundations of buildings, offshore platforms, tunnels, and dams. Geotechnical engineers also evaluate the settlement of buildings, stability of slopes and fills, seepage of groundwater, and effects of earthquakes.

Engineers involved in **Surveying** are responsible for "mapping out" construction sites and their surrounding areas before construction can begin. They locate property lines and determine right-of-ways, while also establishing the alignment and proper placement of the buildings to be constructed. Current surveying practice makes use of modern technology, including satellites, aerial and terrestrial photogrammetry, and computer processing of photographic data.

Construction engineers use both technical and management skills to plan and build facilities—such as buildings, bridges, tunnels, and dams—that other engineers and architects designed. They are generally responsible for such projects from start to finish: estimating construction costs, determining equipment and personnel needs, supervising the construction, and, once completed, operating the facility until the client assumes responsibility. Given the breadth of such projects, construction engineers must be knowledgeable about construction methods and equipment, as well as principles of planning, organizing, financing, managing, and operating construction enterprises.

You can find lots of useful information about civil engineering at the ASCE communities of practice student website at:

http://www.asce.org/community/student/index.cfm

COMPUTER ENGINEERING

Compared to the three previous engineering disciplines we have discussed—electrical engineering, mechanical engineering, and civil engineering—computer engineering a relatively new field. The first accredited computer engineering program in the U.S. was established in 1971 at Case Western Reserve University. Since then, however, computer engineering has experienced rapid growth. It currently ranks fourth in terms of B.S. degrees conferred among engineering disciplines (see table on page 62). And that growth is expected to continue in response to the needs of a world that will become increasingly "computer centered." One indication of the current demand for computer engineers is that the average starting salary for computer engineering graduates in 2005/06 was $53,096 compared to the average for all engineering graduates of $51,465 [13].

Computer engineering, which had its beginnings as a specialty or option within electrical engineering, and continues to rely on much of the same basic knowledge that the EE curriculum teaches, developed into a discipline of its own because of the growing need for specialized training in computer technology. To respond to this need, computer specialists in electrical engineering had to step up their research and course development, which increasingly brought them into contact with computer scientists. Today, although computer engineering and computer science remain separate disciplines, the work of computer engineers and computer scientists is often inseparable—or, more accurately, interdependent. One writer from IEEE aptly explains the relationship between computer engineering and computer science in terms of a "continuum":

> "At one pole is computer science, primarily concerned with theory, design, and implementation of software. It is a true engineering discipline, even though the product is an intangible—a computer program. At the other pole is computer engineering, primarily concerned with firmware (the microcode that controls processors) and hardware (the processors themselves, as well as entire computers). It is not possible, however, to draw a clear line between the two disciplines; many practitioners function to at least some extent as both computer engineers and computer scientists."

While explaining the overlapping nature of the work of computer engineers and scientists, the passage also points out the major difference between them. That is, computer engineers focus more on computer <u>hardware</u>; computer scientists focus more on computer <u>software</u>.

I assume that most of you are already somewhat familiar with these terms. Given their importance in this discussion, however, we'll digress briefly to clarify them. "Hardware" refers to the machine itself: the chips, circuit boards, networks, devices, and other physical components of a computer. "Software" refers to the programs that tell the computer what to do and how to do it. A software program is literally a set of instructions, rules, parameters, and other guidelines, encoded in a special "language" that the hardware can read and then execute. A computer therefore needs both hardware and software, developed in tandem, in order to perform a given function.

As hardware specialists, computer engineers are concerned with the design, construction, assessment, and operation of high-tech devices ranging from tiny microelectronic integrated-circuit chips to powerful systems that utilize those chips and efficient telecommunication systems that interconnect those systems. Applications include consumer electronics (CD and DVD players, televisions, stereos, microwaves, gaming devices) and advanced microprocessors, peripheral equipment (magnetic disks and tapes, optical disks, RAM, ROM, disk arrays, printers and plotters, visual displays, speech and sound software, modems, readers and scanners, keyboards, mouse devices, and speech input systems), systems for portable, desktop and client/server computing, and communications devices (cellular phones, pagers, personal digital assistants). Other applications include distributed computing environments (local and wide area networks, wireless networks, internets, intranets), and embedded computer systems (such as aircraft, spacecraft, and automobile control systems in which computers are embedded to perform various functions). A wide array of complex technological systems, such as power generation and distribution systems and modern processing and manufacturing plans, rely on computer systems developed and designed by computer engineers.

As noted above, however, the work of computer engineers and computer scientists typically involves much crossover. That is, for any given design project, the computer engineer's ability to deliver the appropriate hardware depends on her understanding of the computer scientist's software requirements. As a result, she often participates in the development of the software—and may even create software of her own to support the computer scientist's program. Similarly, the computer scientist's ability to deliver a viable software program depends on his knowledge of hardware. He thus plays a critical role in facilitating the computer engineer's design and development of the necessary physical components, systems, and peripheral devices.

An excellent study "Computer Engineering 2004: Curriculum Guidelines for Undergraduate Degree Programs in Computer Engineering" conduced by a joint task force of the IEEE Computer Society and the Association for Computing Machinery (ACM) lists 18 primary disciplines that make up the body of knowledge for computer engineering [17]. These are:

Algorithms

Computer architecture and organization

Computer systems engineering

Circuits and signals

Database systems

Digital logic

Digital signal processing

Electronics

Embedded systems

Human-computer interaction

Computer networks

Operating systems

Programming fundamentals

Social and professional issues

Software engineering

VLSI design and fabrication

Discrete structures

Probability and statistics

Each of these knowledge areas is further subdivided into sub areas. To give a sense of the scope of the field of computer engineering, for example, the area of "Electronics" includes the following sub areas:

Electronic properties of materials
Diodes and diode circuits
MOS transistors and biasing
MOS logic families
Bipolar transistors and logic families
Design parameters and issues
Storage elements
Interfacing logic families and standard buses
Operational amplifiers
Circuit modeling and simulation
Data conversion circuits
Electronic voltage and current sources
Amplifier design
Integrated circuit building blocks

SYSTEMS ANALYST. Whatever work computer engineers engage in, it is typically generated by some company or government need, which if you recall the engineering design process, leads to a problem definition and specifications. Identifying these needs and initiating design projects to solve them are the responsibility of **systems analysts.** Comprising another fast growing field of computer technology, systems analysts are charged with planning, developing, and selecting new computer systems, or modifying existing programs to meet the needs of an organization. Although their training is in Management Information Systems (as opposed to engineering or computer science), systems analysts are highly computer-literate specialists who work as corporate "watchdogs" to ensure that their company is realizing the maximum benefits from its investment in equipment, personnel, software, and business practices.

COMPUTER SCIENTISTS. Finally, since computer engineers work so frequently—and so closely—with computer scientists, a brief overview of that field would provide a fitting conclusion to our discussion of computer engineering. Computer scientists have already been distinguished as the software experts in the general field of computer technology. As software specialists, their work tends to be highly theoretical, involving extensive, complex applications of math and science principles, algorithms, and other computational processes. However, we have also seen that their theoretical work requires a concomitant knowledge of the many physical components, processes, and functional requirements of computers. The Computing Sciences Accreditation Board (CSAB) begins its definition of the discipline as one that

> "involves the understanding and design of computers and computational processes . . . The discipline ranges from theoretical studies of algorithms to practical problems of implementation in terms of computational hardware and software."

The definition continues, but these two statements alone aptly describe the computer science discipline.

Computer science programs in the U.S. are accredited by the Accreditation Board for Engineering and Technology (ABET) in conjunction with the Computer Science Accreditation Board (CSAB), an organization representing the three largest computer and computer-related technical societies: the Association of Computing Machinery (ACM); the Association for Information Systems (AIS); and the IEEE-Computer Society. During 2004/05, 11,785 computer science degrees were awarded by the 214 universities having accredited computer science programs.

Computer science curricula are comprised of a broad-based core and advanced level subjects. The core provides basic coverage of algorithms, data structures, software design, concepts of programming languages, and computer organization and architecture. Examples of advanced areas include algorithms and data structures, artificial intelligence and robotics, computer networks, computer organization and architecture, database and information retrieval, human-computer interaction, numerical and symbolic computation, operating systems, programming languages, software methodology and engineering, and theory of computation. (It is interesting to note that many of these areas are the same ones listed above for computer engineering. These shared areas only reinforce the overlap and similarities between computer science and computer engineering.)

More information about computing and computer science can be found at the following web sites:

Computer Science Accreditation Board	http://www.csab.org
IEEE Computer Society	http://www.computer.org
Association of Computing Machines	http://www.acm.org
Association for Information Systems	http://plone.aisnet.org

CHEMICAL ENGINEERING

Chemical engineers combine their engineering training with a knowledge of chemistry to transform the laboratory work of chemists into commercial realities. They are most frequently involved in designing and operating chemical production facilities and manufacturing facilities that use chemicals (or chemical processes) in their production of goods.

The scope of the work of chemical engineers is reflected by the industries that employ them—manufacturing, pharmaceuticals, healthcare, design and construction, pulp and paper, petrochemicals, food processing, specialty chemicals, microelectronics, electronic and advanced materials, polymers, business services, biotechnology, and environmental health and safety.

The work of chemical engineers can be seen in a wide variety of products that affect our daily lives, including plastics, building materials, food products, pharmaceuticals, synthetic rubber, synthetic fibers, and petroleum products (e.g., shampoos, soaps, cosmetics, shower curtains, and molded bathtubs).

Chemical engineers also play a major role in keeping our environment clean by creating ways to clean up the problems of the past, prevent pollution in the future, and extend our shrinking natural resources. Many play equally important roles in helping to eliminate world hunger by developing processes to produce fertilizers economically.

The scope of chemical engineering is reflected by the 18 divisions and forums of the American Institute of Chemical Engineers (AIChE):

Divisions and Forums of the AIChE

Catalysis and Reaction Engineering	Environmental
Computational Molecular Science & Engineering	Food, Pharmaceutical & Bioengineering
Computing & Systems Technology	Fuels & Petrochemicals
Transport and Energy Processes	Management
Materials Engineering & Sciences	Nuclear Engineering
Nanoscale Science Engineering	Particle Technology
North American Mixing	Process Development
Safety & Health	Separations
Sustainable Engineering	Forest Products

You can learn more about chemical engineering careers by visiting the AIChE web page at:

http://www.aiche.org/Students/Careers/index.aspx

INDUSTRIAL ENGINEERING

Industrial engineers determine the most effective ways for an organization to use its various resources—people, machines, materials, information, and energy—to develop a process, make a product, or provide a service. Their work does not stop there, however, for they also design and manage the quality control programs that monitor the production process at every step. They also may be involved in facilities and plant design, along with plant management and production engineering.

These multiple responsibilities of an industrial engineer require knowledge not only of engineering fundamentals, but also of computer technology and management practices. At first glance, the industrial engineer might be seen as the engineering equivalent of a systems analyst—except that the industrial engineer plays many more roles and has a much wider window of career opportunities.

Perhaps the single most distinguishing characteristic of industrial engineers is their involvement with the human and organizational aspects of systems design. Indeed, the Institute of Industrial Engineers (IIE) describes industrial engineering as "The People-Oriented Engineering Profession."

Sixty percent of industrial engineers are employed by manufacturing companies, but industrial engineers can be found in every kind of institution (e.g., financial, medical, agricultural, governmental) and commercial field (e.g., wholesale and retail trade, transportation, construction, entertainment, etc.).

Given its breadth of functions in so many areas, industrial engineering has been particularly impacted by recent advances in computer technology, automation of manufacturing systems, developments in artificial intelligence and database systems, management practices (as reflected by the "quality movement"), and the increased emphasis on strategic planning.

The scope of industrial engineering can been seen from the 11 technical societies and divisions of the IIE:

Technical Societies and Divisions of the IIE

Engineering & Management Systems	Quality Control & Reliability Engineering
Work Science	Applied Ergonomics
Computer & Information Systems	Construction
Engineering Economy	Lean
Operations Research	Process Industries
Health Systems	

The unique role of industrial engineering in improving productivity, reducing costs, enhancing customer satisfaction, and achieving superior quality is perhaps reflected by the fact that the IIE includes a *Lean* Division. To learn more about industrial engineering, visit the IIE web site at:

http://www.iienet2.org

OVERVIEW OF OTHER ENGINEERING DISCIPLINES

The following sections provide an overview of each of the more specialized, non-traditional engineering disciplines.

BIOENGINEERING/BIOMEDICAL ENGINEERING. Bioengineering is a wide-ranging field, alternatively referred to as biomedical engineering, which was created some 40 years ago by the merging interests of engineering and the biological/medical sciences. Bioengineers work closely with health professionals in the design of diagnostic and therapeutic devices for clinical use, the design of prosthetic devices, and the development of biologically compatible materials. Pacemakers, blood analyzers, cochlear implants, medical imaging, laser surgery, prosthetic implants, and life support systems are just a few of the many products and processes that have resulted from the team efforts of bioengineers and health professionals.

Biomedical engineering is a field in continual change and creation of new areas due to rapid advancement in technology; however, some of the well established specialty areas within the field are: bioinstrumentation; biomaterials; biomechanics; cellular, tissue and genetic engineering; clinical engineering; medical imaging; orthopedic surgery; rehabilitation engineering; and systems physiology. For more information about careers in biomedical engineering, see the Biomedical Engineering Society (BMES) web page at:

http://www.bmes.org/careers.asp

AEROSPACE ENGINEERING. Aerospace engineers design, develop, test, and help manufacture commercial and military aircraft, missiles, and spacecraft. They also may develop new technologies in commercial aviation, defense systems, and space exploration. In this work, they tend to focus on one type of aerospace product such as commercial transports, helicopters, spacecraft, or rockets. Specialties within aerospace engineering include aerodynamics, propulsion, thermodynamics, structures, celestial mechanics, acoustics, and guidance and control systems.

For more information about aerospace engineering, go to the American Institute of Aeronautics and Astronautics (AIAA) web page at:

http://www.aiaa.org/content.cfm?pageid=214

MATERIALS ENGINEERING/METALLURGICAL ENGINEERING. Materials engineers are generally responsible for improving the strength, corrosion resistance, fatigue resistance, and other characteristics of frequently used materials. The field encompasses the spectrum of materials: metals, ceramics, polymers (plastics), semiconductors, and combinations of materials called composites. Materials engineers are involved in selecting materials with desirable mechanical, electrical, magnetic, chemical, and heat transfer properties that meet special performance requirements. Examples are graphite golf club shafts that are light but stiff, ceramic tiles on the Space Shuttle that protect it from burning up during reentry into the atmosphere, and the alloy turbine blades in a jet engine.

The materials field offers unlimited possibilities for innovation and adaptation through the ability to actually engineer, or create, materials to meet specific needs. This engineering can be carried out at the atomic level through the millions of possible combinations of elements. It can also be done on a larger scale to take advantage of unique composite properties that result from microscopic-scale combinations of metals, ceramics and polymers, such as in fiber reinforcement to make a graphite fishing rod or, on a slightly larger scale, for steel-belted radial tires. Finally, it can be practiced on an even larger scale with bridges, buildings, and appliances.

Metallurgical engineers deal specifically with metals in one of the three main branches of metallurgy—extractive, physical, and mechanical. Extractive metallurgists are concerned with removing metals from ores, and refining and alloying them to obtain useful metal. Physical metallurgists study the nature, structure, and physical properties of metals and their alloys, and design methods for processing them into final products. Mechanical metallurgists develop and improve metal-working processes such as casting, forging, rolling, and drawing.

For more information about materials engineering, go to the Materials Science & Engineering Career Resource Center web site at:

http://www.crc4mse.org/Index.html

ARCHITECTURAL ENGINEERING. Architectural engineers work closely with architects on the design of buildings. Whereas the architect focuses primarily on space utilization and aesthetics, the architectural engineer is concerned with safety, cost, and sound construction methods.

Architectural engineers focus on areas such as the following: the structural integrity of buildings to anticipate earthquakes, vibrations and wind loads; the design and analysis of heating, ventilating and air conditioning systems; efficiency and design of plumbing, fire protection and electrical systems; acoustic and lighting planning; and energy conservation issues.

AGRICULTURAL ENGINEERING. Agricultural engineers are involved in every aspect of food production, processing, marketing, and distribution. Agricultural engineers design and develop agricultural equipment, food processing equipment, and farm structures. Major technical areas of agricultural engineering include food processing, information and electrical technologies, power and machinery, structures, soil and water, forestry, bioengineering, and aqua culture. With their technological knowledge and innovations, agricultural engineers have literally revolutionized the farming industry, enabling farmers today to produce approximately ten times more than what they could just 100 years ago.

For more information on agricultural engineering, visit the American Society of Agricultural and Biological Engineers (ASABE) web site at:

http://www.asabe.org/membership/beengin.html

SYSTEMS ENGINEERING. Systems engineers are involved with the overall design, development, and operation of large, complex systems. Their focus is not so much on the individual components that comprise such systems; rather, they are responsible for the integration of each component into a complete, functioning "whole." Predicting and overseeing the behavior of large-scale systems often involves knowledge of advanced mathematical and computer-based techniques, such as linear programming, queuing theory, and simulation.

For more information on systems engineering, visit the International Council on Systems Engineering (INCOSE) web site at:

http://www.incose.org

Click on "Education & Careers." Then click on "Careers in SE."

ENVIRONMENTAL ENGINEERING. Environmental engineers, relying heavily on the principles of biology and chemistry, develop solutions to environmental problems. Environmental engineers work in all aspects of environmental protection including air pollution control, industrial hygiene, radiation protection, hazardous waste management, toxic materials control, water supply, wastewater management, storm water management, solid waste disposal, public health, and land management.

Environmental engineers conduct hazardous-waste management studies in which they evaluate the significance of the hazard, offer analysis on treatment and containment, and develop regulations to prevent mishaps.

They design municipal water supply and industrial wastewater treatment systems. They conduct research on proposed environmental projects, analyze scientific data, and perform quality control checks. They provide legal and financial consulting on matters related to the environment. For information about environmental engineering, see the American Academy of Environmental Engineers (AAEE) web site at:

http://www.aaee.net/Website/Careers.htm

MARINE ENGINEERING/OCEAN ENGINEERING/NAVAL ARCHITECTURE. Naval Architects, Marine Engineers, and Ocean Engineers design, build, operate, and maintain ships and other waterborne vehicles and ocean structures as diverse as aircraft carriers, submarines, sailboats, tankers, tugboats, yachts, underwater robots, and oil rigs. These interrelated professions address our use of the seas and involve a variety of engineering and physical science skills, spanning disciplines that include hydrodynamics, material science, and mechanical, civil, electrical, and ocean engineering

Marine Engineers are responsible for selecting ships' machinery, which may include diesel engines, steam turbines, gas turbines, or nuclear reactors, and for the design of mechanical, electrical, fluid, and control systems throughout the vessel. Some marine engineers serve aboard ships to operate and maintain these systems. Ocean Engineers study the ocean environment to determine its effects on ships and other marine vehicles and structures. Ocean engineers may design and operate stationary ocean platforms, or manned or remote-operated sub-surface vehicles used for deep sea exploration. Naval Architects are involved with basic ship design, starting with hull forms and overall arrangements, power requirements, structure, and stability. Some naval architects work in shipyards, supervising ship construction, conversion, and maintenance.

For more information on marine engineering, ocean engineering, and naval architecture, visit the Society of Naval Architects & Marine Engineers web site at:

http://www.sname.org/careers.htm

PETROLEUM ENGINEERING. Petroleum engineers work in all capacities related to petroleum (gas and oil) and its byproducts. These include designing processes, equipment, and systems for locating new sources of oil and gas; sustaining the flow of extant sources; removing, transporting, and storing oil and gas; and refining them into useful products.

For more information about petroleum engineering, go to the Society of Petroleum Engineering (SPE) web site at:

http://www.spe.org

Click on "Career Development" and then click on "About Petroleum Engineers."

NUCLEAR ENGINEERING. Nuclear engineers are concerned with the safe release, control, utilization, and environmental impact of energy from nuclear fission and fusion sources. Nuclear engineers are involved in the design, construction, and operation of nuclear power plants for power generation, propulsion of nuclear submarines, and space power systems. Nuclear engineers are also involved in processes for handling nuclear fuels, safely disposing radioactive wastes, and using radioactive isotopes for medical purposes.

MINING ENGINEERING/GEOLOGICAL ENGINEERING. The work of mining and geological engineers is similar to that of petroleum engineers. The main difference is the target of their efforts. That is, mining and geological engineers are involved in all aspects of discovering, removing, and processing minerals from the earth. The mining engineer designs the mine layout, supervises its construction, and devises systems to transport minerals to processing plants. The mining engineer also devises plans to return the area to its natural state after extracting the minerals.

MANUFACTURING ENGINEERING. Manufacturing engineers are involved in all aspects of manufacturing a product. These include studying the behavior and properties of required materials, designing appropriate systems and equipment, and managing the overall manufacturing process.

To learn more about manufacturing engineering, visit the Society of Manufacturing Engineers (SME) web site at:

http://www.manufacturingiscool.com

CERAMIC ENGINEERING. Ceramic engineers direct processes that convert nonmetallic minerals, clay, or silicates into ceramic products. Ceramic engineers work on products as diverse as glassware, semiconductors, automobile and aircraft engine components, fiber-optic phone lines, tiles on space shuttles, solar panels, and electric power line insulators.

REFLECTION

Reflect on the 20 engineering disciplines described in this section. Have you already decided which one you will major in? Why did you choose it? If you haven't yet chosen a specific engineering discipline, which one is the most appealing to you at this point in time? What specifically about it do you find appealing?

2.7 ENGINEERING JOB FUNCTIONS

Another way to understand the engineering profession is to examine engineers from the perspective of the work they do or the job functions they perform. For example, an electrical engineer could also be referred to as a *design* engineer, a *test* engineer, or a *development* engineer—depending on the nature of his or her work. Following is a description of the nine main engineering job functions.

ANALYSIS

The **analytical engineer** is primarily involved in the mathematical modeling of physical problems. Using the principles of mathematics, physics, and engineering science—and making extensive use of engineering applications software—the analytical engineer plays a critical role in the initial stage of a design project, providing information and answers to questions that are easy and inexpensive to obtain. Once the project moves from the conceptual, theoretical stage to the actual fabrication and implementation stage, changes tend to be time-consuming and costly.

DESIGN

The **design engineer** converts concepts and information into detailed plans and specifications that dictate the development and manufacture of a product. Recognizing that many designs are possible, the design engineer must consider such factors as production cost, availability of materials, ease of production, and performance requirements. Creativity and innovation, along with an analytic mind and attention to detail, are key qualifications for a design engineer.

TEST

The **test engineer** is responsible for developing and conducting tests to verify that a selected design or new product meets all specifications. Depending on the product, tests may be required for such factors as structural integrity, performance, or reliability—all of which must be performed under all expected environmental conditions. Test engineers also conduct quality control checks on existing products.

DEVELOPMENT

The **development engineer,** as the title indicates, is involved in the development of products, systems, or processes. The context in which such "development" occurs, however, can vary considerably. Working on a specific design project, the development engineer acts as a kind of "intermediary" between the design and test engineers. He helps the design engineer to formulate as many designs as possible that meet all specifications and accommodate any constraints. Once a design is selected, the development engineer oversees its fabrication—usually in the form of a prototype or model. The results of his collaboration with the design engineer and subsequent supervision of the prototype's fabrication are bound to affect the kind and amount of testing the test engineer will then need to conduct.

In a more general context, the development engineer is instrumental in turning concepts into actual products or applying new knowledge to improve existing products. In this capacity, he is the "D" in "R&D," which, as you probably know, stands for the Research and Development arm of many companies. Here, the development engineer is responsible for determining how to actualize or apply what the researcher discovers in the laboratory, typically by designing, fabricating, and testing prototypes or experimental models.

SALES

The **sales engineer** is the liaison person between the company and the customer. In this role, the sales engineer must be technically proficient in order to understand the product itself and the customer's needs. That means she must be able to explain the product in detail: how it operates, what functions it can perform, and why it will satisfy the customer's requirements. She also needs to maintain a professional working relationship as long as the customer is using her company's products. She must be able to field questions about the product, explain its features to new users, and arrange prompt, quality service should the customer experience problems with the product. Obviously, along with solid technical knowledge, the sales engineer must possess strong communication skills and related "people" skills.

RESEARCH

The work of the **research engineer** is not unlike that of a research scientist in that both are involved in the search for new knowledge. Where they differ is the purposes that motivate their work. Scientific researchers are generally interested in the new knowledge itself: what it teaches or uncovers about natural phenomena. Engineering researchers are interested in ways to apply the knowledge to engineering practices and principles. Research engineers thus explore mathematics, physics, chemistry and engineering sciences in search of answers or insights that will contribute to the advancement of engineering.

Given the nature and demands of their work, research engineers usually need to have an advanced degree in their field. Indeed, most positions available in engineering research require a Ph.D.

MANAGEMENT

If you are successful as an engineer and have strong leadership skills, within a few years of graduation you could very well move into management. Opportunities exist primarily in two areas: **line management** and **project management**.

In a company, the technical staff is generally grouped into an engineering "line organization." At the base of this "line" are units of ten to 15 engineers, who are managed by a unit supervisor. At the next level up the line, these units report to a group manager. This organizational line continues up to department managers, a chief engineer or engineering vice president, and finally the president. Often the president of a technical company is an engineer who worked his or her way up through the line organization.

Project management is a little different, as the personnel are organized according to a specific project or assignment. At the head of each project is a project manager. For a small project, one manager is usually sufficient to oversee the entire project; for a larger project, the project manager is assisted by a professional staff, which can range from one to several hundred people. The overall responsibility of the project manager and staff is to see that the project is completed successfully, on time, and within budget.

CONSULTING

The work of the **consulting engineer** differs from that of all other engineers in that a consulting engineer performs services for a client on a contractual basis. Some consulting engineers are self-employed, while others work for consulting firms that "hire out" their engineers to companies that either lack the expertise the consulting engineer can provide or want an outside evaluation of their organization's performance. Depending on the client's specific needs, the consulting engineer's work can vary considerably. Investigations and analyses; preplanning, design and design implementation; research and development; construction management; and recommendations regarding engineering-related problems are just a few examples.

The time a consulting engineer puts into each assignment also can vary. Sometimes the work can be done in a day; other times it can require weeks, months, or even years to complete. Last, engineering consulting is increasingly becoming a global enterprise. Both the public and private sectors of developing nations have growing technological needs and so turn to U.S. consulting firms for technical assistance. If the diversity of work and opportunity to travel catch your interest, a career in engineering consulting could be for you.

TEACHING

The **engineering professor** has three primary areas of responsibility: teaching, research, and service. Teaching includes not only classroom instruction, but also course and curriculum development, laboratory development, and the supervision of student projects or theses. Research involves the pursuit of new knowledge, which is then disseminated throughout the professional engineering community by papers published in engineering journals, presentations at scholarly meetings, textbooks, and software. The research demands of the engineering educator also include success in generating funds to support research projects, as well as participation in professional societies. "Service" is a catch-all term that refers to the many other functions expected of engineering professors. These include such activities as community involvement, participation in faculty governance, public service, and consulting.

The Ph.D. degree in engineering is virtually mandatory to qualify for a full-time position on an engineering faculty at a four-year institution, while an M.S. degree is generally sufficient for a teaching position at a community college. More information about academic careers in engineering can be found in Reference 18.

REFLECTION

Reflect on the nine engineering job functions described in this section. Which of them is the most appealing to you? Analysis? Design? Test? Development? Sales? Research? Could you see yourself in management? Could you see yourself as an engineering professor?

2.8 EMPLOYMENT OPPORTUNITIES

When you graduate in engineering, you will face a number of choices. The first will be whether you want to continue your education full time or seek work as a practicing engineer. If you elect to continue your education, you next need to decide whether you want to pursue your M.S. degree in engineering or do graduate work in another field, such as business administration, law, or medicine. Opportunities for graduate study will be discussed in Chapter 8.

If you decide to seek a full-time engineering position, many opportunities and choices will await you. The field of engineering practice is so vast and the job opportunities so varied, you may well need to devote a substantial amount of time to understand fully the opportunities and areas of practice available to you.

Rather than waiting until you graduate to learn about the many opportunities that engineering has to offer, you should make this an objective early on in your engineering studies. Besides saving time and energy when you launch your job search later, knowing NOW about the many areas in which engineers are needed and the diverse opportunities that await you will be a strong incentive for you to complete your engineering studies.

Let's start, then, with a "big picture" view of the major areas in which most engineers work. The table below, which lists these areas, along with numbers and percentages tabulated for 2003, provides this view [19].

Employed Individuals with Engineering Degrees – 2003

Employment Area	Number	Percentage
Business/Industry	1,848,900	79.2%
Federal Government	136,600	5.9%
State/Local Government	124,600	5.3%

Educational Institutions	126,500	5.4%
Self-Employed	96,500	4.1%
Total	**2,333,200**	**100%**

As you can see, the first area, "Business/Industry," is clearly the largest, employing 79.2 percent of engineers. You should know, however, that "industry" is a blanket term for two distinct categories: (1) manufacturing; and (2) non-manufacturing (service). *Manufacturing* is involved in converting raw materials into products, while *non-manufacturing* concerns the delivery of services. Government, the next highest area, employing 11.2 percent of engineers, has needs for engineers at the local, state, and federal levels. Following business, industry, and government comes educational institutions, which employ a large number of engineers, both as engineering professors and as researchers in university-operated research laboratories. Finally, there is a small but significant area of self-employed engineers, most of whom are consulting engineers.

You will also note that the total number of employed individuals having engineering degrees is 2.33 million, whereas we previously stated that the number of people working with the title of "engineer" was 1.4 million (see page 47). The difference in these numbers reflects the fact that about one-third of individuals having engineering degrees work in positions that do not have the title "engineer."

ORGANIZATION OF INDUSTRY IN THE UNITED STATES

If almost 80 percent of engineers work in the "Business/Industry" area, it is likely that you, too, will find yourself working in this area. Although we briefly mentioned the two categories into which industry is divided (manufacturing and non-manufacturing), we have barely scratched the surface of this huge, complex field. For a more detailed, comprehensive perspective on the many, many diverse fields that comprise U.S. business and industry, **The North American Industry Classification System (NAICS)** [20] is the best resource available.

Developed and maintained by the U.S. government, the NAICS system dissects the monolithic term "business and industry" into 1,179 national industries, each identified by a six-digit classification code. It then lists all the products or services that each national industry provides.

To give you an idea of how NAICS works, I randomly selected the following ten of the 1,179 national industries in the NAICS classification system:

211111	Crude petroleum and natural gas extraction
221112	Fossil-fuel electric power generation
237310	Highway, street, and bridge construction
325611	Soap and other detergent manufacturing
334510	Electromedical and electrotherapeutic apparatus manufacturing
335311	Power, distribution, and specialty transformer manufacturing
335921	Fiber-optic cable manufacturing
336414	Guided missile and space vehicle manufacturing
517212	Cellular and other wireless telecommunications
541330	Engineering services

The first two digits designate a major "Economic Sector," and the third digit designates an "Economic Subsector." For example, all of the industry subgroups above starting with 33 are part of the "Manufacturing" Economic Sector. The two national industries in the list whose first three digits are 335 fall under the "Electrical Equipment, Appliance, and Component Manufacturing" Economic Subsector. The remaining digits of each six-digit classification code further subdivide the subsectors into: industry groups (4 digits); NAICS industries (5 digits); and national industries (6 digits).

As an example, consider the "Economic Sector,"

33 – Manufacturing

Under this economic sector, there are eight "Economic Subsectors,"

331 – Primary metal manufacturing
332 – Fabricated product metal manufacturing
333 – Machinery manufacturing
334 – Computer and electronic product manufacturing
335 – Electrical equipment, appliance, and component manufacturing
336 – Transportation equipment manufacturing
337 – Furniture and related product manufacturing
339 – Miscellaneous manufacturing

Take, one of the "Economic Subsectors," for example, NAICS 334, Computer and Electronic Product Manufacturing. Under this economic subsector, there are six "Industry Groups."

3341 – Computer and peripheral equipment manufacturing
3342 – Communications equipment manufacturing
3343 – Audio and video equipment manufacturing
3344 – Semiconductor and other electronic component manufacturing
3345 – Navigational, measuring, electromedical, and control instrument manufacturing
3346 – Manufacturing and reproducing magnetic and optical media

Take one of the "Industry Groups," for example NAICS 3345, Navigational, measuring, electromedical, and control instrument manufacturing. Under this industry group there are ten national industries:

334510 – Electromedical/Electrotherapeutic Apparatus Manufacturing
334511 – Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing
334512 – Automatic Environmental Control Manufacturing for Residential, Commercial, and Appliance Use
334513 – Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables
334514 – Totalizing Fluid Meter and Counting Device Manufacturing
334515 – Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals
334516 – Analytical Laboratory Instrument Manufacturing
334517 – Irradiation Apparatus Manufacturing
334518 – Watch, Clock, and Part Manufacturing
334519 – Other Measuring and Controlling Device Manufacturing

And if you pick just one of these ten national industries, say for example 334510 – Electromedical/Electrotherapeutic Apparatus Manufacturing, you'll find listed more than 50 major products such as magnetic resonance imaging equipment, medical ultrasound equipment, pacemakers, hearing aids, electrocardiographs, and electromedical endoscopic equipment.

I hope this has given you an idea of the enormity of U.S. business and industry and the tools you need to access that industry. You can explore the North American Industry Classification System on your own on line at: http://www.census.gov. Click on "NAICS," followed by "NAICS Search." Then enter one of two types of keywords:

(1) a product or service (e.g., "fiber optic")

(2) an NAICS classification (e.g., "NAICS 541330")

EXERCISE

Go to the U.S. Bureau of Census web page at: http://www.census.gov. Click on "NAICS" and then conduct a "NAICS search" on the manufacturing economic sector "NAICS 33." Scroll down until you find a national industry you would be interested in working in. Click on the six-digit code for that national industry to see a listing of the products manufactured by that industry. Pick one of the products and do an Internet search using a search engine such as Google to identify the companies that compete in the marketplace for that product. Pick one of the companies and go to that company's web site and see if you can identify job listings for engineers.

Because, as we learned earlier, almost 80 percent of engineers work in business and industry, it would be good to know how many of these engineers work in various areas of both "manufacturing" and "service" industries

The economic sectors or economic subsectors that employ the largest number of engineers are shown in the following table.

Economic Sector or Subsector	NAICS Code	Number of Engineers	% of All Engineers
Manufacturing Subsector			
Computer and electronic product	334	189,610	13.1%
Transportation equipment	336	119,130	8.4
Machinery	333	62,050	4.4
Fabricated metal product	332	31,810	2.3
Chemical	325	27,530	1.9
Electrical equipment, appliance, and component	335	22,960	1.6

Service Sector			
Professional, scientific, and technical services	54	402,070	28.5%
Information	51	46,190	3.3
Construction	23	37,610	2.7
Wholesale Trade	42	37,390	2.7
Administrative and support	56	36,710	2.6
Management of companies and enterprises	55	35,300	2.5
Utilities	22	27,720	2.0
Mining	21	18,260	1.3

The following sections briefly describe these economic sectors and subsectors.

Manufacturing Subsectors Employing Highest Numbers of Engineers

Computer and Electronic Product Manufacturing. These industries are engaged in the manufacture of computers, computer peripherals, communication equipment, and related electronic equipment. Their manufacturing processes differ fundamentally from those of other machinery and equipment in that the design and use of integrated circuits and the application of highly specialized miniaturization technologies are common elements in the manufacturing processes of computer and electronic products.

Transportation Equipment Manufacturing. These industries produce equipment and machinery needed for transporting people and goods. Their manufacturing processes are similar to those used in most other machinery manufacturing establishments—bending, forming, welding, machining, and assembling metal or plastic parts into components and finished products. Evidence of the equipment and machinery manufactured in this subsector can be found in such transportation products as motor vehicles, aircraft, guided missiles and space vehicles, ships, boats, railroad equipment, motorcycles, bicycles, and snowmobiles.

MACHINERY MANUFACTURING. These industries design and produce products that require mechanical force to perform work. Both general-purpose machinery and machinery designed to be used in a particular industry are included in this subsector. Examples of general-purpose machinery include heating, ventilation, air-conditioning, and commercial refrigeration equipment; metalworking machinery; and engine, turbine, and power transmission equipment. Three categories of special purpose machinery are included: agricultural, construction, and mining machinery; industrial machinery; and commercial and service industry machinery.

FABRICATED METAL PRODUCT MANUFACTURING. These industries transform metal into intermediate or end products using forging, stamping, bending, forming, and machining to shape individual pieces of metal. They also use processes, such as welding and assembling, to join separate parts together. Examples of products include hand tools, kitchen utensils, metal containers, springs, wire, plumbing fixtures, firearms, and ammunition.

CHEMICAL MANUFACTURING. These industries manufacture three general classes of products: (1) basic chemicals, such as acids, alkalies, salts, and organic chemicals; (2) chemical products to be used in further manufacture, such as synthetic fibers, plastics materials, dry colors, and pigments; and (3) finished chemical products to be used for human consumption, such as drugs, cosmetics, and soaps; or products to be used as materials or supplies in other industries, such as paints, fertilizers, and explosives.

ELECTRICAL EQUIPMENT, APPLIANCE, AND COMPONENT MANUFACTURING. These industries manufacture products that generate, distribute, and use electrical power. Electric lighting equipment, household appliances, electric motors and generators, batteries, and insulated wire and wiring devices are but a few of the many products that come under this manufacturing subsector.

SERVICE SECTORS EMPLOYING HIGHEST NUMBERS OF ENGINEERS

PROFESSIONAL, SCIENTIFIC, AND TECHNICAL SERVICES. This sector includes industries from three large areas, only one of which—"Technical Services"—applies to engineering. Under "Technical Services," however, NAICS includes a broad, varied list of both engineering and computer services. Engineering services may involve any of the following: provision of advice (i.e., engineering consulting), preparation of feasibility studies, preparation of preliminary plans and designs, provision of technical services during the construction or implementation stages of a project, inspection and evaluation of completed projects, and related services. Computer services are equally varied, including activities such as programming, computer-integrated systems design, data preparation and processing, information retrieval, facilities management, as well as computer leasing, maintenance, and repair.

INFORMATION. These industries are engaged in three main processes: (1) producing and distributing information and cultural products; (2) providing the means to transmit or distribute these products, along with data or communications; and (3) processing data. Subsectors under this sector include publishing industries, motion picture and sound recording industries, broadcasting and telecommunications, and information and data processing services.

CONSTRUCTION. These industries cover three broad areas of construction: (1) building construction, such as dwellings, office buildings, commercial buildings, stores, and farm buildings; (2) heavy construction other than buildings, such as highways, streets, bridges, sewers, railroads, irrigation projects, flood control projects, and marine construction; and (3) special trades for heavy construction such as painting, electrical work, plumbing, heating, air-conditioning, roofing, and sheet metal work.

WHOLESALE TRADE. Wholesale trade includes: (1) merchant wholesalers who take title to the goods they sell; (2) sales branches or offices maintained by manufacturing, refining, or mining enterprises; and (3) agents, merchandise or commodity brokers, and commission merchants. The merchandise includes the outputs of agriculture, mining, manufacturing, and certain information industries, such as publishing.

ADMINISTRATION AND SUPPORT. These industries perform routine support activities for the day-to-day operations of other organizations. These essential activities are often undertaken in-house by establishments in many sectors of the economy. Activities performed include: office administration, hiring and placing of personnel, document preparation and similar clerical services, solicitation, collection, security and surveillance services, cleaning, and waste disposal services.

MANAGEMENT OF COMPANIES AND ENTERPRISES. This sector comprises (1) establishments that hold the securities of (or other equity interests in) companies and enterprises for the purpose of owning a controlling interest or influencing management decisions or (2) establishments (except government establishments) that administer, oversee, and manage establishments of the company or enterprise and that normally undertake the strategic or organizational planning and decision making role of the company or enterprise. Presumably, engineers who are provided to companies on a contract basis are included in this economic sector.

UTILITIES. These industries are engaged in providing electric power, natural gas, steam, water, and sewage removal. Providing electric power includes generation, transmission, and distribution, while natural gas only involves distribution. Supplying steam includes provision and/or distribution; supplying water involves treatment and distribution. Sewage removal includes collection, treatment, and disposal of waste through sewer systems and sewage treatment facilities.

MINING. These industries extract naturally occurring mineral solids, such as coal and ores; liquid minerals, such as crude petroleum; and gases, such as natural gas. The term "mining" is used in the broad sense to include quarrying, well operations, beneficiating (e.g., crushing, screening, washing, and flotation), and other preparatory functions customarily done at the mine site.

2.9 IMPORTANT FIELDS FOR THE FUTURE

We are in a period of intense change. One way to underscore this is to reflect on the fact that none of the following existed as recently as 1980 (25 years ago).

1. The Internet
2. Cell phone
3. Personal computers
4. Fiber optics
5. E-mail
6. Commercialized Global Positioning System (GPS)
7. Portable computers
8. Memory storage discs
9. Consumer level digital camera
10. Radio frequency ID tags
11. Micro-Electrical-Mechanical Systems (MEMS)
12. DNA fingerprinting
13. Air bags
14. ATM
15. Advanced batteries

16. Hybrid car
17. Organic Light Emitting Diodes (OLEDs)
18. Display panels
19. HDTV
20. Space shuttle
21. Nanotechnology
22. Flash memory
23. Voice mail
24. Modern hearing aids
25. Short Range, High Frequency Radio

This list of the top 25 non-medically related technology innovations of the past 25 years was developed by a panel of technology leaders assembled by the Lemelson-MIT Program at MIT in 2005. These advances have not only created exciting new opportunities for engineers, they have resulted in a "flattening" of the world.

I would encourage you to read Thomas L. Friedman's excellent book *The World is Flat: A Brief History of the Twenty-First Century* [21]. Doing so will help you understand the world you will be living and working in. In the book, Friedman explores the political and technological changes that have flattened the world and made it a smaller place. From the fall of the Berlin Wall to the explosion of the Internet to the *dot com* bubble and bust and outsourcing of jobs to India and China, globalization has evened the playing field for many emerging economies.

The following is a list of some of the major events and changes that will influence your future as an engineer:

Major Events and Changes Affecting the Future

The fall of the Berlin Wall
Advances in computer technology
Advances in communications
The knowledge and information explosion
Globalization (outsourcing, offshoring)
Increased focus on the environment
Events of September 11, 2001
World population explosion

Understanding these changes can help you prepare for the engineering fields that will be particularly important and "in demand" in the years ahead. The following are ten areas of technology that the National Science Foundation (NSF) [22,23] and the National Academy of Engineering (NAE) [24] have targeted for rapid development in the future.

MANUFACTURING FRONTIERS

Manufacturing is the foundation of the U.S. economy. There is now an unprecedented opportunity to accelerate the application of new knowledge and advanced technologies to dramatically improve the manufacturing capabilities of U.S. industries. Important technologies include "intelligent" manufacturing, advanced fabrication and processing methods, integrated computer-based tools for product design and manufacturing, systems and processes to prevent pollution and to minimize resource waste, and "total quality management" systems and processes.

INFORMATION AND COMMUNICATION SYSTEMS

Advances in **information and communication technologies** are key to U.S. economic growth and competitiveness—as well as to our national defense. The transition from analog to digital processing is enabling the U.S. to regain its competitiveness in consumer electronics. We can hardly imagine a world without computers, cellular phones, e-mail, I-pods, and the Internet. Information and communication technologies will continue to bring about major changes in health care delivery systems, advanced manufacturing technology, civil infrastructure systems, and approaches to learning in engineering education.

SMART AND ENGINEERED MATERIALS

Improvement in the manufacture and performance of **materials** will enhance our quality of life, national security, industrial productivity, and economic growth. New materials will be created that feature precisely tailored properties and enhanced performance. Examples of these materials are biodegradable polymers, high-temperature ceramics, and durable materials for artificial limbs and joints. Work is underway on developing "smart" materials that are designed to react to changes in their environment, such as materials that can sense motion and counter it, thus damping vibration, or change shape or viscosity in response to stress, temperature or electrical activity, but "remember" their original configurations. In the future, smart materials will be employed in creating the coming generation of compact, low-power sensors that can detect toxic chemicals, bio-hazards or radiation, as well as dozens of other stimuli.

BIOENGINEERING

Bioengineering is expected to have a profound impact on health care, agriculture, energy, and environmental management. Major areas of activity focus on developing better ways to manufacture and mass-produce pharmaceuticals, better safeguards for the environment (including the eradication of past problems), and better means of improving, restoring, and preserving human health. Exciting and developing fields within bioengineering include: tissue engineering, biomechanics, rehabilitation engineering, bioinformatics, neural engineering, and biomedical imaging.

CRITICAL INFRASTRUCTURE SYSTEMS

Our **critical infrastructure system** is the framework of networks and systems that provides a continual flow of good and services essential to the defense and economic security of the United States. These include: agriculture and food; water; public health; emergency services; the defense industrial base; information and telecommunications; energy and power; transportation; and banking and finance. The facilities, systems, and functions that comprise our critical infrastructures are highly sophisticated, interdependent, and complex. Engineering will play a major role in maintaining and improving this infrastructure. Of particular concern is the civil engineering infrastructure—consisting of roads, bridges, rail networks, airports, sewage treatment plants, deep-water ports, municipal water systems, and energy generation and transmission systems—which is both deteriorating and inadequate to meet growing demands. Rebuilding and expanding this infrastructure will involve new designs, more durable materials, network systems with better controls and communications, and improved management processes.

HOMELAND SECURITY

Since the events of September 11th, the prospect of continued terrorism in the U.S. and abroad and the issues related to **homeland security** have been of paramount importance to policy makers and the public. Engineers will play an important role in the process of improving our security. Technologies originally developed for other purposes are now being explored for counter-terrorism, as in the application of optical spectroscopy to the detection chemical weapons. New technologies, such as face recognition software, are also being created. Moreover, new technologies developed outside of the arena of terrorism concerns, such as wireless computing, present a new set of security issues.

IMPROVED HEALTH CARE DELIVERY

There is a critical national need to contain the costs of health care**,** while also **improving the quality of and access to health care**. Engineering will help meet this need by developing new ways to increase productivity in hospitals, new technologies for the delivery of care outside of hospitals, improved materials for use in implants or external devices to increase longevity, and improved information and communication systems to expedite access to health care and increase patients' independence.

NANOTECHNOLOGY

Nanotechnology is a catch-all phrase for materials and devices that operate at the nanoscale. In the metric system of measurement, "Nano" equals a billionth and therefore a nanometer is one-billionth of a meter. Two main approaches are used in nanotechnology: one is a "bottom-up" approach where materials and devices are built up atom by atom, the other a "top-down" approach where they are synthesized or constructed by removing existing material from larger entities. Increasingly control of matter and energy at the molecular level is already leading to revolutionary breakthroughs in such critical fields as advanced computing, communications, materials development, and medicine. In communications, nanostructures are dramatically reducing the size of signal processing components and have led to new abilities to control light beams. In medicine, ultra-miniaturized sensors and fluid channels are ushering in a new era of tiny diagnostic and detection devices. Nanofabrication of miniature electronic components may revolutionize information processing.

ADVANCED ENVIRONMENTAL TECHNOLOGY

Our nation's industrial development and economic growth will require solutions to extremely **complex environmental problems**, such as finding new ways to manage natural resources, while stepping up the production of goods and services. Engineers will play important roles in creating technologies and processes that will remediate existing problems and prevent future problems. One example of such technologies is environmentally sound extraction/production systems that minimize or prevent waste and contamination. Engineers also will be involved in promoting a better understanding of the relationships between human needs and the environment.

SENSORS AND CONTROL SYSTEMS

Because of technological advances in the areas of signal processing, communications, bioengineering, computing power, and sensor technology, the field of **sensors and control systems** can provide new, more accurate, less expensive, and more efficient control solutions to existing and novel problems. We are moving toward autonomous underwater, land, air, and space vehicles; highly automated manufacturing; intelligent robots; highly efficient and fault tolerant voice and data networks; reliable electric power generation and distribution; seismically tolerant structures; and highly efficient fuel control for a cleaner environment.

2.10 ENGINEERING AS A PROFESSION

When you receive your B.S. degree in engineering, you will join the engineering profession. Engineering may be considered a profession insofar as it meets the following characteristics of a learned professional group [25]:

- Knowledge and skill in specialized fields above that of the general public
- A desire for public service and a willingness to share discoveries for the benefit of others
- Exercise of discretion and judgment
- Establishment of a relation of confidence between the professional and client or employer
- Self-imposed (i.e., by the profession) standards for qualifications
- Acceptance of overall and specific codes of conduct
- Formation of professional groups and participation in advancing professional ideals and knowledge
- Recognition by law as an identifiable body of knowledge

As an engineering professional, you will have certain rights and privileges, as well as certain responsibilities and obligations. As described above, you will be responsible for serving the public, sharing your discoveries for the benefit of others, exercising discretion and judgment, maintaining confidentiality with clients and employers, and accepting specific codes of conduct.

As an engineering professional, you will have the legal right to represent yourself using the title of engineer. You will be eligible to participate in professional organizations. And you will have the right to seek registration as a *Professional Engineer*.

PROFESSIONAL REGISTRATION

You can formalize your status as a professional by seeking registration as a *Professional Engineer* (P.E.). Professional registration is an impressive credential, and you will find the title ***P.E.*** proudly displayed on the business cards of engineers who have acquired that status. For most engineers, professional registration is optional. However, in certain fields of work that involve public safety, professional registration may be mandatory. Approximately 30 percent of all practicing engineers are registered. The percentage is much higher for civil engineers because of the nature of their work.

Professional registration is handled by the individual states, each of which has a registration board. Although the requirements and procedures differ somewhat from state to state, they are generally fairly uniform due to the efforts of the National Council of Examiners for Engineers and Surveyors (NCEES). For details about the process of becoming a registered Professional Engineer, visit the NCEES web page:

http://www.ncees.org

State boards are responsible for evaluating the education and experience of applicants for registration, administering an examination to those applicants who meet the minimum requirements, and granting registration to those who pass the examination.

Although registration laws vary, most boards require four steps:

1. Graduation from a four-year engineering program accredited by the Accreditation Board for Engineering and Technology (ABET)
2. Passing the Fundamentals of Engineering (FE) examination
3. Completing four years of acceptable engineering practice
4. Passing the Principles and Practice of Engineering (PE) examination

Once you complete these four steps, you will become licensed as a Professional Engineer in the state in which you wish to practice, and will be certified to use the prestigious "P.E." designation after your name. Most states provide for reciprocal licensure, so that once you become licensed in one state, you can become licensed in other states without further examination.

THE FUNDAMENTALS OF ENGINEERING EXAM. The Fundamentals of Engineering Exam (FE) is administered each year in April and October. The FE exam is an eight-hour multiple-choice exam. The four-hour morning session is common to all engineering disciplines and is comprised of 120 one-point questions covering the following topics:

Mathematics (15%)
Engineering probability and statistics (7%)
Chemistry (9%)
Engineering economics (8%)
Computers (7%)
Ethics and business practice (7%)
Engineering mechanics (statics and dynamics) (10%)
Strength of materials (7%)
Material properties (7%)
Fluid mechanics (7%)
Electricity and magnetism (9%)
Thermodynamics (7%)

The four-hour afternoon exam is comprised of 60 two-point questions and covers one of seven engineering disciplines (electrical, mechanical, civil, industrial, chemical, environmental, general) chosen by you.

The FE exam can be taken prior to graduation in engineering, ideally sometime in your senior year, or soon after you graduate. This is the time when you have the best command of engineering fundamentals. Once you have passed this exam and graduated, you are designated as an Intern-Engineer or Engineer-in-Training.

One note. Your required engineering curriculum may not include courses that cover all of the topics included on the FE exam, so you may need to take an EIT review course, do extensive self-study, or even elect to take an additional course or two (e.g., engineering mechanics, thermodynamics, material science) during your undergraduate years.

THE PRINCIPLES AND PRACTICE OF ENGINEERING EXAM. After four years of acceptable experience as an Intern Engineer or Engineer-in-Training, you will be eligible to take the Principles and Practice of Engineering Exam (PE Exam). Offered in April and October, the PE

Exam is an eight-hour multiple-choice exam in a specific engineering discipline (civil, mechanical, electrical, chemical, industrial, etc.). The four-hour morning session consists of 40 questions covering the discipline broadly. The afternoon session consists of 40 questions in a subspecialty of the discipline selected by you.

PROFESSIONAL SOCIETIES

Each of the engineering disciplines described in Section 2.6 has a professional society that serves the technical and professional needs of engineers and engineering students in that discipline. These societies are usually organized on both national and local levels, and most support the establishment of student chapters on university campuses. The societies publish technical journals and magazines, organize technical conferences, sponsor short courses for professional development, develop codes and ethical standards, and oversee the accreditation of engineering programs in their discipline.

The benefits of getting actively involved in the student chapter corresponding to your engineering discipline will be discussed in Chapter 7. In the meantime, you can gain valuable information about the various engineering disciplines by exploring the web pages listed below.

Professional Society	Web Site
American Academy of Environmental Engineers (AAEE)	http://www.aaee.net
American Institute of Aeronautics and Astronautics (AIAA)	http://www.aiaa.org
American Institute of Chemical Engineers (AIChE)	http://www.aiche.org
American Nuclear Society (ANS)	http://www.ans.org
American Society of Agricultural and Biological Engineers (ASABE)	http://www.asabe.org
American Society of Civil Engineers (ASCE)	http://www.asce.org
American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)	http://www.ashrae.org

American Society of Mechanical Engineers (ASME)	http://www.asme.org
Biomedical Engineering Society (BMES)	http://www.bmes.org
Institute of Electrical and Electronics Engineers (IEEE)	http://www.ieee.org/portal/site
Institute of Industrial Engineers (IIE)	http://www.iienet2.org
Society of Automotive Engineers (SAE)	http://www.sae.org
Society of Manufacturing Engineers (SME)	http://www.sme.org
Society for Mining, Metallurgy, and Exploration (SME-AIME)	http://www.smenet.org
Society of Naval Architects and Marine Engineers (SNAME)	http://www.sname.org
Society of Petroleum Engineers (SPE)	http://www.spe.org
The Minerals, Metals & Materials Society (TMS)	http://www.tms.org

SUMMARY

In this chapter you were introduced to the engineering profession—past, present, and future. You were encouraged to take every opportunity to learn as much as you can about engineering. This will be a lifelong process, but it has already begun.

First, we helped you develop an articulate answer to a question you are likely to be asked frequently: "What is engineering?" You learned that, at its core, engineering is the process of developing a product or process that meets a customer need or perceived opportunity.

Next, we gave you a view of the past by presenting the 20 Greatest Engineering Achievements of the 20^{th} Century. Reading about these not only provided an interesting retrospective of the engineering field; hopefully, it also served as an incentive to you as a new engineering student. For the achievements of the 21^{st} century are bound to be even more spectacular than the accomplishments of the 20^{th} century. And you may very well be responsible for one of the "Greatest Engineering

Achievements of the 21st Century." In any event, whether you look backward to the past or forward to the future, you can see what an important and exciting profession you will be joining.

We then discussed the many rewards and opportunities that will be yours if you are successful in graduating in engineering. By developing individual "top ten" lists of these rewards and opportunities, starting with a discussion of "Ray's Top Ten" list, you should have a clear picture of how an engineering degree will greatly enhance the quality of your life—as well as the lives of others.

Next, to flesh out your understanding of the engineering profession, you saw how engineers can be categorized according to their academic discipline and job function, each of which we studied in some detail.

You then learned about the employment opportunities that will await you upon graduation. The North American Industry Classification System (NAICS) was used to give you a feel for the enormous economic engine that your engineering education is preparing you to be part of. We paid particular attention to the industry sectors that employ the largest numbers of engineers, and discussed the technical fields that are expected to grow rapidly in the future. You may want to begin preparing yourself today for a career in one of these "hot" fields of the future.

Finally, you learned that engineering is a profession that you will enter when you graduate. We discussed the requirements that define a "profession," including the rights and privileges that come with responsibilities and obligations. Among the rights you will be accorded is to become licensed as a registered Professional Engineer (P.E.). You will also have the opportunity to participate in the engineering society appropriate to your academic discipline, both while you are in school and throughout your engineering career.

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PROBLEMS

1. Review the definitions of engineering presented in Appendix A. Combine the best ideas from these definitions, write out your own definition of "engineering," and memorize it. Ask people you come in contact with whether they know what engineering is. If they say, "No," then recite your definition to them.

2. Review the National Engineers Week web page:

   http://www.eweek.org

   and answer the following questions:

   a. Who are the sponsors of National Engineers Week?
   b. What is the purpose of National Engineers Week?
   c. What are some of the major activities scheduled for the next National Engineers Week celebration?

d. What are some of the products available to help promote National Engineers Week?

3. Write a one-page paper about the influences (teachers, parents, TV, etc.) that led you to choose engineering as your major.
4. Pick one of the engineering guidance web sites listed at the end of Section 2.1. Explore the web site to learn as much about engineering as you can from it. Write a one-page paper summarizing what you learned.
5. Write a list of specifications for a motorized wheel chair that could be used on a sandy beach. Include performance specifications, economic specifications, and scheduling specifications.
6. Review the list of needed products at the end of Section 2.3. Add five additional needed products that you think would sell if developed into actual products.
7. Pick one of the items from Problem 6 and write a set of design specifications for the proposed product.
8. Pick one of the 20 Greatest Engineering Achievements of the 20th Century. Write a one-page paper describing the impact of that engineering achievement on the quality of your life.
9. Create a list of activities you can do that will increase your understanding of engineering careers. Develop a plan for implementing three of these activities.
10. Add ten or more additional items to the list of rewards and opportunities of an engineering career presented in Section 2.5. Pick your top ten from the total list and rank them in order of importance.
11. Write a three-page paper on "Why I Want to be an Engineer" by expanding on your top four items from Problem 10 and explaining why each is important to you personally.
12. Have you ever had a job you didn't like? Describe the job. What didn't you like about it? If that job played any role in your subsequent decision to major in engineering, explain what that role was.
13. Read a biography of one of the famous people listed in Section 2.5 who were educated as an engineer. Make a list of the ways their engineering education supported their achievements.
14. Write down five non-engineering careers (e.g., politician, entrepreneur, movie director, etc.) that you might be interested in.

Discuss how obtaining your B.S. degree in engineering could help you pursue each of those careers.

15. What is the most challenging problem you have ever tackled in your life? Were you able to succeed at solving the problem? Did you enjoy the experience? Write a two-page essay that addresses these questions.

16. Answer the following questions related to making money:

    a. What is the legal "minimum wage" (per hour) in the U.S.?

    b. What is the highest hourly wage you have ever made?

    c. What hourly wage would correspond to the average starting annual salary for engineering graduates in 2005/06 ($51,465)?

    d. What is the hourly wage of an engineering executive making $250,000 a year?

17. As indicated in Section 2.5, engineering graduates make up only 4.5 percent of all college graduates. Go to your career center and find out how many employers interview on campus annually. What percentage of those employers interview engineering majors only? What percentage interview business majors only? What percentage interview all other majors? What is the significance of your findings?

18. Find out how the following things work (if you don't already know):

    a. Fuel cell
    b. Radar gun
    c. Microwave oven
    d. Solar cell
    e. Digital display

    Prepare a three-minute oral presentation about one of the items that you will give at the next meeting of your Intro to Engineering course.

19. Go to the National Engineers Week web page (http://www.eweek.org) and click on "The Creative Engineer." There you will find eight elements of creativity:

    challenging   connecting
    visualizing   collaborating
    harmonizing   improvising
    reorienting   synthesizing

    Pick one of these elements. Look up the definition of the term in the dictionary, study the example on the National Engineers Week web page, and conduct further research on the element. Write a one-page paper explaining why this "element of creativity" is important in engineering work.

20. Go to Professor John Lienhard's *The Engines of Our Ingenuity* web page: http://www.uh.edu/engines. Pick three of the more than 2,150 episodes you will find there. Study those three. Write a two-page paper on why you picked the ones you did and what you learned from studying them.
21. In Section 2.6, you learned that engineering disciplines can be divided into two categories: (1) the six largest disciplines (electrical, mechanical, civil, computer, chemical, and industrial); (2) a much larger number of smaller, more specialized disciplines. Make a list of the advantages and disadvantages of selecting your major in one or the other of these categories.
22. Which of the engineering disciplines listed in Section 2.6 are offered by your university? Find out how many students graduate annually from your university in each of these disciplines.
23. Pick one of the engineering disciplines listed in Section 2.6. Visit the web page of the professional society corresponding to that discipline and take note of any information that applies specifically to engineering students. Share what you learned with your classmates in your next Introduction to Engineering class.
24. Pick one of the engineering disciplines listed in Section 2.6. Write a three-page paper describing that discipline.
25. Pick one of the technical divisions or societies of either the American Society of Mechanical Engineers (ASME), the Institute of Electrical and Electronics Engineers (IEEE), or the American Society of Civil Engineers (ASCE) listed in Section 2.6 that you would like to know more about. Research the division or society and write a one-page paper describing it.
26. Which of the civil engineering specialties described in Section 2.6 would provide you the greatest opportunity to benefit society? Why?
27. Go to the U.S. Bureau of Labor Statistics web-based "Occupational Outlook Handbook" at: http://www.bls.gov/oco/ocos027.htm. Study the information there to learn as much as you can about "engineers." What does it say about the job outlook for "engineers"?

28. Go to the American Institute of Chemical Engineers (AIChE) "CareerEngineer" web page: http://www.aiche.org/CareersEducation. Click on "Find a Job," and read about the ones listed there. Which one appeals to you the most? Prepare a two-minute talk describing its appeal to your Introduction to Engineering classmates.

29. Interview a practicing engineer. Find out the answers to the following questions:

    a. What engineering discipline did he or she graduate in?

    b. To what extent do the knowledge and principles of that discipline apply in his or her current job?

    c. What industry sector does he or she work in?

    d. What percentage of his or her time is spent in the various engineering job functions (design, test, development, management, etc.)?

30. Develop a list of attributes that would be desirable for each of the engineering job functions described in Section 2.7. Which of these job functions appeals most to you? Be ready to explain your reasons in a class discussion when your Intro to Engineering course next meets.

31. Familiarize yourself with the NAICS system by doing the following exercise. Begin by accessing the Internet. Then proceed as directed by the steps below:

    a. Go to: http://www.census.gov

    b. Click on "NAICS"

    c. Click on "NAICS Search"

    d. Enter keyword "NAICS 334"

    e. Browse through all the products listed under NAICS 3345

    f. Find the products listed under NAICS 334510 and print them out

32. Pick one of the products listed under NAICS 334510 from Problem 31 and research what companies manufacture that product. Contact that company and investigate how they use engineers in the design, manufacture, test, and marketing of that product. Write a summary of what you learned.

33. Learn about the "Engineering Services" industries by following the steps outlined in Problem 31 and entering the keyword "NAICS

541330." How many entries did you find? Would you be interested in working in this industry? Why or why not?

34. Obtain a list of employers that conduct on-campus interviews of engineering graduates through your career center. Try to identify which industry sector each employer belongs in, based on those listed in Section 2.8. Do some of the employers fit into more than one industry sector?
35. Identify the two or three engineering disciplines that you think would be most closely associated with each of the eight "Service" Economic Sectors and six "Manufacturing" Economic Subsectors described in Section 2.8.
36. Make a list of ten products that would be manufactured by each of the six "Manufacturing" Economic Subsectors listed in Section 2.8.
37. Pick one of the important fields for the future described in Section 2.9. After researching this field, write a three-page paper that first describes the field in detail and then discusses future employment opportunities that the field will offer.
38. Explain how each of the "Major Events and Changes" listed in Section 2.9 will impact your future. What effect will each have on the engineering job market? (Will it increase or decrease the number of jobs? In which disciplines? Will it change the nature of current jobs?)
39. Make a list of 1) the rights and privileges; and 2) the responsibilities and obligations you will have when you join the engineering profession.
40. Obtain information about the process of becoming a registered Professional Engineer in your state. How do the requirements and procedures differ from those presented in Section 2.10? What engineering disciplines are licensed in your state?
41. Set a personal goal of passing the Fundamentals of Engineering Exam (FE) before or soon after you graduate. Develop a set of strategies that will ensure that you are well prepared to pass the exam.