CHAPTER

What Engineers Do

1

Source: iStockphoto.com/Antonis Papantoniou.

1.1 INTRODUCTION

What is an engineer, and what does he or she do? You can get a good answer to this question by just looking at the word itself. The word *engine* comes from the Latin *ingenerare*, meaning "to create." About 2000 years ago, the Latin word *ingenium* ("the product of genius") was used to describe the design of a new machine. Soon after, the word *ingen* was used to describe all machines. In English, *ingen* was spelled "engine," and people who designed creative things were known as "engine-ers." In French, German, and Spanish today, the word for *engineer* is *ingenieur*, and in Italian it is *ingegnere*.

So, to reiterate:

What does the word engineer *mean?*
Answer: The word *engineer* refers to someone who is a creative, ingenious person who finds solutions to practical problems.

Today the word *engineer* refers to people who use creative design and analysis processes that incorporate energy, materials, motion, and information to serve human needs in innovative ways. Engineers express knowledge in the form of variables, numbers, and units. There are many kinds of engineers, but all share the ideas and methods introduced in this book.

1.2 WHAT IS *ENGINEERING*?

The late scientist and science fiction writer Isaac Asimov once said that "Science can amuse and fascinate us all but it is engineering that changes the world."[1] Almost everything you see around you has been touched by an engineer. Engineers are creative people who use mathematics, scientific principles, material properties, and computer methods to design new products and to solve human problems. Engineers can do just about anything,

[1]Isaac Asimov's *Book of Science and Nature Quotations* (New York: Simon & Schuster, 1970).

designing and building roads, bridges, cars, planes, space stations, cell phones, computers, medical equipment, and so forth.

Engineers can be classified according to the kind of work they do—administration, construction, consulting, design, development, teaching, planning (also called *applications engineers*), production, research, sales, service, and test engineers. Because engineering deals with the world around us, the number of engineering disciplines is very large. Table 1.1 lists some of the many engineering fields.

Table 1.1 A Few of the Many Engineering Fields Available Today

Aerospace	Ceramic	Electrical	Mechanical	Petroleum
Agricultural	Chemical	Environmental	Metallurgical	Sanitary
Architectural	Civil	Geological	Mining	Systems
Automotive	Computer	Manufacturing	Nuclear	Textile
Biomedical	Ecological	Marine	Ocean	Transportation

1.3 WHAT DO ENGINEERS DO?

Most engineers specialize in a field of engineering. The following list contains information on a few of the engineering fields in the Federal Government's Standard Occupational Classification (SOC) system.[2] Note that some of the engineering fields may have several subdivisions. For example, Civil engineering includes structural and transportation engineering, and materials engineering includes ceramic, metallurgical, and polymer engineering.

- **Biomedical engineers** develop devices and procedures that solve medical and health-related problems by combining biology and medicine with engineering principles. Many biomedical engineers develop and evaluate systems and products such as artificial organs, instrumentation, and health management and care delivery systems.
- **Chemical engineers** apply the principles of chemistry to solve problems involving the production or use of chemicals and other products. They design equipment and processes for biotechnical use and large-scale chemical manufacturing, plan and test methods of manufacturing products and treating byproducts, and supervise production.
- **Civil engineers** design and supervise the construction of roads, buildings, airports, tunnels, dams, bridges, and water supply and sewage systems. Civil engineering is one of the oldest engineering disciplines[3] and encompasses many specialties. The major ones are structural, water resources, construction, transportation, and geotechnical engineering.
- **Computer engineers** research, design, develop, test, and oversee the manufacture and installation of computer hardware, including computer chips, circuit boards, computer systems, and related equipment, such as keyboards, routers, and printers. Computer engineers may also design and develop the software systems that control computers.

[2]Abstracted from the Bureau of Labor Statistics (http://www.bls.gov/oco/ocos027.htm).

[3]The oldest type of engineering is military engineering. Civil engineers are called such to distinguish them from military engineers. The word *civil* is a contraction of the word *civilian*.

- **Electrical engineers** design, develop, test, and supervise the manufacture of electrical equipment. Some of this equipment includes electric motors; machinery controls, lighting, and wiring in buildings; radar and navigation systems; communications systems; and power generation, control, and transmission devices used by electric utilities.
- **Environmental engineers** use the principles of biology and chemistry to develop solutions to environmental problems. They are involved in water and air pollution control, recycling, waste disposal, and public health issues. Environmental engineers conduct hazardous-waste management studies in which they evaluate the significance of the hazard, and develop regulations to prevent mishaps.
- **Industrial and manufacturing engineers** determine the most effective ways to use the basic items of production—people, machines, materials, information, and energy—to make a product or provide a service. They are concerned with increasing productivity through the management of people, methods of business organization, and technology. These engineers study product requirements and then design manufacturing systems to meet those requirements.
- **Materials engineers** are involved in the development, processing, and testing of the materials used to create a range of products, from computer chips and aircraft wings to golf clubs and snow skis. They work with metals, ceramics, plastics, semiconductors, and composites to create new materials that meet certain mechanical, electrical, and chemical requirements.
- **Mechanical engineers** research, design, develop, manufacture, and test all types of mechanical devices. Mechanical engineering is one of the broadest engineering disciplines. Mechanical engineers work on power-producing machines such as electric generators, internal combustion engines, and steam and gas turbines; they also work on power-using machines such as refrigeration and air-conditioning equipment, machine tools, material-handling systems, and robots.
- **Nuclear engineers** research and develop the processes, instruments, and systems used to derive benefits from nuclear energy and radiation. They design, develop, monitor, and operate nuclear plants to generate power. They may work on the nuclear fuel cycle—the production, handling, and use of nuclear fuel and the safe disposal of nuclear waste.

You can find more about what today's engineers do within their specialties by searching the Internet. Here are some of the many engineering societies[4] that represent different engineering fields: ASME (mechanical engineers), IEEE (electrical engineers), AIChE (chemical engineers), ASTM (materials and testing engineers), ASCE (civil engineers), BMES (biomedical engineering), ANS (nuclear engineering), and AIAA (aeronautical engineering).

Unsurprisingly you will discover that the basic college engineering courses have much in common with all engineering disciplines. They cover scientific principles, application of logical problem solving processes, principles of design, the value of teamwork, and engineering ethics. If you are considering an engineering career, we highly recommend you consult web resources to refine your understanding of the various fields of engineering.

1.4 WHERE DO ENGINEERS WORK?

Most engineers work in office buildings, laboratories, or industrial plants. Others may spend time outdoors at construction sites and oil and gas exploration and production sites, where they monitor or direct operations or solve onsite problems. Some engineers travel extensively to plants or worksites here and abroad.

[4] A typical engineering society has several functions. They define the core disciplines needed for membership and advocate for them. They also define codes and standards for their discipline, provide further educational courses, and offer a code of engineering ethics customized for that particular profession. Canadian engineering societies basically follow a similar nomenclature as do others worldwide.

Many engineers work a nominal 40-hour week. At times, deadlines or design standards may bring extra pressure to a job, requiring engineers to work longer hours.

Engineers usually work in teams. Sometimes, the team has only two or three engineers, but in large companies, engineering teams can have hundreds of people working on a single project (the design and manufacture of a large aircraft, for example). Engineers are responsible for communicating, planning, designing, manufacturing, and testing among other duties.

Engineers are capable of designing the processes and equipment needed for a project, and sometimes that involves inventing new technologies. Engineers must also test their work carefully before it is used by trying to anticipate all of the things that could go wrong and make sure that their products perform safely and effectively.

More than 1.2 million engineers work in the United States today, making engineering the nation's second-largest profession. According to the 2011 survey by the National Association of Colleges and Employers, engineering majors have the highest baccalaureate degree starting salaries—often in excess of $60,000 per year.

An engineering degree also opens doors to other careers. Engineering graduates can move into other professions, such as medicine, law, and business, where their engineering problem solving ability is a valuable asset. A list[5] is available of famous engineers who became American Presidents, Nobel Prize winners, astronauts, corporate presidents, entertainers, inventors, and scientists.

In the United States, distinguished engineers may be elected to the National Academy of Engineering (NAE); it is the single highest national honor for engineers. In many countries there are parallel organizations (e.g., The Royal Academy of Engineering in the United Kingdom).

1.5 WHAT IS *ENGINEERING TECHNOLOGY*?

The following definition of engineering technology was established by the Technology Accreditation Commission of ABET, Inc. (Accreditation Board for Engineering and Technology) and was approved by the Engineering Technology Council of the American Society for Engineering Education.

> *Engineering technology is the profession in which a knowledge of mathematics and natural sciences gained by higher education, experience, and practice is devoted primarily to the implementation and extension of existing technology for the benefit of humanity.*

Engineering technologists work closely with engineers in coordinating people, material, and machinery to achieve the specific goals of a particular project. The engineering technologist is often responsible for design and development.

Many engineering technicians work in quality control, inspecting products and processes, conducting tests, or collecting data. In manufacturing, they may assist in product design, development, or production.

There is a wide range of options when it comes to educational preparation in engineering technology. Most employers prefer to hire engineering technologists with at least a two-year associate degree in engineering technology. Some universities offer two-year associate degrees, others offer three- or four-year BS degree programs, and some offer both types of degrees.

1.6 WHAT MAKES A "GOOD" ENGINEER?

This is actually a difficult question to answer because the knowledge and skills required to be an engineer (i.e., to create ingenious solutions) is a moving target. The factors that will lead to your career success are not the same as they were 20 years ago. In this book, we illustrate the key characteristics of a successful 21st-century engineer by

[5] See http://www.sinc.sunysb.edu/Stu/hnaseer/interest.htm.

exploring the multidisciplinary creative engineering process required to produce "good" competitive products for the 21st century.

So just what *does* the 21st century hold for the young engineer? It will be characterized by the *convergence* of many technologies and engineering systems. The products of today and tomorrow will be "smarter." The incorporation of computers, sensors, controls, modern alloys, and plastics are as important as continuing expertise in the traditional engineering disciplines. This book is intended to appeal to a number of aspects of modern engineering subdisciplines.

1.7 WHAT THIS BOOK COVERS

In your mind, what makes a "good" consumer product, say, an automobile? If you were in the market to purchase one, you might want one that has high performance and good gas mileage and is roomy, safe, and stylish. Or you might describe it in categories like new or used; sedan, sports car, or SUV; two doors or four doors. Or, maybe, you would be interested in only the price tag.

As a consumer making a decision about purchasing a car, it is enough to use the preceding words, categories, and questions to reach a decision. But engineers think differently. They design and analyze, and consequently, they must have a different set of words, categories, and questions. To design and analyze, engineers ask precise questions that can be answered with **variables**, **numbers**, and **units**. They do it to produce a safe and reliable product. From this point of view, an automobile is an engineer's answer to the question "What is a good way to move people safely and reliably?"

The purpose of this book is to introduce you to the engineering profession. It does so by introducing you to the way engineers think, ask, and answer questions like these: What makes an automobile—or a computer, or an airplane, or a washing machine, or a bridge, or a prosthetic limb, or an oil refinery, or a space satellite—*good*?

We use the automobile as an example at this point strictly for convenience. Presumably, you have, or at least think you have, some idea of what constitutes an automobile. But, it no more or less expresses the essence of engineering than would an example based on a computer, an airplane, a washing machine, a bridge, a prosthetic limb, an oil refinery, or a space satellite. In each case, the essence of the example would focus on the creative use of energy, materials, motion, and information to serve human needs, so a more detail-oriented engineer might answer our original question like this:

> *A good 21st-century automobile employs stored energy (on the order of 100 million joules), complex materials (on the order of 1000 kilograms [about one ton] of steel, aluminum, glass, and plastics), and information (on the order of millions of bits processed every second) so that it is capable of high speed (on the order of 40 meters/second ≈ 90 mph), low cost (a few tens of cents per mile), low pollution (a few grams of pollutants per mile), and high safety.*

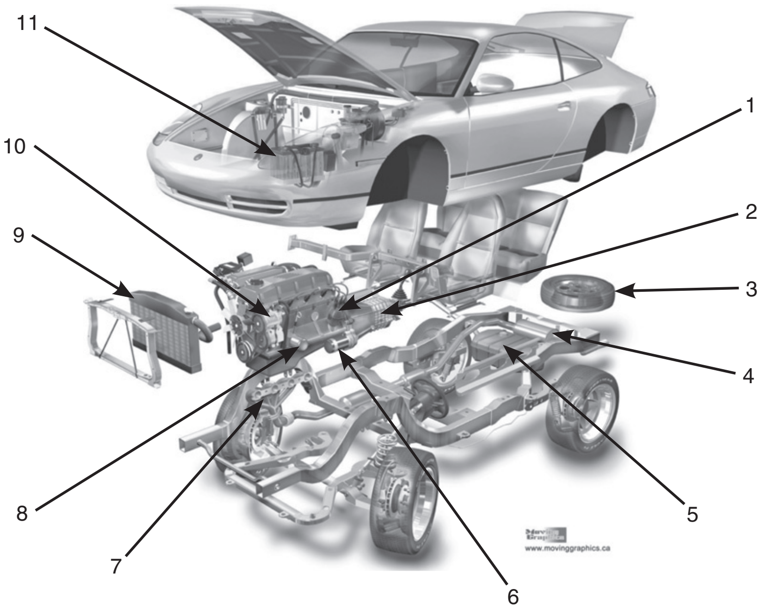
That is a long and multidimensional answer, but an engineer would be unapologetic about that. Engineering is *inherently* multidimensional and multidisciplinary. It needs to be multidimensional to create compromises among conflicting criteria, and it needs to be multidisciplinary to understand the technical impact of the compromises. Making a car heavier, for example, might make it safer, but it would also be less fuel efficient. Engineers often deal with such competing factors. They break down general issues into concrete questions. They then answer those questions with design variables, units, and numbers.

Engineering is not a spectator sport. It is a *hands-on* and *minds-on* activity. In this book, you will be asked to participate in a "Design Studio." This is the part of the course that is "hands on"—and, it is *fun!* But, you will still learn the principles of good design practice (irrespective of your intended engineering major), and you will have to integrate skills learned in construction, electrical circuits, logic, and computers in building a device (the "device" could be a car, robot, boat, bridge, or anything else appropriate to your course). It will have to compete against similar devices built by other young engineers also in your class and whose motivation may be to stop your device from succeeding in achieving the same goals! You will learn how to organize data and the vital importance of good communication skills. You will present your ideas and your designs orally and in written format. In the Design Studio, you will design and build increasingly complex engineering systems, starting with the tallest tower made from a single sheet of paper and ending with a controlled device combining many parts into a system aimed at achieving complex goals.

As a precursor to the "minds-on" portion of the book, can you mentally take apart and put back together an imaginary automobile or toaster, or computer or bicycle? Instead of using wrenches and screwdrivers, your tools are mental and computerized tools for engineering thought.

Example 1.1

Figure 1.1 shows a generic car with numbered parts. Without cheating from the footnote, fill in the correct number corresponding to the parts in each of the blanks.[6]



Radiator: _____

Battery: _____

Spare Tire: _____

Exhaust Manifold: _____

Gas Tank: _____

Starter Motor: _____

Muffler: _____

Alternator: _____

Distributor: _____

Oil Filter: _____

Transmission: _____

FIGURE 1.1 An Exploded View of a Modern Automobile. *Source:* © Moving Graphics

As visually appealing as Figure 1.1 is, an engineer would consider it inadequate because it fails to express the functional connections among the various parts. Expressing in visual form the elements and relationships involved in a problem is a crucial tool of engineering, called a **conceptual sketch.** A first step in an engineer's approach to a problem is to draw a conceptual sketch of the problem. Artistic talent is not an issue nor is graphic accuracy. The engineer's conceptual sketch may not look at all like the thing it portrays. Rather, it is intended to

[6]Answer: 1—distributor, 2—transmission, 3—spare tire, 4—muffler, 5—gas tank, 6—starter motor, 7—exhaust manifold, 8—oil filter, 9—radiator, 10—alternator, 11—battery.

(1) help the engineer identify the elements in a problem, (2) see how groups of elements are connected together to form subsystems, and (3) understand how all those subsystems work together to create a working system.

Example 1.2

On a piece of paper draw a conceptual sketch of what happens when you push on the pedal of a bicycle. Before you begin here are some questions you should think about:

What are the key components that connect the pedal to the wheel?
Which ones are connected to each other?
How does doing something to one of the components affect the others?
What do those connections and changes have to do with accomplishing the task of accelerating the bicycle?

Solution

Figure 1.2 shows what your sketch should contain. The pedal is connected to a crank, and the crank is connected to a sprocket. A chain connects the sprocket to a smaller sprocket on the rear wheel. This sprocket is connected to some type of transmission with gears that turns the rear wheel.

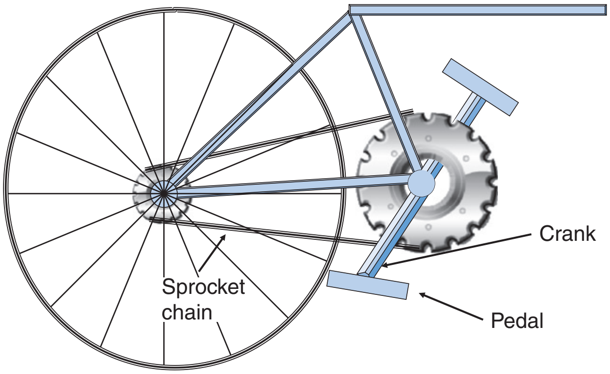


FIGURE 1.2 Bicycle Transmission

For any engineering concept, many different conceptual sketches are possible. You are encouraged to draw conceptual sketches of each of the key points in the learning sections in this book.

1.8 PERSONAL AND PROFESSIONAL ETHICS

What are *personal* ethics . . . and what do they have to do with engineering?

Personal ethics are the standards of human behavior that individuals of different cultures have constructed to make moral judgments about personal or group situations. Ethical principles developed as people reflected on the intentions and consequences of their acts. Naturally, they vary over time and from culture to culture, resulting in conflict when what is acceptable in one culture is not in another. For example, the notion of privacy in U.S. culture is very strong, and a desk is considered an extension of that privacy, whereas in another culture, such as Japan, office space is open and one's desk would be considered public domain.

Suppose you are a passenger in a car driven by a close friend. The friend is exceeding the speed limit and has an accident. There are no witnesses, and his lawyer tells you that if you testify that your friend was not exceeding the speed limit, it will save him from a jail sentence. What do you do?

Lying is more accepted in cultures that stress human relationships, but it is less accepted in cultures that stress laws. People in cultures that emphasize human relationships would most likely lie to protect the relationship, whereas people in cultures that put greater value on laws would lie less in order to obey the law.

How do you reconcile a belief in certain moral absolutes such as "I will not kill anyone" with the reality that, in some circumstances (e.g., war), it might be necessary to endanger or kill innocent people for the greater good? This issue gets particularly difficult if one denies tolerance to other faiths, yet the prevailing morality that most of us would describe as "good" is to extend tolerance to others.

1.8.1 The Five Cornerstones of Ethical Behavior

Here are some examples of codes of personal ethics. At this point, you might want to compare your own personal code of ethics with the ones listed here.[7]

1. Do what you say you will do.
2. Never divulge information given to you in confidence.
3. Accept responsibility for your mistakes.
4. Never become involved in a lie.
5. Never accept gifts that compromise your ability to perform in the best interests of your organization.

1.8.2 Top Ten Questions You Should Ask Yourself When Making an Ethical Decision[8]

10. Could the decision become habit forming? *If so, don't do it.*
9. Is it legal? *If it isn't, don't do it.*
8. Is it safe? *If it isn't, don't do it.*
7. Is it the right thing to do? *If it isn't, don't do it.*
6. Will this stand the test of public scrutiny? *If it won't, don't do it.*
5. If something terrible happened, could I defend my actions? *If you can't, don't do it.*
4. Is it just, balanced, and fair? *If it isn't, don't do it.*
3. How will it make me feel about myself? *If it feels lousy, don't do it.*
2. Does this choice lead to the greatest good for the greatest number? *If it doesn't, don't do it.*

And the number 1 question you should ask yourself when making an ethical decision:

1. Would I do this in front of my mother? *If you wouldn't, don't do it.*

1.9 WHAT ARE *PROFESSIONAL* ETHICS?

A professional code of ethics has the goal of ensuring that a profession serves the legitimate goals of *all* its constituencies: self, employer, profession, and public. The code protects the members of the profession from some undesired consequences of competition (for example, the pressure to cut corners to save money) while

[7]Manske, F.A., Jr., *Secrets of Effective Leadership* (Columbia, TN: Leadership Education and Development, Inc., 1987).
[8]From http://www.cs.bgsu.edu/maner/heuristics/1990Taylor.htm.

leaving the members of the profession free to benefit from the desirable consequences of competition (for example, invention and innovation).

Having a code of ethics enables an engineer to resist the pressure to produce substandard work by saying, *"As a professional, I cannot ethically put business concerns ahead of professional ethics."* It also enables the engineer to similarly resist pressure to allow concerns such as personal desires, greed, ideology, religion, or politics to override professional ethics.

1.9.1 National Society of Professional Engineers (NSPE) Code of Ethics for Engineers

Engineering is an important and learned profession. As members of this profession, engineers are expected to exhibit the highest standards of honesty and integrity. Engineering has a direct and vital impact on the quality of life for all people. Accordingly, the services provided by engineers require honesty, impartiality, fairness, and equity and must be dedicated to the protection of the public health, safety, and welfare. Engineers must perform under a standard of professional behavior that requires adherence to the highest principles of ethical conduct.[9]

1.9.2 Fundamental Canons[10]

Engineers, in the fulfillment of their professional duties, shall

- Hold paramount the safety, health, and welfare of the public.
- Perform services only in areas of their competence.
- Issue public statements only in an objective and truthful manner.
- Act for each employer or client as faithful agents or trustees.
- Avoid deceptive acts.
- Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

Example 1.3: An Ethical Situation

The following scenario is a common situation faced by engineering students. Read it and discuss how you would respond. What are your ethical responsibilities?

You and your roommate are both enrolled in the same engineering class. Your roommate spent the weekend partying and did not do the homework that is due on Monday. You did your homework, and your roommate asks to see it. You are afraid he/she will just copy it and turn it in as his/her own work. What are you ethically obligated to do?

a. Show your roommate the homework.
b. Show the homework but ask your roommate not to copy it.
c. Show the homework and tell the roommate that if the homework is copied, you will tell the professor.
d. Refuse to show the homework.
e. Refuse to show the homework but offer to spend time tutoring the roommate.

[9] See http://www.nspe.org/ethics/eh1-code.asp.
[10] Canons were originally church laws; the word has come to mean rules of acceptable behavior for specific groups.

Solution

For the purposes of this course, the answer to an ethics question consists of appropriately *applying a code of ethics*. In this example, the Five Cornerstones of Ethical Behavior are used, since they are familiar to you in one form or another.

Let us see which of the Five Cornerstones apply here:

1. **Do what you say you will do.** If the teacher has made it clear that this is an individual assignment, then by participating in the assignment, you have implicitly agreed to keep your individual effort private. Allowing one's homework to be copied means going back on this implicit promise. This implies that answer d or e, "Refuse to show the homework" is at least part of the right answer.
2. **Never divulge information given to you in confidence.** Again, homework is implicitly a confidential communication between an individual student and a teacher. By solving the problem, you have created a confidential communication with the teacher. This is more support for choice d or e.
3. **Accept responsibility for your mistakes.** Sharing your homework enables your roommate to evade this standard. Being an accomplice in the violation of standards by others is itself an ethical violation. This is further support for choice d or e.
4. **Never become involved in a lie.** Allowing your homework to be copied is participating in a lie: that the work the roommate turns in is his or her own work. This further supports choice d or e.
5. **Never accept gifts that compromise your ability to perform in the best interests of your organization.** Since the roommate has not offered anything in exchange for the help, this standard appears not to apply in this case.

Four of the five cornerstones endorse choice d or e, refuse to show the homework, while the fifth cornerstone is silent. These results indicate that your ethical obligation under this particular code of personal ethics is to refuse to show the homework.

Many people find the Five Cornerstones to be incomplete because they lack a canon common to most of the world's ethical codes: the Golden Rule.[11] Including the Golden Rule would create the additional obligation to show some empathy for your roommate's plight, just as you would hope to receive such empathy if you were in a similar situation. This suggests the appropriateness of choice e, offering to tutor the roommate in doing the homework. In much the same way, in subsequent exercises, you may feel the need to supplement the Code of Ethics for Engineers with elements from your own personal code of ethics. However, this must not take the form of *replacing* an element in the Code of Ethics for Engineers with a personal preference.

In subsequent chapters, the NSPE Code of Ethics for Engineers is used, but this does not constitute an endorsement of the code or any other particular code for personal ethics. Use of the NSPE Code of Ethics for Engineers in subsequent answers, by contrast, *does* constitute a reminder that you must accept that code in your professional dealings if you want to be a professional engineer.

1.10 ENGINEERING ETHICS DECISION MATRIX

To avoid creating an unintentional contrast between ethics and engineering, you will be asked to focus on a particular tool: the **engineering ethics decision matrix**. This tool presents a simple way of applying the canons of engineering ethics and further to see the spectrum of responses that might apply in a given situation. In particular, it should give you pause not to accept the first simple do/do not response that comes to you.

In Table 1.2, the rows of the matrix are the canons of engineering ethics (here, the NSPE set) and the columns are possible ways to resolve the problem. (You should add additional ones as they occur to you.) Each box of the

[11] There are many versions of the Golden Rule in the world's major religions. Here's one attributed to Confucius: "Do not do to others what you would not like yourself."

Table 1.2 The Engineering Ethics Decision Matrix

Options → NSPE Canons ↓	Go along with the decision	Appeal to higher management	Quit your job	Write your state representative	Call a newspaper reporter
Hold paramount the safety, health, and welfare of the public					
Perform services only in the area of your competence					
Issue public statements only in an objective and truthful manner					
Act for each employer or client as faithful agents or trustees					
Avoid deceptive acts					
Conduct yourself honorably					

matrix must be filled with a very brief answer to the question "Does this one particular solution meet this particular canon?" Like other engineering tools, the ethical decision matrix is a way to divide-and-conquer a problem, rather than trying to address all its dimensions simultaneously.

Example 1.4

You are a civil engineer on a team designing a bridge for a state government. Your team submits what you believe to be the best design by all criteria, at a cost that is within the limits originally set. However, some months later the state undergoes a budget crisis and cuts your funds. Your supervisor, also a qualified civil engineer, makes design changes to achieve cost reduction that he/she believes will not compromise the safety of the bridge. You are not so sure, though you cannot conclusively demonstrate a safety hazard. You request that a new safety analysis be done. Your supervisor denies your request on the grounds of time and limited budget. What do you do?

Solution

Table 1.3 shows a typical set of student responses. How would *you* fill out this table?

Notice the multidimensional character of these answers. Here's one way to make some sense of your answer. Total the yeses and the noes in each column (ignore "maybe"). By this criterion, you should appeal to higher management, which of course might still ignore you. But that is the first action you should consider even though your boss may strenuously disagree with you. You have a powerful ally in the engineering ethics decision matrix to persuade others to your point of view. Some engineering ethics decision matrices have just one overwhelming criterion that negates all other ethical responses on your part; if so, you must follow that path—but usually the engineering ethics decision matrix has multiple conflicting factors. All you should expect from the matrix is that it will stimulate most or all of the relevant terms you should consider and help you avoid immediately accepting the first thought that entered your head.

Table 1.3 Student Responses to the Ethical Scenario

Options → Canons ↓	**Go along with the decision**	**Appeal to higher management**	**Quit your job**	**Write your state representative**	**Call a newspaper reporter**
Hold paramount the safety, health, and welfare of the public.	No. Total assent may put public at risk.	Maybe. Addresses risk, but boss may bury issue.	No. If you just quit, risks less likely to be addressed.	Yes. Potential risk will be put before public.	Yes. Potential risk will be put before public.
Perform services only in the area of your competence	Yes. You are not a safety expert.	Yes. Though not a safety expert, you are competent to surface an issue.	Maybe.	No. You are not an expert in government relations.	No. You are not an expert in press relations.
Issue public statements only in an objective and truthful manner	No. Silence may seem like untruthful assent.	Maybe. You are publicly silent, but have registered dissent.	No. Quitting to avoid the issue is being untruthful.	Maybe. Your personal involvement may hurt your objectivity.	No. The press is likely to sensationalize what is as yet only a potential issue.
Act for each employer or client as faithful agents or trustees	Yes. As an agent, you are expected to follow orders.	Yes. As an agent, you are expected to alert management to potential problems.	Maybe. Quitting a job is not bad faith.	No. As an agent or trustee, you may not make internal matters public without higher approval.	No. As an agent or trustee, you may not make internal matters public without higher approval.
Avoid deceptive acts	No. Assenting to something you disagree with is deceptive.	Yes. You honestly reveal your disagreement.	No. Quitting to avoid responsibility is deceptive.	Yes. You honestly reveal your disagreement.	Yes. You honestly reveal your disagreement.
Conduct yourself honorably	No. Deceptive assent dishonors the profession.	Yes. Honorable dissent is in accord with obligations.	Maybe.	Yes. Honorable dissent is in accord with obligations.	Maybe. Might be publicity seeking, not honorable dissent.
Totals	Yes = 2 No = 4 Maybe = 0	Yes = 4 No = 0 Maybe = 2	Yes = 0 No = 3 Maybe = 3	Yes = 3 No = 2 Maybe = 1	Yes = 2 No = 3 Maybe = 1

1.11 WHAT SHOULD YOU EXPECT FROM THIS BOOK?

The old joke goes something like this: A year ago, I couldn't even spell *injuneer*, but now I *are* one! Well, you will *not* be an engineer at the end of this course, and if anything, you will learn at least that much. On the other hand, if you pay attention, you will learn the following:

1. Engineering is based on well-founded fundamental principles grounded in physics, chemistry, mathematics, and logic, to name just a few skills.
2. Its most general principles include (a) definition of a force unit, (b) conservation of energy, (c) conservation of mass, and (d) the use of system control boundaries.
3. Engineering problems are multidisciplinary in approach, and the lines between each subdiscipline blur.
4. Engineering success is often based on successful teamwork.
5. The ability to carry out an introductory analysis in several engineering disciplines should be based on fundamental principles. It often depends on
   - **a.** Identifying the basic steps in the design process
   - **b.** Applying those basic steps to simple designs
   - **c.** Completing a successful team design project
6. You require sound thinking skills as well as practical hands-on skills.
7. The Design Studio will teach you that you also need writing and oral presentation skills.
8. No project is complete without reporting what you have accomplished. Therefore, you need to demonstrate effective communication skills.
9. Computer skills are essential to answer many kinds of practical engineering problems.
10. Engineering skills can be intellectually rewarding as well as demanding.
11. You should come away with some idea of what is meant by each subdiscipline of engineering and, for those who will continue to seek an engineering career, some idea of which of these subdisciplines most appeals to you.
12. We offer a practical way to ask if your behavior is ethical according to well-established engineering ethical canons. If you always act in concordance, no matter the short-term temptations not to, you *will* come out ahead.

SUMMARY

Engineering is about changing the world by creating new solutions to society's problems. This text covers introductions to bioengineering, chemical engineering, civil engineering, computer engineering, electrical engineering, electrochemical engineering, environmental engineering, green energy engineering, manufacturing engineering, materials engineering, mechanical engineering, and nuclear engineering.

What is common to the branches of engineering is their use of fundamental ideas involving variables, numbers, and units and the creative use of energy, materials, motion, and information. Engineering is both hands-on and minds-on. The hands-on activity for this book is the Design Studio, in which good design practices are used to construct a "device" to compete against similar devices built by other students. You will learn how to keep a log book and how to protect your designs. You will use conceptual sketches to advance your designs.

Finally, you will take your first steps in learning the importance of professional ethics in your career; ethics are an ongoing concern that you will encounter irrespective of the direction your career takes.

EXERCISES

1. Draw a conceptual sketch of your computer. Identify the keyboard, screen, power source, and information storage devices using arrows and labels.
2. Draw a conceptual sketch of an incandescent lightbulb. Identify all the components using arrows and numbers as in Figure 1.1.
3. Draw a sketch of a ballpoint pen. Identify all the components with arrows and labels as in Figure 1.2.
4. Figure 1.3 is an exploded view of a table. Identify and label all the components.

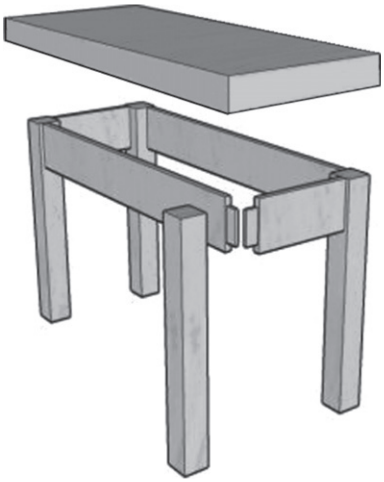


FIGURE 1.3 Image of Exploded Table for Exercise 4

5. Figure 1.4 is an exploded view of a box. Identify and label all the components.

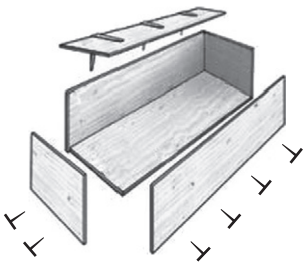


FIGURE 1.4 Image of Exploded Box for Exercise 5

Unless otherwise directed in the problems that follow, if a code of ethics is required, use the National Society of Professional Engineers (NSPE) Code of Ethics (http://www.nspe.org/Ethics/CodeofEthics/index.html). Format as in Table 1.2.

6. Repeat Example 1.3 using the NSPE Code of Ethics for Engineers. Solve using the engineering ethics matrix.

7. Repeat Example 1.4 using the Five Cornerstones of Ethical Behavior. Solve using the engineering ethics matrix.

8. It is the last semester of your senior year and you are anxious to get an exciting electrical engineering position in a major company. You accept a position from company A early in the recruiting process, but continue to interview hoping for a better offer. Then, your dream job offer comes along from company B. More salary, better company, more options for advancement, it is just what you have been looking for. What should you do?
   a. Just don't show up for work at company A.
   b. Send a letter to A retracting your job acceptance with them.
   c. Ask company B to contact company A and tell them you won't be working for them.
   d. Reject the offer from company B and work for company A anyway.

9. A company purchased an expensive computer program for your summer job with them. The license agreement states that you can make a backup copy, but you can use the program on only one computer at a time. Your senior design course professor would like you to use the program for your senior design project. What should you do?
   a. Give the program to your professor and let him/her worry about the consequences.
   b. Copy the program and use it because no one will know.
   c. Ask your supervisor at the company that purchased the program if you can use it at school on your senior project.
   d. Ask your professor to contact the company and ask for permission to use the program at school.

10. You are attending a regional conference along with five other students from your institution. The night before the group is scheduled to return to campus, one of the students is arrested for public intoxication and is jailed. Neither he nor the other students have enough cash for bail, and he doesn't want his parents to know. He asks you to lend him the organization's emergency cash so that he doesn't have to spend the night in jail; he'll repay you as soon as his parents send money. What should you do?
    a. Lend him the money, since his parents are wealthy and you know he can repay it quickly.
    b. Tell him to contact his parents now and ask for help.
    c. Give him the money, but ask him to write and sign a confessional note to repay it.
    d. Tell him to call a lawyer since it's not your problem.

11. You are testing motorcycle helmets manufactured by a variety of your competitors. Your company has developed an inexpensive helmet with a liner that will withstand multiple impacts but is less effective on the initial impact than your competitor's. The vice president for sales is anxious to get this new helmet on the market and is threatening to fire you if you do not release it to the manufacturing division. What should you do?
    a. Follow the vice president's orders, since he/she will ultimately be responsible for the decision.
    b. Call a newspaper to "blow the whistle" on the unsafe company policies.
    c. Refuse to release the product as unsafe and take your chances on being fired.
    d. Stall the vice president while you look for a job at a different company.

12. Paul Ledbetter is employed at Bluestone Ltd. as a manufacturing engineer. He regularly meets with vendors who offer to supply Bluestone with needed services and parts. Paul discovers that one of the vendors, Duncan Mackey, like Paul, is an avid golfer. They begin comparing notes about their favorite

golf courses. Paul says he's always wanted to play at the Cherry Orchard Country Club, but since it is a private club, he's never had the opportunity. Duncan says he's been a member there for several years and that he's sure he can arrange a guest visit for Paul. What should Paul do?[12]

a. Paul should accept the invitation since he has always wanted to play there.
b. Paul should reject the invitation since it might adversely affect his business relationship with Duncan.
c. Paul should ask Duncan to nominate him for membership in the club.
d. Paul should ask his supervisor if it's OK to accept Duncan's invitation.

13. Some American companies have refused to promote women into positions of high authority in their international operations in Asia, the Middle East, and South America. Their rationale is that business will be hurt because some foreign customers do not wish to deal with women. It might be contended that this practice is justified out of respect for the customs of countries that discourage women from entering business and the professions.

Some people feel that such practices are wrong and that gender should not to be used in formulating job qualification. Further, they believe that customer preferences should not justify gender discrimination. Present and defend your views on whether or not this discrimination is justified.

14. Marvin Johnson is an environmental engineer for one of several local plants whose water discharges flow into a lake in a flourishing tourist area. Included in Marvin's responsibilities is the monitoring of water and air discharges at his plant and the periodic preparation of reports to be submitted to the Department of Natural Resources.

Marvin just prepared a report that indicates that the level of pollution in the plant's water discharge slightly exceeds the legal limitations. However, there is little reason to believe that this excessive amount poses any danger to people in the area; at worst, it will endanger a small number of fish. On the other hand, solving the problem will cost the plant more than $200,000.

Marvin's supervisor says the excess should be regarded as a mere "technicality" and he asks Marvin to "adjust" the data so that the plant appears to be in compliance. He explains: "We can't afford the $200,000. It would set us behind our competitors. Besides the bad publicity we'd get, it might scare off some of tourist industry." How do you think Marvin should respond to Edgar's request?

15. Derek Evans used to work for a small computer firm that specializes in developing software for management tasks. Derek was a primary contributor in designing an innovative software system for customer services. This software system is essentially the "lifeblood" of the firm. The small computer firm never asked Derek to sign an agreement that software designed during his employment there becomes the property of the company. However, his new employer did.

Derek is now working for a much larger computer firm. Derek's job is in the customer service area, and he spends most of his time on the telephone talking with customers having systems problems. This requires him to cross-reference large amounts of information. It now occurs to him that by making a few minor alterations in the innovative software system he helped design at the small computer firm, the task of cross-referencing can be greatly simplified.

On Friday, Derek decides he will come in early Monday morning to make the adaptation. However, on Saturday evening, he attends a party with two of his old friends, you and Horace Jones. Since it has been some time since you have seen each other, you spend some time discussing what you have been doing recently. Derek mentions his plan to adapt the software system on Monday. Horace asks, "Isn't that

[12]Extracted from *Teaching Engineering Ethics; A Case Study Approach*, Michael S. Pritchard, editor, Center for the Study of Ethics in Society, Western Michigan University: http://ethics.tamu.edu/pritchar/golfing.htm.

unethical? That system is really the property of your previous employer." "But," Derek replies, "I'm just trying to make my work more efficient. I'm not selling the system to anyone, or anything like that. It's just for my use—and, after all, I did help design it. Besides, it's not exactly the same system—I've made a few changes." What should be done about this situation?[13]

16. Jan, a professional engineer on unpaid leave, is a part-time graduate student at a small private university and is enrolled in a research class for credit taught by Dimanro, a mechanical engineering professor at the university. Part of the research being performed by Jan involves the use of an innovative geothermal technology.

The university is in the process of enlarging its facilities, and Dimanro, a member of the university's building committee, has responsibility for developing a request for proposal (RFP) to solicit interested engineering firms. Dimanro plans to incorporate an application of the geothermal technology into the RFP. Dimanro asks Jan to serve as a paid consultant to the university's building committee in developing the RFP and reviewing proposals. Jan's employer will not be submitting a proposal and is not averse to having Jan work on the RFP and proposal reviews. Jan agrees to serve as a paid consultant.

Is it a conflict of interest for Jan to be enrolled in a class for credit at the university and at the same time serve as a consultant to the university?[14]

FINAL THOUGHTS[15]

A Calvin and Hobbes comic strip nicely illustrates the importance of thinking ahead in engineering and ethical issues. As they are cascading down a treacherous hill in Calvin's wagon, they discuss their circumstance:

Calvin: Ever notice how decisions make chain reactions?
Hobbes: How so?
Calvin: Well, each decision we make determines the range of choices we'll face next. Take this fork in the road for instance. Which way should we go? Arbitrarily I choose left. Now, as a direct result of that decision, we're faced with another choice: Should we jump this ledge or ride along the side of it? If we hadn't turned left at the fork, this new choice would never have come up.
Hobbes: I note with some dismay, you've chosen to jump the ledge.
Calvin: Right. And *that* decision will give us *new* choices.
Hobbes: Like, should we bail out or die in the landing?
Calvin: Exactly. Our first decision created a chain reaction of decisions. Let's jump.

After crash-landing in a shallow pond, Calvin philosophizes: "See? If you don't make each decision carefully, you never know *where* you'll end up. That's an important lesson we should learn some time." Hobbes replies, "I wish we could talk about these things without the visual aids." Hobbes might prefer that they talk through a case study or two before venturing with Calvin into engineering practice.

[13]Adapted from http://ethics.tamu.edu/pritchar/property.htm.
[14]Adapted from NSPE Board of Ethical Review Case No. 91-5.
[15]This section is from *Teaching Engineering Ethics: A Case Study Approach,* Michael S. Pritchard, editor, Center for the Study of Ethics in Society, Western Michigan University, Copyright 1992: http://ethics.tamu.edu/pritchar/an-intro.htm.