CHAPTER **3**

Introduction to Engineering Design

Chapter Objectives

When you complete your study of this chapter, you will be able to:

- Identify and explain the key steps in the design process
- Explain the importance of the customer's role in the design process
- Apply the design process to solving an open-ended problem
- Understand the importance of the engineering design process in development of engineering solutions to society's needs

3.1 An Introduction to Engineering Design

What do you say when asked why you are planning to be an engineer? One possible response is, "I want to become an engineer to design . . . ." It might be to design a water-quality system for a developing country, a new spacecraft for NASA, the tallest building in the world, an auto-guidance device for automobiles, new and improved sports equipment, or even synthetic blood. The key is that engineers design devices, systems, or processes to help humankind.

So what is engineering design? Engineering design is a systematic process by which solutions to the needs of humankind are obtained. Design is the essence of engineering. The design process is applied to problems (needs) of varying complexity. For example, mechanical engineers will apply the design process to develop an effective, efficient vehicle suspension system; electrical engineers will apply the process to design lightweight, compact wireless communication devices; and materials engineers will apply the process to design strong, lightweight composites for aircraft structures.

The vast majority of complex problems in today's high technology society do not depend for solutions on a single engineering discipline; rather, they depend on teams of engineers, scientists, environmentalists, economists, sociologists, legal personnel, and others. Solutions are dependent not only on the appropriate applications of technology but also on public sentiment as executed through government regulations and political influence. As engineers we are empowered with the technical expertise to develop new and improved products and systems; however, at the same time we must be increasingly aware of the impact of our actions on society and the environment in general and work conscientiously toward the best solution in view of all relevant factors.

The systematic design process can be conveniently represented by the six steps introduced in Sec. 3.2.

1. Define the problem to be solved.
2. Acquire and assemble pertinent data.
3. Identify solution constraints and criteria.
4. Develop alternative solutions.
5. Select a solution based on analysis of alternatives.
6. Communicate the results.

Building on an Engineering Degree

Nick Mohr

Nick Mohr received his BS in mechanical engineering and then went on to obtain his medical degree. He is currently a resident physician in emergency medicine, caring for patients in the emergency departments of two trauma centers and on a helicopter transport service in Indianapolis, Indiana.

Once he finishes his residency, he plans then either to look for a faculty appointment at a university or to pursue further training, perhaps in a postgraduate aerospace medicine program offered by Johnson Space Center (JSC) in conjunction with the University of Texas. Recently, he spent some time at JSC working with the flight surgeons in space medicine, which he found to be "incredible."

Dr. Mohr was involved with numerous student organizations and activities while pursuing his engineering degree, including Team PrISUm (Iowa State University's solar car team), the Cosmic Ray Observation Project, and the Ames (Iowa) Free Clinic. He feels that his involvement outside the classroom was one of the most important aspects of his undergraduate training. It provided him experience in learning how (1) to solve novel problems and make decisions without knowing the right answers; (2) to succeed and fail when the stakes for failure are high; and (3) to identify what consequences are worth fearing, and using those consequences to choose risks worth taking.

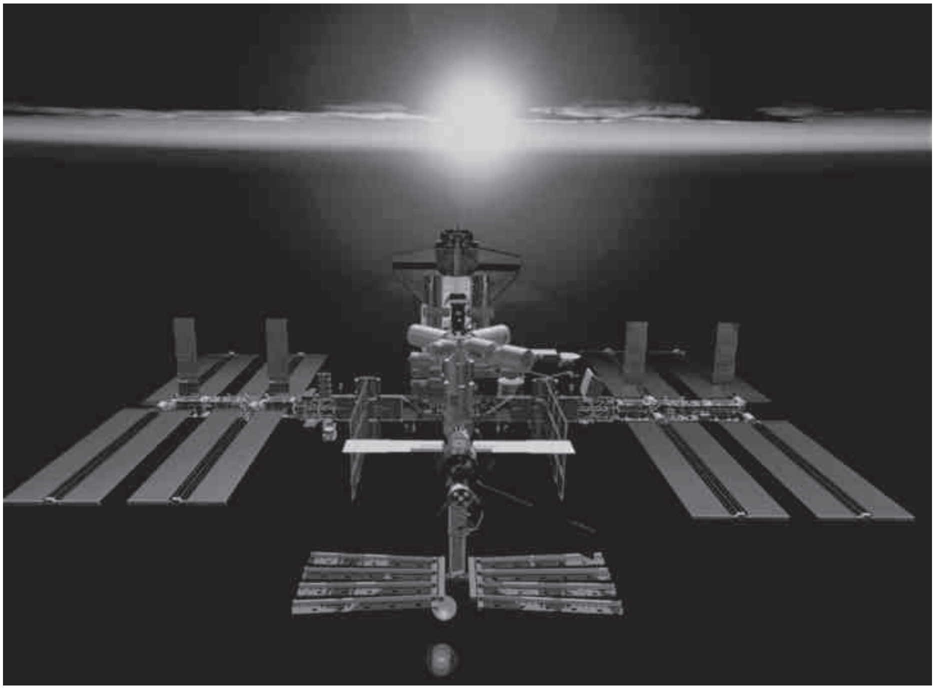
Dr. Mohr recalls that as a student, he had no idea how many doors an engineering degree could open and offers the following advice to students just beginning their engineering education:

"There is no harm in being uncertain about what path your career may take, and in fact, many people change their direction along the way—that's not bad. The important part is to have dreams, and to follow them wholeheartedly until they change. If we do that, we will solve some very interesting problems in our lives and can improve the world in which we live. A strong and diverse educational foundation in engineering has opened doors that I never could have imagined when I was in college."

A formal definition of engineering design is found in the curriculum guidelines of the Accreditation Board for Engineering and Technology (ABET). ABET accredits curricula in engineering schools and derives its membership from the various engineering professional societies. Each accredited curriculum has a well-defined design component that falls within the ABET guidelines. The ABET statement on design reads as follows:

Engineering design is the process of devising a system, component, or process to meet desired needs (Fig. 3.1). It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system descriptions. Further, it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact.

Figure 3.1



The engineering design process was very critical in the design of the international space station.

3.2 The Design Process

A simple definition of design is "a structured problem-solving activity." A process, on the other hand, is a phenomenon identified through step-by-step changes that lead toward a required result. Both these definitions suggest the idea of an orderly, systematic approach to a desired end. The design process, however, is not linear. That is, one does not necessarily achieve the best solution by simply proceeding from one step in the process to the next. New discoveries, additional data, and previous experience with similar problems generally will result in several iterations through some or all the steps of the process (Fig. 3.2).

It is important to recognize that any project will have time constraints. Normally before a project is approved a time schedule and a budget will be approved by management.

For your initial introduction to the design process, we will explain in more detail what is involved at each of the six steps above. Simply memorizing the steps will not give you the needed understanding of design. We suggest that you take one or more of the suggested design problems at the end of the chapter, organize a team of two to four students, and develop a workable solution for each problem selected. By working as a team you will generate more and better solution ideas and develop a deeper understanding of the process.

The process begins with a definition of the problem (Step 1) to be solved. In many cases the engineering design team does not identify or define the

Figure 3.2

Environmental engineers used the engineering design process to maximize the efficiency of this recycling system without causing damage to the environment.

problem. Instead customers, field representatives for the company, and management will provide the initial request. The team must be careful not to define a solution at this step. If it does it has not satisfied the design process. For example, assume company management asks a team to design a cart to transport ingots of metal from one building to another, the buildings approximately 200 meters apart. The solution to this problem is already known: a cart. It is a matter of seeing what is available on the market for handling the required load. It may be to the company's benefit to find a "new system" that effectively and efficiently moves heavy loads over a short distance. This would open up the possibility for a rail system, conveyor, or other creative solution. Usually a simple problem definition allows the most flexibility for the design team. For example, the initial problem could be defined as simply "Currently there are ingots of metal stored in building one. We need a way to get the ingots from that building to building two."

The team next acquires and assembles all pertinent information on the problem (Step 2). Internal company documents, available systems, Internet searches, and other engineers are all possible sources of information. Once all team members are up to speed on the available information, the solution constraints and criteria are identified (Step 3). A constraint is a physical or practical limitation on possible solutions; for example, the system must operate with 220-volt electricity. Criteria are desirable characteristics of a solution; for example, the solution must be reliable, must be easy to operate, must have an acceptable cost, and must be durable. You might think of a constraint as a requirement—all possible solutions must meet it—while a criterion is a relative consideration, in that one solution is better than another ("durable" is a criterion, for example).

Now the team is ready for the creative part of the process, developing alternative solutions (Step 4). This is where experience and knowledge, combined with group activities such as brainstorming, yield a variety of possible solutions (Fig. 3.3). Each of the alternatives is now analyzed using the constraints and comparing each to the specified criteria. In many cases prototypes are built and tested to see if they meet constraints and criteria. Computer modeling

Figure 3.3

The brainstorming of new ideas for solving an engineering problem is important in the design process.

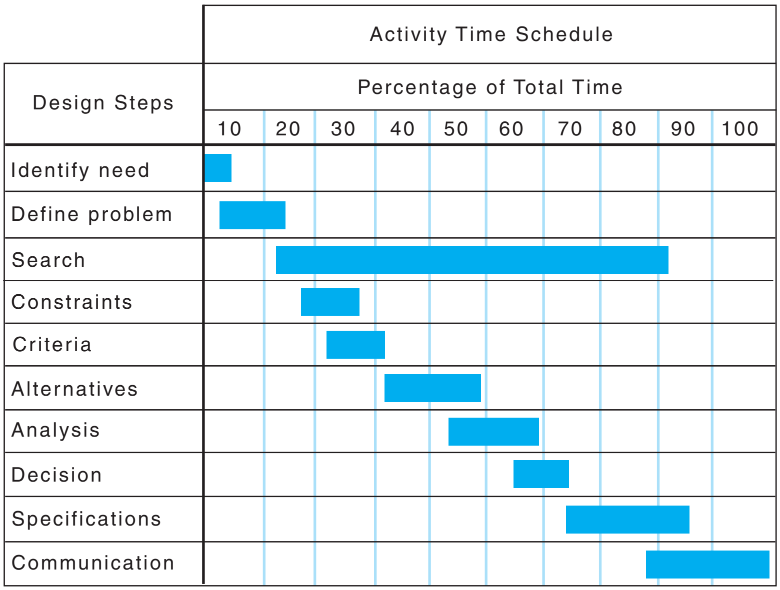
and analysis are used heavily during this step. Then, using a device such as a decision matrix, a solution is selected (Step 5).

The last step of the design process often involves the most time and requires resources outside the original design team. Communicating the results (Step 6) involves developing all the details and reports necessary for the design to be built or manufactured as well as presentations for management and customers.

Although the systematic design process appears to end at Step 6, it really remains open throughout the product life cycle. Field testing, customer feedback, and new developments in materials, manufacturing processes, and so on may require redesign any time during the life cycle. Today many products are required to have a disposal plan prior to marketing. In these cases the original design needs to include disposal as a constraint on the solution. Although a six (6) step design process is outlined above, other more expanded steps are in common use. For example, Figure 3.4 illustrates a nine-step design process.

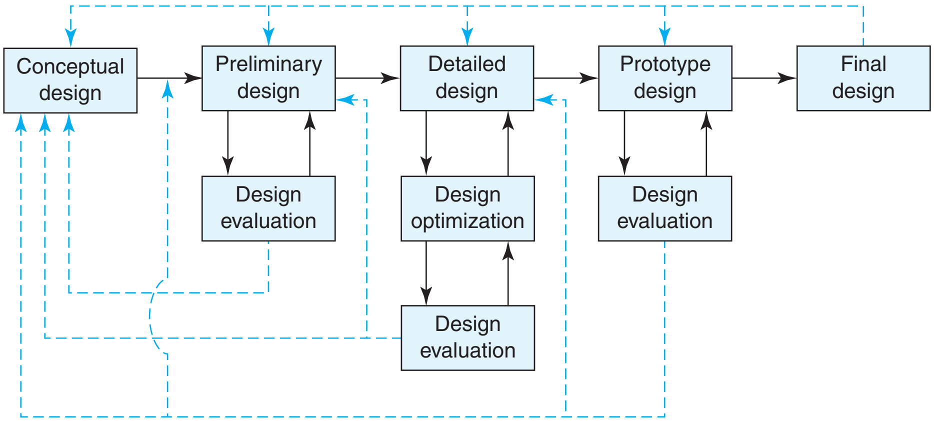
To further illustrate the iterative nature of the design process, study Figure 3.5 for a typical industrial activity. The process begins with a conceptual design and proceeds to preliminary design, detailed design, prototype design, and the final design. Note that design evaluation is conducted frequently during the process. Also note that the design is optimized at the detailed design stage. Optimization is beyond the scope of this introduction, but suffice it to say that it occurs after the solution is determined and is based on the analysis of alternatives (Step 5).

Figure 3.4



A time schedule must be developed early in order to control the design process.

Figure 3.5

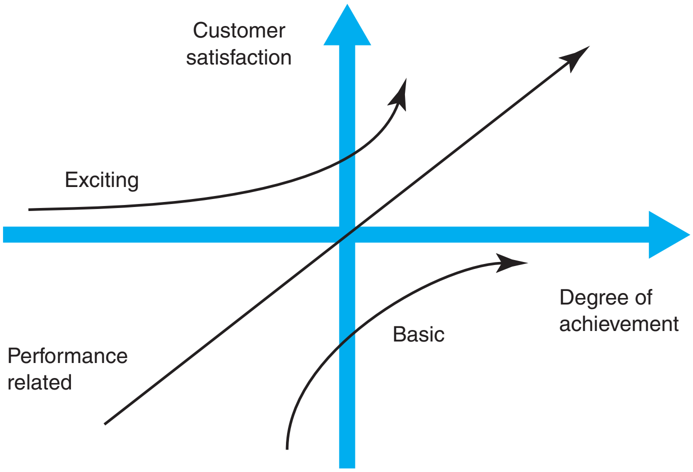


A flow diagram for the categories of engineering design.

3.3 Design and the Customer

Often customer requirements are not well defined. The design team must determine, in consultation with the customer, the expectations of the solution. The customer therefore must be kept informed of the design status at all times during the process. It is likely that compromises will have to be made. Both the design team and customer may have to modify their requirements in order to meet deadlines, cost limits, manufacturing constraints, and performance requirements. Figure 3.6 is a simple illustration of the Kano model showing the relationship between degree of achievement (horizontal axis) and customer satisfaction (vertical axis). Customer requirements are categorized in three areas: basic, performance related, and exciting.

Figure 3.6



Factors in generating customer satisfaction.

Basic customer requirements are simply expected by the customer and assumed to be available. For example, if the customer desires a new electric-powered barbeque grill, the customer assumes that the design team and the company have proven their ability, with existing successful products, to design and manufacture electric-powered barbeque grills.

Performance-related customer requirements are the basis for requesting the new product. In the example of the barbecue grill, cooking time, cooking effectiveness, ease of setting the controls, and ease of cleaning are among the many possible performance-related items that a customer may specify. As time goes by and more electric powered grills reach the marketplace, these requirements may become basic.

Exciting customer requirements are generally suggested by the design team. The customer is unlikely to request these features because they are often outside the range of customer knowledge or vision. The exciting requirements are often a strong selling point in the design because they give the customer an unexpected bonus in the solution. Perhaps the capability of programming a cooking cycle to vary the temperature during the cooking process would be a unique (but perhaps costly) addition to the solution.

Figure 3.6 indicates that the basic requirements are a must for customer satisfaction. The customer will be satisfied once a significant level of performance-related requirements is met. The exciting requirements always add to customer satisfaction, so the more of these features that can be added, the greater is the satisfaction.

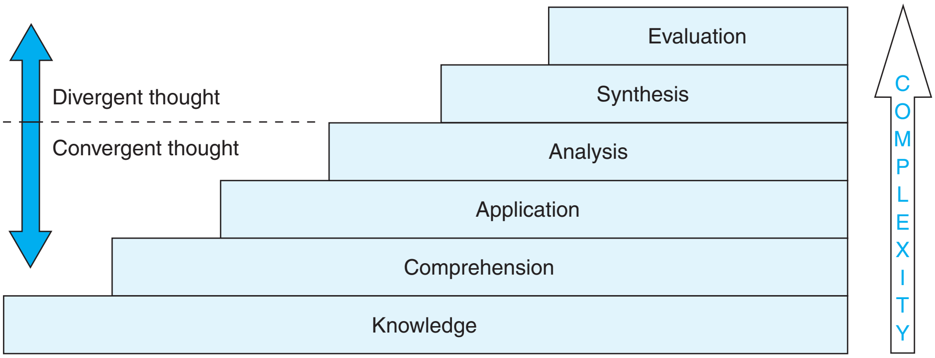
3.4 The Nature of Engineering Design

In the first half of the 20th century, engineering design was considered by many to be a creative, ad hoc process that did not have a significant scientific basis. Design was considered an art, with successful designs emanating from a few talented individuals in the same manner as great artwork is produced by talented artists. However, there are now a wealth of convincing arguments that engineering design is a cognitive process that requires a broad knowledge base, intelligent use of information, and logical thinking. Today successful designs are generated by design teams, comprised of engineers, marketing personnel, economists, management, customers, and so on, working in a structured environment and following a systematic strategy. Utilizing tools such as the Internet, company design documentation, brainstorming, and the synergy of the design team, information is gathered, analyzed, and synthesized with the design process yielding a final solution that meets the design criteria.

What do we mean by a cognitive process? In the 1950s Benjamin Bloom developed a classification scheme for cognitive ability that is called Bloom's taxonomy. Figure 3.7 shows the six levels of complexity of cognitive thinking and provides an insight into how the design process is an effective method of producing successful products, processes, and systems. The least complex level, knowledge, is simply the ability to recall information, facts, or theories. [What was the date of the Columbia space shuttle accident?]

The next level is comprehension, which describes the ability to make sense of (understand) the material. [Explain the cause of the Columbia accident.] The

Figure 3.7



Bloom's taxonomy on learning aligns with the engineering design process.

third level is application, which is the ability to use knowledge and comprehension in a new situation and to generalize the knowledge. [What would you have done to prevent the Columbia accident?]

The fourth level is analysis, which is the ability to break learned material into its component parts so that the overall structure may be understood. It includes part identification, relationships of the parts to each other and to the whole, and recognition of the organizational principles involved. The individual must understand both the content and structure of the material. Figure 3.7 shows that analysis is the highest level of convergent thinking, whereby the individual recalls and focuses on what is known and comprehended to solve a problem through application and analysis. [What lessons did we learn about the space program from the Columbia accident?]

Levels 5 and 6 on Bloom's taxonomy represent divergent thinking, in which the individual processes information and produces new insights and discoveries that were not part of the original information (thinking outside the box). Synthesis refers to the ability to put parts together to form a new plan or idea. Everyone synthesizes in a different manner. Some accomplish synthesis by quiet mental musing; others must use pencil and paper to doodle, sketch, outline ideas, and so on. [Propose an alternative to the Columbia fuel tank insulation design that would perform the required functions.]

Evaluation is the highest level of thinking. It is the ability to judge the value of material based on specific criteria. Usually the individual is responsible for formulating the criteria to be used in the evaluation. [Assess the impact of the Columbia accident on the U.S. space program.]

To help your understanding of the levels of cognitive thinking, review several exams you have taken in college in mathematics, chemistry, physics, and general education courses (e.g., economics, sociology, history, etc). For each question, decide which level of thinking was required to obtain a successful result. You will find while moving along in your engineering curriculum that exam questions, homework problems, and projects will reflect higher and higher levels of thinking.

3.5 Experiencing the Design Process in Education

The design process, although structured, is an iterative process with flexibility to make necessary adjustments as the design progresses. The emphasis in this chapter is on conceptual design. At this stage of your engineering education it is important that you undergo the experience of applying the design process to a need with which you can identify based on your personal experiences. As you approach the baccalaureate degree you will have acquired the technical capability to conduct the necessary analyses and to make the appropriate technical decisions required for complex products, systems, and processes. Most engineering seniors will participate in a capstone design experience that will test their ability to apply knowledge toward solving a complicated design problem in their particular discipline.

3.6 Design Opportunities and Challenges of the Future

The world continues to undergo rapid and sometimes tumultuous change. As a practicing engineer, you will occupy center stage in many of these changes in the near future and will become even more involved in the more distant future. The National academy of Engineering has identified 14 "Engineering Grand Challenges." These include: 1) make solar energy economical; 2) provide energy from fusion; 3) develop carbon sequestration methods; 4) manage the nitrogen cycle; 5) provide clear water; 6) restore and improve urban infrastructure; 7) advance health informatics; 8) engineer better medicines; 9) reverse-engineer the brain; 10) prevent nuclear terror; 11) secure cyberspace; 12) enhance virtual reality; 13) advance personalized learning; and 14) engineer tools of scientific discovery. (Source: National Academy of Engineering of the National Academies, "Grand Challenges for Engineering," www.engineeringchallenges.org, viewed 8/16/2010.) The huge tasks of providing solutions to these problems will challenge the technical community beyond anyone's imagination.

Engineers of today have nearly instantaneous access to a wealth of information from technical, economic, social, and political sources. A key to the success of engineers in the future will be the ability to study and absorb the appropriate information in the time allotted for producing a design or solution to a problem. A degree in engineering is only the beginning of a lifelong period of study in order to remain informed and competent in the field.

Engineers of tomorrow will have even greater access to information and will use increasingly powerful computer systems to digest this information. They will work with colleagues around the world solving problems and creating new products. They will assume greater roles in making decisions that affect the use of energy, water, and other natural resources. Engineering design solution considerations for energy, the environment, infrastructure, and global competitiveness are addressed in the following sections.

3.6.1 Energy

In order to develop technologically, nations of the world require vast amounts of energy. With a finite supply of our greatest energy source, fossil fuels, alternate supplies must be developed and existing sources must be controlled with a worldwide usage plan. A key factor in the design of products must be minimum use of energy.

As demand increases and supplies become scarcer, the cost of obtaining the energy increases and places additional burdens on already financially strapped regions and individuals. Engineers with great vision are needed to develop alternative sources of energy from the sun, radioactive materials, wind, biomaterials, and ocean and to improve the efficiency of existing energy consumption devices (Fig. 3.8). Ethanol and biodiesel are two fuels that are produced in the United States from renewable resources that can assist in reducing America's dependence on foreign sources of energy. Waste-to-energy and biomass resources are also recognized by the U.S. Department of Energy as renewable energy source and are included in the department's tracking of progress toward achieving the federal government's renewable energy goal.

Along with the production and consumption of energy come the secondary problems of pollution and global warming. Such pollutants as smog, acid rain, heavy metals, nutrients, and carbon dioxide must receive attention in order to maintain the balance of nature. Also, increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change, thus causing global warming. According to the National Academy of Sciences, the Earth's surface temperature has risen by about 1 degree Fahrenheit in the past century, with accelerated warming during the past two decades.

3.6.2 Environment

Our insatiable demand for energy, water, and other national resources creates imbalances in nature that only time and serious conservation efforts can

Figure 3.8

Windmill farms are an increasingly significant factor in the electrical infrastructure.

keep under control (Fig. 3.9). The concern for environmental quality is focused on four areas: cleanup, compliance, conservation, and pollution prevention. Partnerships among industry, government, and consumers are working to establish guidelines and regulations in the gathering of raw materials, the manufacturing of consumer products, and the disposal of material at the end of its designed use.

The American Plastics Council publishes a guide titled *Designing for the Environment*, which describes environmental issues and initiatives affecting product design. All engineers need to be aware of these initiatives and how they apply in their particular industries:

Design for the Environment (DFE): Incorporate environmental considerations into product designs to minimize impacts on the environment.

Environmentally Conscious Manufacturing (ECM) or Green Manufacturing: Incorporating pollution prevention and toxics use reduction into product manufacturing.

Extended Product or Producer Responsibility (Manufacturer's Responsibility or Responsible Entity): Product manufacturers are responsible for taking back their products at the product's end of life and managing them according to defined environmental criteria.

Figure 3.9

Hydroelectric generating stations produce electricity important for industry and residence areas.

Life Cycle Assessment (LCA): Quantified assessment of the environmental impacts associated with all phases of a product's life, often from the extraction of base minerals through the product's end of life.

Pollution Prevention: Prevent pollution by reducing pollution sources (e.g., through design) as opposed to addressing pollution after it is generated.

Product Life Cycle Management (PLCM): Managing the environmental impacts associated with all phases of a product's life, from inception to disposal.

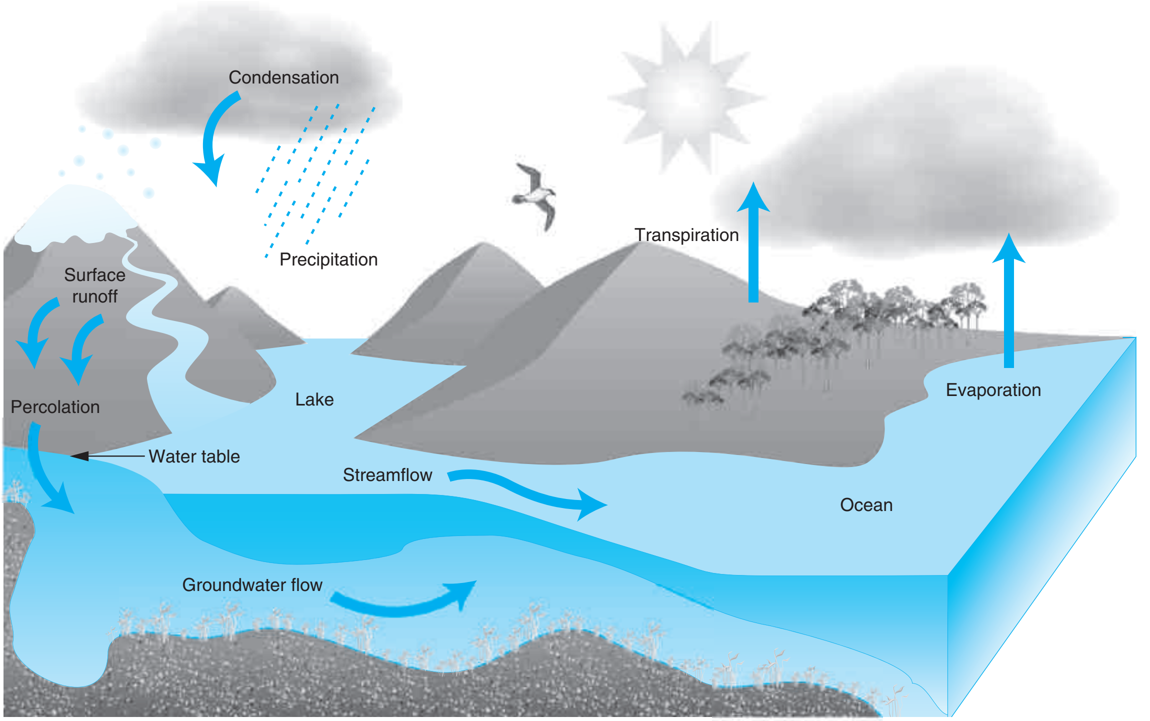
Product Takeback: The collection of products by manufacturer at the product's end of life.

Toxic Use Reduction: Reduce the amount, toxicity, and number of toxic chemicals used in manufacturing.

As you can see from these initiatives, all engineers regardless of discipline must be environmentally conscious in their work. In the next few decades we will face tough decisions regarding our environment. Engineers will play a major role in making the correct decisions for our small, delicate world.

The basic water cycle—from evaporation to cloud formation, then to rain, runoff, and evaporation again—is taken for granted by most people. (See Fig. 3.10.) However, if the rain or the runoff is polluted, then the cycle is interrupted

Figure 3.10



Understanding the water cycle (hydrologic cycle) is necessary in order to be able to engineer systems to control water pollution to our water resources.

and our water supply becomes a crucial problem. In addition, some highly populated areas have a limited water supply and must rely on water distribution systems from other areas of the country. Many formerly undeveloped agricultural regions are now productive because of irrigation systems. However, the irrigation systems deplete the underground streams of water that are needed downstream.

These problems must be solved in order for life to continue to exist as we know it. Because of the regional water distribution patterns, the federal government must be a part of the decision-making process for water distribution. One of the concerns that must be eased is the amount of time required to bring a water distribution plan into effect. Government agencies and the private sector are strapped by regulations that cause delays of several years in planning and construction. Greater cooperation and a better informed public are goals that public works engineers must strive to achieve. Developing nations around the world need additional water supplies because of increasing population growth. Many of these nations do not have the necessary freshwater and must rely on desalination, a costly process. The continued need for water is a concern for leaders of the world, and engineers will be asked to create additional sources of this life-sustaining resource.

3.6.3 Infrastructure

All societies depend on an infrastructure of transportation, waste disposal, and water distribution systems for the benefit of the population (Fig. 3.11). In the United States much of the infrastructure is in a state of deterioration without sound plans for upgrading. For example:

1. Commercial jet fleets include aircraft that are 35 to 40 years old. Major programs are now underway to extend safely the service life of these jets. In order to survive economically, airlines must balance new replacement jets with a program to keep older planes flying safely.
2. One-half of the sewage treatment plants cannot satisfactorily handle the demand.
3. The interstate highway system, over 50 years old in many areas, needs major repairs throughout. Over-the-road trucking has increased wear and tear on a system designed primarily for the automobile. Local paved roads are deteriorating because of a lack of infrastructure funds.
4. Many bridges are potentially dangerous to the traffic loads on them.
5. Railroads continue to struggle with maintenance of railbeds and rolling stock in the face of stiff commercial competition from the air freight and truck transportation industries.
6. Municipal water and wastewater systems require billions of dollars in repairs and upgrades to meet public demands and stricter water-quality requirements.

It is estimated that the total value of the public works facilities is over $2 trillion. To protect this investment, innovative thinking and creative funding must be fostered. Some of this is already occurring in road design and repair. For example, a new method of recycling asphalt pavement actually produces a stronger product. Engineering research is producing extended-life pavement

Figure 3.11

Development of new and improved infrastructure, such as this new rail system, are important to the economy of our nation.

with new additives and structural designs. New, relatively inexpensive methods of strengthening old bridges have been used successfully.

3.6.4 A Competitive Edge in the World Marketplace

We have all purchased or used products that were manufactured outside the country. Many of these products incorporate technology that was developed in the United States. In order to maintain our strong industrial base, we must develop practices and processes that enable us to compete not just with other U.S. industries but with international industries (Fig. 3.12). Engineers must also be able to design products that will be accepted by other cultures and work in their environments. It is therefore most important that engineers develop their global awareness and cultural adaptability competence.

The goal of any industry is to generate a profit. In today's marketplace this means creating the best product in the shortest time at a lower price than the competition. A modern design process incorporating sophisticated analysis procedures and supported by high-speed computers with graphical displays increases the capability for developing the "best" product. The concept of integrating the design and manufacturing functions shortens the design-to-market time for new products and for upgraded versions of existing products. The development of the automated factory is an exciting concept that is receiving a great deal of attention from manufacturing engineers today. Remaining

Figure 3.12

A global design team at work on an engineering design problem.

competitive by producing at a lesser price requires a national effort involving labor, government, and distribution factors. In any case engineers are going to have a significant role in the future of our industrial sector.

Problems

3.1 Complete the statement "I want to become an engineer to design . . ." in as much detail as you can.

3.2 Choose an engineering company that you would someday consider working for. From the information found on their Web site, write a one-page paper on the engineering problems that they are solving and how they are addressing their customer's needs.

3.3 Find three textbooks that introduce the engineering design process. Copy the steps in the process from each textbook. Compare with the six steps in Sec.

3.1. Note similarities and differences and write a paragraph describing your conclusions.

3.4 Interview an engineer working in your chosen field of study, describe in a one-page paper what steps of the design process he/she is engaged with in their job.

3.5 Select a specific discipline of engineering and list at least 20 different companies and/or government agencies that utilize engineers from this field.

3.6 Choose a product that was most likely designed by an engineer in your chosen field of study. Identify what problem this product solved, what constraints were applied to its design, and what criteria were most likely used to evaluate this design.

3.7 Choose one of the National Academy of Engineering's Greatest Challenges found in Sec. 3.6 and write a one-page paper on how you as an engineer could be involved in helping to solve this challenge.

3.8 Choose one of the products from the list below and note key features and functions for the product as produced today. Then, go back one generation (18–25 years) to family, relatives, or friends and ask them to describe the key features and functions of the same product as produced at that time. Note changes and improvements and prepare a brief report.

(a) toaster
(b) electric coffeemaker
(c) color television
(d) landline telephone
(e) cookware (pots, pans, skillets)
(f) vacuum cleaner
(g) microwave oven

3.9 Choose a product that you use every day and evaluate how effective the company that designed it was in meeting your customer needs and the needs of others. What suggestions would you make to help the designers improve the project? How could this product be used for another application?

3.10 Choose a device or product that you believe can be improved upon. Answer the following questions: 1) what do you already know about this device/product; 2) what do you think you know about this device/product; and (3) what do you need to know about this device/product? Based on your responses to these questions conduct research to confirm or reveal what you know and don't know. Write a short report to summarize your findings. Use proper citation methods to list your research sources.

3.11 Choose one of the following topics (or one suggested by your instructor) and write a paper that discusses technological changes that have occurred in this area in the past 15 years. Include commentary on the social and environmental impact of the changes and on new problems that may have arisen because of the changes.

(*a*) passenger automobiles
(*b*) electric power-generating plants
(*c*) computer graphics
(*d*) heart surgery
(*e*) heating systems (furnaces)
(*f*) microprocessors
(*g*) water treatment
(*h*) road paving (both concrete and asphalt)
(*i*) composite materials
(*j*) robotics
(*k*) air-conditioning

3.12 Investigate current designs for one or more of the items listed below. If you do not have the items in your possession, purchase them or borrow from friends. Conduct the following "reverse engineering" procedures on each of the items:

(*a*) Write down the need that the design satisfies.
(*b*) Disassemble the item and list all the parts by name.
(*c*) Write down the function of each of the parts in the item.
(*d*) Reassemble the item.
(*e*) Write down answers to the following questions:

- Does the item satisfactorily solve the need you stated in part (*a*)?
- What are the strengths of the design?
- What are the weaknesses of the design?
- Can this design be easily modified to solve other needs? If so, what needs and what modifications should be made?
- What other designs can solve the stated need?

The items for your study are the following:

- Mechanical pencil
- Safety razors from three vendors; include one disposable razor
- Flashlight
- Battery-powered slide viewer
- Battery-powered fabric shaver

3.13 The following list of potential design projects can be addressed by following the six-step design process discussed in the chapter. A team approach to a proposed solution, with three or four members on each team, is recommended. Develop a report and oral presentation as directed by your instructor.

- A device to prevent the theft of helmets left on motorcycles
- An improved rack for carrying packages or books on a motorcycle or bicycle
- A child's seat for a motorcycle or bicycle
- A device to permit easier draining of the oil pan by weekend mechanics
- A heated steering wheel for cold weather
- A sun shield for an automobile
- An SOS sign for cars stalled on freeways
- A storage system for a cell phone in a car (including charger)
- An improved wall outlet
- A beverage holder for a card table
- A better rural mailbox
- An improved automobile traffic pattern on campus
- An alert for drowsy or sleeping drivers
- Improved bicycle brakes
- A campus transit system
- Improved pedestrian crossings at busy intersections
- Improved parking facilities in and around campus
- A device to attach to a paint can for pouring
- An improved soap dispenser
- A better method of locking weights to a barbell shaft
- A shoestring fastener to replace the knot
- A better jar opener
- A system or device to improve efficiency of limited closet space

- A shoe transporter and storer
- A pen and pencil holder for college students
- A rack for mounting electric fans in dormitory windows
- A device to pit fruit without damage
- An automatic device for selectively admitting and releasing pets through an auxiliary door
- A device to permit a person loaded with packages to open a door
- A more efficient toothpaste tube
- A fingernail catcher for fingernail clippings
- A more effective alarm clock for reluctant students
- A clock with a display showing that the alarm has been set to go off
- A device to help a parent monitor small children's presence and activity in and around the house
- A simple pocket alarm that is difficult to shut off, used for discouraging muggers
- An improved storage system for luggage, books, and so on in dormitories
- A lampshade designed to permit one roommate to study while the other is asleep
- A device that would permit blind people to vote in an otherwise conventional voting booth
- A one-cup coffeemaker
- A silent wake-up alarm
- Home aids for the blind (or deaf)
- A safer, more efficient, and quieter air mover for room use
- A can crusher
- A rain-sensitive house window that would close automatically when it rains
- A better grass catcher for a riding lawn mower
- A built-in auto refrigerator
- A better camp cooler
- A dormitory cooler
- An impact-hammer adapter for electric drills
- An improved method of detecting and controlling the level position of the bucket on a bucket loader
- An automatic tractor-trailer-hitch aligning device
- A jack designed expressly for motorcycle use (special problems involved)
- Improved road signs for speed limits, curves, deer crossings, and so on
- Automatic light switches for rooms
- A device for dealing with oil slicks
- An egg container (light, strong, compact) for camping and canoeing
- Ramps or other facilities for handicapped students