What Is Engineering?

SECTIONS

OBJECTIVES

After reading this chapter, you will be able to:

- *identify the elements that all engineering disciplines have in common;*
- *describe how engineers help others.*

1 INTRODUCTION

The question posed by the title of this chapter may seem a bit strange. After all, you do not have to ask the meaning of brain surgery, soccer, or veterinary science—and there are many more engineers in the world than brain surgeons, professional soccer players, or veterinarians. Your familiarity with engineered *systems* (highways, buildings, computers, and factories, to name a few) does not tell you much about the *process* that made those systems. The process is engineering. In this chapter, you will explore the characteristics that engineers and engineering disciplines have in common.

2 DEFINING ENGINEERING

What is engineering? This simple question has a very complex answer. Engineering is a diverse collection of professions, academic disciplines, and skills. You can start your exploration of engineering with the dictionary. Your ego may be boosted to learn that the word “engineering” stems from the Latin *ingenium*, meaning skill. (Other words sharing this Latin root include “ingenious” and “ingenuity.”) Engineers are skilled at what they do. But what do they do? The dictionary offers you further insight. The Latin root *ingenium* comes from *in* + *gignere*, meaning to produce or beget (also the source of the words “generate” and “kin”). Thus, engineers are skilled producers or creators of things.

This exercise in word origins does not do justice to the field of engineering. Many definitions of “engineering” and “engineer” are possible. Most definitions have some elements in common.

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PONDER THIS **Based on your experiences, what is your definition of engineering?**

Key idea: Engineers are professionals who apply science and mathematics to useful ends, solve problems creatively, optimize, and make reasoned choices.

Common elements in the definitions include the following:

- Engineers apply science and mathematics to useful ends.
- Engineers solve problems creatively.
- Engineers optimize.
- Engineers make choices.
- Engineers help others.
- Engineering is a profession.

You will examine each of these elements in more detail in this chapter.

3 ENGINEERING AS AN APPLIED DISCIPLINE

3.1 Knowledge Generation versus Knowledge Implementation

Almost everyone would agree that engineering is the application of science and mathematics to practical ends. Indeed, the emphasis on practice and application always is in the mind of the engineer. They care more about *using* basic knowledge than *generating* basic knowledge. They care more about converting basic science into technology and converting technology into useful products than in expanding basic science.

However, the emphasis on application tells only part of the story of engineering. The pure engineer may be concerned only with practice, just as the pure scientist is concerned only with generating new knowledge. In reality, both practicing scientists and engineers contribute to the complicated and rewarding process of converting ideas into reality. The pure scientist and the pure engineer are extremes of a spectrum of skills required to make new things.

3.2 The Role of Engineering

The role of the engineer in turning ideas into usable ideas or objects* is illustrated in Figure 1. Both scientists and engineers use mathematics and natural sciences as their tools. Engineers focus on answering the questions that lie on the more applied side of the spectrum. In your career as an engineer, it is likely that you will help develop and implement technology. You will likely work from the middle to the right side of the spectrum

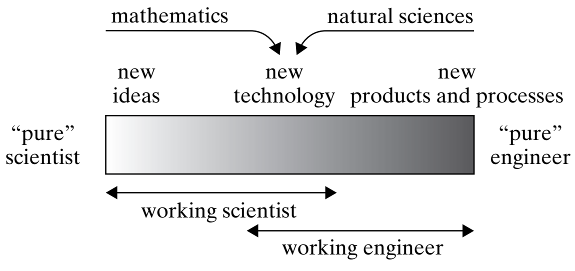

Figure 1. Spectrum of Skills in Engineering and Science.

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*Engineers develop both *products* (e.g., ballpoint pens, toasters, microprocessors, and satellites) and *processes* (e.g., better ways to stock inventory, new approaches to manufacturing compact discs, and innovative ways to treat wastewater).

in Figure 1. As an engineer, you will acquire a pool of skills required to translate new knowledge into usable ideas.

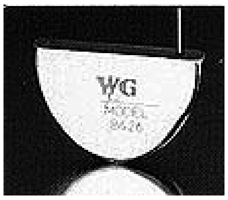
You are urged to return to Figure 1 throughout your career. It may help you remember that knowledge generation and product design are two ends of the same spectrum. Neither skill is useful without the other.

Figure 1 is a good road map for getting the most out of your courses. For example, if you are suffering from motivational problems in your science and mathematics courses, think about how the material can be applied. Speak to your science and mathematics professors about the practical use of the material. Ask engineering mentors how they use basic science and mathematics in their everyday professional lives.

EXAMPLE 1: APPLICATION OF SCIENTIFIC PRINCIPLES

In your high school or freshman chemistry course, you may have learned about the unit of chemical concentration called the *mole.* At first glance, the use of molar units of concentration may seem very theoretical and not applied. Give an example of how each main engineering discipline can use this concept.

SOLUTION



Lithium iodine batteries as small as 4 mm thick have been used in implantable cardiac pacemakers for over 20 years (Photo courtesy of Greatbatch, Inc.)

Engineers use different sets of units to solve different kinds of problems. Molar units express the proportions in which chemicals combine. Therefore, they are very useful for solving problems involving *combining proportions.*

Almost every engineering discipline uses molar units for some applications. For example, a civil engineer (in the environmental engineering specialty) might use molar units for determining doses of chemicals to react with pollutants and solve pollution problems. A chemical engineer may use moles to determine the ratios of chemicals used to synthesize polymers on a commercial scale. An electrical engineer would use molar units to determine the number of electrons per time (also called the current) produced by an electrochemical cell (such as a battery). Molar units could be used by an industrial engineer to design monitoring devices to make the workplace safer. Mechanical engineers use the concept of the mole to optimize material properties. All engineers may work together to use molar units to design sensors capable of detecting chemical or biological agents.

4 ENGINEERING AS CREATIVE PROBLEM SOLVING

4.1 Solving Problems

Engineers solve problems. These three simple words have far-reaching ramifications on the life of an engineer. First, since engineers solve problems, engineering work is usually motivated by a concern or roadblock. This idea may conjure up an image of lone warriors furiously performing dense calculations in a cubicle under a green-shaded desk lamp.

No image of engineering could be more incorrect. In reality, engineers often solve other people's problems. Thus, engineers must be able to *listen to a concern* and *map out a solution.* Whether the problem is to make cars that pollute less or to make oil refining more efficient or to reduce the manufacturing cost of a child's toy, engineers must be able to understand problems that their clients face. In this way, engineering is a very people-oriented profession.

4.2 Standard Approaches to Solving Problems

Second, engineers must be skilled in using standard approaches to solve problems. We all respect the brilliant physician who can leap to a diagnosis using intuition and experience. We marvel at the aircraft mechanic who spots the mechanical problem by "feel."

However, we also know that *every* physician must be able to follow standard diagnostic procedures and *every* mechanic must be familiar with the inspection checklist. Similarly, engineers must know the well-established protocols used in solving many problems.

4.3 Creative Approaches to Solving Problems

Key idea: The solution to engineering problems involves both standard and creative approaches.

Third, engineers must be creative in solving problems. Just like the physician and aircraft mechanic, engineers must supplement the standard solution methods with creativity and insight. Engineering is a highly creative profession. As Theodore von Kármán (1881–1963), a well-known Hungarian-born specialist in fluid mechanics and aerodynamics, put it, “The scientist describes what is; the engineer creates what never was” (Mackay, 1991). This quotation should not be interpreted as minimizing the creativity of scientists. Rather, it points out that engineers must have vision to create something that did not previously exist.

5 ENGINEERING AS CONSTRAINED OPTIMIZATION

5.1 Constraints

constrained optimization: determining the best solution to a problem, given limitations on the solution

Engineering, like life, is about ***constrained optimization***. In high school, it was likely that you did not strive to be the *best* student you could be. Rather, you strived to be the best student you could be *given that* you had to work part-time or you had family obligations or you were active in community groups. In other words, your time available for studying was *constrained* by other activities.

Key idea: Engineering solutions are often constrained.

Similarly, engineers always face constraints in solving problems. As an example, electrical engineers rarely seek to design the fastest computer chip. To be useful, computer chips must exhibit other characteristics as well.

PONDER THIS

List some constraints on computer chip design.

We could list the various constraints on computer chip design, but a better goal is just to say that we seek to develop the fastest computer chip of sufficiently small size with adequate heat dissipation characteristics that can be mass-produced at a reasonable cost.

Is it *ever* valuable to build the fastest chip? Absolutely! An electrical engineer specializing in the research side of research and development (R&D) may, in fact, seek to design the fastest computer chip. Some major breakthroughs in engineering have been generated by engineers and scientists who ignored constraints. However, most engineers seek to put ideas into practice. This means taking the real world and its constraints into account when designing engineered systems.

Key idea: Engineering solutions must take into account the probability of failure.

One aspect of the constrained nature of engineering is that engineers live in a probabilistic world. In other words, engineers must consider the *chances* of certain events occurring, including the probability of failure. A civil engineer does not design a bridge that will never fall down. Such a bridge would be infinitely expensive. Rather, the civil engineer examines the probabilities that certain loads will occur on the bridge from traffic, earthquakes, and wind. A bridge is designed to perform acceptably for a specified period of time under the anticipated loads and stresses. Similarly, an environmental engineer does not design a drinking water treatment plant to remove *all* pollutants completely. Such a plant is probably not possible (and if it was possible, the drinking water it produced would be unaffordable). Instead, engineers design treatment plants to meet water quality standards and minimize risk at a socially acceptable cost.

Due to constrained optimization in a probabilistic world, engineers must constantly ask: How strong is strong enough? How clean is clean? Have I thought of everything that could go wrong?[*] An example of extremely constrained optimization is given in the *Focus on Constrained Optimization: A Square Peg in a Round Hole*.

5.2 Feasibility

The ability of an engineering project to meet its constraints is often expressed in terms of feasibility. There are several aspects of feasibility, which will be introduced here. *Technical* (or engineering) *feasibility* measures whether or not a project meets its technical goals. It addresses several questions, such as "Does the new road handle the traffic?" and "Is the upgraded electrical transmission system more efficient?"

Key idea: To be successful, engineering projects must be technically, economically, fiscally, socially, politically, and environmentally feasible.

Most of your undergraduate course work is focused on technical feasibility. However, it is not sufficient for an engineering project to be technically feasible. Engineering projects also must be economically feasible. *Economic feasibility* addresses whether the project benefits outweigh the project costs. In the examples above, economic feasibility addresses whether the road benefits (e.g., tolls collected, elimination of slowdowns, and increased safety) are greater than the road construction and maintenance costs or whether the money saved from the more efficient transmission systems will pay for the upgrade work. Sometimes, the benefits and costs are difficult to quantify. What is the value of a five-minute reduction in commuting time or one less incidence of cancer for every one million people? To answer these questions, engineers may seek the advice of social scientists and economists.

Another factor to consider is *fiscal feasibility*. Fiscal feasibility measures whether sufficient funds can be generated to build the project. Many engineering projects would be profitable (i.e., are economically feasible), but are not built because start-up money cannot be acquired. The difference between economic and fiscal feasibility is important. For large, multimillion dollar engineering projects, obtaining money through loans or bonds to achieve fiscal feasibility may be the critical step. Engineers who ignore fiscal feasibility will never see their ideas translated into reality.

The last type of feasibility is social, political, and environmental feasibility. Engineers cannot work in a vacuum. Engineering projects must be socially acceptable, have political backing, and result in an acceptable environmental impact. Many engineering projects remain only on paper because societal and political support was lacking. Should you, as an engineer, be upset because some projects die due to nontechnical issues? No. It should remind you that engineers are part of the fabric of society. The public cares about the impact of engineering projects. As a result, you must consider the social consequences of your proposal along with the technical details.

FOCUS ON CONSTRAINED OPTIMIZATION: A SQUARE PEG IN A ROUND HOLE

BACKGROUND

Engineering is about constrained optimization. The need to "make the best with what you have" is demanding when the constraints are the most severe. For example, a space vehicle located 200,000 nautical miles from Earth presents some of the most severe constraints that an engineer will face.

Such was the case with *Apollo 13*, launched April 11, 1970. The crew of the spacecraft—Commander James A. Lovell, Lunar Module Pilot Fred W. Haise, Jr., and Command Module Pilot John L. Swigert, Jr.—was hard at work and enjoying the ride. Suddenly, about 56 hours into the flight, the crew heard a loud noise (which is never a good sign in a spacecraft). The pressure in Cryogenic Oxygen Tank 2 had begun to rise

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[*] For an insightful and entertaining discussion of this question as it pertains to civil engineering, see Petroski (1992).

Launch of Apollo 13, Saturday, April 11, 1970

very quickly. Within two minutes, the tank lost pressure. Why did this matter? Electricity on *Apollo 13* was generated by a fuel cell, where oxygen and hydrogen were combined. No oxygen meant no power—and no way to return to Earth.

PROBLEMS AND SOLUTIONS

The ground crew quickly assessed the situation. The three people in space required three things to return to Earth alive: power, water (to drink and to cool the equipment), and oxygen. With the fuel cells virtually inoperable, the only source of power was the batteries in the Lunar Module (LM, the *Aquarius*). It became clear that the LM, with its own ample oxygen supplies, would become the lifeboat for the crew. But the LM had its own problems. Its batteries would need to be recharged to provide enough power for the journey home. However, there was no direct electrical connection between the Command Service Module (CSM, the *Odyssey*) and the LM to recharge the batteries. Engineers on the ground discovered a way to leak current slowly from the CSM to the batteries. By turning off nonessential equipment, the crew limped home with an amazing 20% of the LM power left.

The problem with water could be addressed only by drinking less. The crew cut its water ration to 200 milliliters per person per day (a little over one-half of a soft drink can). The crew lost a collective 31 pounds on the trip home, arriving in poor health and with 10% of the water supply remaining.

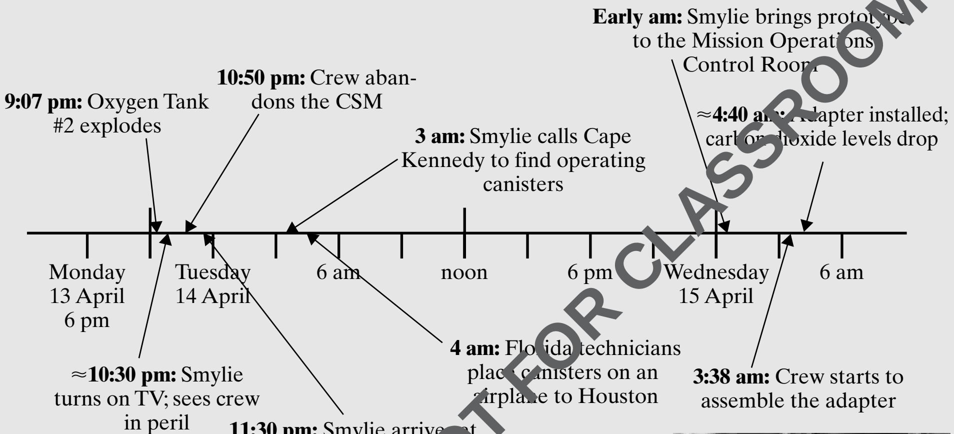
The LM had a sufficient oxygen supply, but the ground crew soon realized that *another* air supply problem would threaten the astronauts: the build-up of carbon dioxide (CO_2) exhaled by the crew. The CO_2 was removed by lithium hydroxide (LiOH) canisters through a chemical reaction. The LM was designed to transport two members of the crew from lunar orbit to the surface of the Moon. It had a sufficient canister capacity to remove the CO_2 produced by two people for about 30 hours, not the CO_2 exhaled by three people for the long trip back to Earth. Even by allowing the CO_2 levels to rise a little, the canisters could operate for only about 187 person-hours, when at least 288 person-hours would be needed. The solution? The CSM had its own LiOH canisters. But as luck would have it, the CSM canisters had *square* connectors that would not fit in the *round* fittings of the LM.

CONSTRAINED OPTIMIZATION

In a brilliant feat of constrained optimization, the ground crew had to develop an interface between the square CSM canisters and the round LM fittings from material available to the astronauts. (The near-impossibility of this task is shown dramatically in a famous scene from the movie *Apollo 13*.) The adapter, called the "mailbox," was designed by ground engineer Ed Smylie. (In NASA-speak, the adapter is known officially as the "supplemental carbon dioxide removal system.") It was made of two CSM canisters, a space suit exhaust hose, cardboard from instructional cue cards in the LM, plastic stowage bags from liquid-cooled undergarments, and one roll of duct tape. (Ironically, much of this material would have been otherwise unused by the astronauts. The cue cards contained instructions for lifting off from the moon and the undergarments were to be worn on moonwalks.)

Timeline for the Apollo 13 Carbon Dioxide Crisis
(all times are Central Standard Time for Houston, TX)

Deke Slayton displays the prototype



Astronaut John L. Swigert Jr. in the Apollo 13 LM
(duct tape-wrapped object beside him is the "mailbox" adapter)

The efforts of engineer Ed Smylie, the other Houston personnel, and the astronauts were truly unbelievable. Only about 30 hours elapsed between the time Smylie turned on his television set to learn of *Apollo 13*'s problems and the time that the astronauts finished building the mailbox in space. (See the accompanying timeline.) Smylie and his assistant, Jim Correale, had no operational LiOH canisters to test the interface. Working canisters from Florida (intended for *Apollo 14* or *Apollo 15*) were airlifted to Houston to enable testing of the device. After testing on the ground, the ground crew issued about an hour's worth of instructions by radio so that the astronauts could construct the adapter in space.

The *Apollo 13* flight had a very happy ending, due to the bravery of the astronauts and the ingenuity of the engineers. When faced with an overwhelmingly constrained problem, the engineers created a solution that saved the lives of three American heroes.

6 ENGINEERING AS MAKING CHOICES

Key idea: Engineers make recommendations by selecting from a list of feasible alternatives.

feasibility assessment: evaluation of the feasibility of an engineering project

The discussion thus far has centered on what engineering *is* rather than what engineers *do*. So what *does* an engineer do? Engineers listen carefully to the problem. (See Section 4.1.) Using accepted and creative methods (see Sections 4.2 and 4.3), they develop a list of feasible solutions or alternatives. Here, “feasible” means that each solution is technically, economically, fiscally, and socially/politically/environmentally feasible. (Evaluating whether a project is feasible is called a ***feasibility assessment***. See Example 2 for an example.) Finally, engineers select an alternative from among the feasible solutions and recommend it to their client.

In a real sense, engineering is about generating alternatives and selecting feasible solutions. The selection step sets engineers apart from other professionals (e.g., technicians and designers) who may be trained to do the calculations and use the software, but may not be trained to make recommendations. To recommend an alternative, an engineer has to balance the technical, economic, fiscal, and social/political/environmental issues. A person trained only to crunch numbers will fail in this critical decision-making task. A person trained only to crunch numbers is not an engineer.

EXAMPLE 2: FEASIBILITY ASSESSMENT

Conduct a feasibility assessment for buying a used car to commute to a part-time job.

SOLUTION

A feasibility assessment determines the technical, economic, fiscal, and social/political/environmental feasibility of an alternative.

Technical feasibility: Technical feasibility probes whether the alternative will solve the problem. In this case, you need to ask whether buying the car will allow you to commute to work safely and reliably. Perhaps the car you can afford will not be sufficiently reliable. Perhaps other more reliable alternatives exist, such as public transportation.

Economic feasibility: Economic feasibility questions whether the benefits of the alternative exceed its costs. The costs of car ownership include depreciation, financing, insurance, taxes and fees, fuel, maintenance, and repairs. For a used 2000 Honda Accord two-door LX coupe in Buffalo, New York, the purchase and ownership costs average about $7,570 per year for the first five years (as determined by the cost calculator at www.edmunds.com). The benefits include your ability to get to your part-time job and the freedom and convenience that car ownership engenders. Other alternatives (such as a monthly bus pass) may have lower costs, but they do not have the freedom and convenience of car ownership.

Fiscal feasibility: Fiscal feasibility probes whether you can get the start-up funds to finance the project. In this example, purchasing the car is fiscally feasible if you can qualify for a reasonable car loan.

Social/political/environmental feasibility: In this example, social/political/environmental feasibility centers on environmental impact. In spite of the large social, political, and environmental costs of reliance on the internal combustion engine, car ownership remains socially acceptable in North America. You could consider, as an alternative, a car with lower environmental impact. (Buying a new Toyota Prius has about twice the purchase + interest + depreciation costs of the Honda, but about half the fuel + maintenance + repair costs.)

7 ENGINEERS AS HELPING OTHERS

Professions can be characterized in many ways. Some people are attracted to the so-called caring professions.

PONDER THIS

Make a list of caring professions.

Caring professions include medicine, nursing, social work, and teaching. Did your list include engineering?

Engineering is also one of the caring professions. Why? Nearly every project that an engineer completes satisfies a need or concern of the public. For example, if you become an electrical engineer, you may develop sensors to make more powerful neonatal incubators. Perhaps as a civil engineer, you may work on earthquake-resistant buildings or develop drinking-water treatment systems for less developed countries. (Water-related diseases, the leading cause of death globally, is responsible for 14,000 deaths *per day* because more than one billion people on the planet lack access to safe drinking water.) Maybe you will become a chemical engineer and work on ways to mass-produce HIV medications, making such drugs affordable to every HIV-positive person in the world. Perhaps you will go into industrial engineering and devise systems to help nonprofit organizations better serve their clients. (Volunteers from several professional and student chapters of the Institute of Industrial Engineers recently helped make a women's shelter in Pittsburgh become more efficient to save resources.) Or maybe you will become a mechanical engineer and develop a robust heart valve for premature infants. Whatever field of engineering interests you, know that you can use your training to make the world a better place and to make people's lives healthier and more fulfilling.

8 ENGINEERING AS A PROFESSION

Finally, engineering is a profession. This means, of course, that engineers get paid for what they do. In addition, it means that to be called an engineer, you must meet certain requirements. Just as the public must be assured that a person called a dentist or lawyer is fully certified, so the public must know that a person using the title "engineer" has been trained properly. The process of meeting the requirements is called *registration*. A registered engineer holds the title *professional engineer*, or PE.

All professions have ethical standards. Engineers, as professionals, must meet high standards of professional ethics.

9 SUMMARY

The dictionary tells us that engineers give birth to things creatively. In particular, the work of engineers is characterized by six elements. First, engineers apply science and mathematics to useful ends. Second, engineers solve problems using both standard and creative approaches. Third, engineers optimize solutions subject to the constraints of the real world. The constraints are often grouped under the headings of technical feasibility (will the system perform the task for which it was designed?), economic feasibility (do benefits outweigh costs?), fiscal feasibility (are start-up funds available?), and social/political/environmental feasibility. Fourth, engineers make reasoned choices. They select and recommend feasible alternatives. Fifth, engineers help others. Without a public to serve, engineering as a profession would not exist. Finally, engineers are professionals. This means that engineers may seek professional registration and must meet ethical standards.

SUMMARY OF KEY IDEAS

- Engineers are professionals who apply science and mathematics to useful ends, solve problems creatively, optimize, and make reasoned choices.
- The solution to engineering problems involves both standard and creative approaches.
- Engineering solutions are often constrained.
- Engineering solutions must take into account the probability of failure.
- To be successful, engineering projects must be technically, economically, fiscally, socially, politically, and environmentally feasible.
- Engineers make recommendations by selecting from a list of feasible alternatives.
- Engineering is a profession and engineers have ethical responsibilities.

Problems

1. What are the six main elements of engineering?
2. Some pharmaceuticals are manufactured by genetically engineered bacteria to produce the drug. Discuss the role of the engineer (if any) in the following steps of the development of a new drug:
    - Synthesis of the drug for animal tests
    - Genetic engineering of the bacteria
    - Mass production through bacterial synthesis
    - Clinical trials
    - Development of the time-release capsules and transdermal patches
    - Efficiency study of the manufacturing process, and
    - Design of the marketing strategy
3. Explain the differences in the contributions to society of scientists and engineers. Which contribution appeals more to you and why?
4. Give an example of constrained optimization in an engineering problem.
5. For Problem 4, what is a possible solution, given the constraints? How would the solution change if the constraints were different?
6. From your local newspaper, find an example of an engineering project that was not implemented because it was not economically or fiscally feasible.
7. Explain the difference between economic feasibility and fiscal feasibility.
8. Give an example of an engineering project that is economically feasible, but not fiscally feasible. Give an example of an engineering project that is fiscally feasible, but not economically feasible.

9. From your local newspaper, find an example of an engineering project that was not implemented because it was not socially, politically, or environmentally feasible.

10. For your answer in Problem 9, how would you change the project to make it feasible?

11. Talk with an engineer in government service (e.g., a town, city, or county engineer) about the difference between economic and fiscal feasibility. Illustrate the difference with an example from your community.

12 Two towns are separated by a river and wish to exchange goods. List several alternative solutions to this problem. Perform a feasibility assessment and rank the alternatives according to their feasibility. (Be sure to include all types of feasibility.) Recommend a solution to the problem.

13. Make a list of the professions that are licensed by your state. What do the professions have in common? Which licenses are in technical fields?

14. Which agency in your state licenses engineers? (Try searching the Internet for your state name and the phrase "professional engineer.") How many engineers are licensed in your state?

15. How do engineers in your area participate in public service?

Engineering Careers

SECTIONS

OBJECTIVES

After reading this chapter, you will be able to:

- list the types of jobs available to engineers;
- explain why job satisfaction is high in engineering;
- describe the future of engineering employment.

1 INTRODUCTION

You have learned about the activities and approaches common to many engineers. This chapter explores the kinds of careers for which an engineering education prepares you. Engineering jobs will be discussed in general terms in this chapter. Jobs specific to each engineering discipline will be presented elsewhere.

2 ENGINEERING JOBS

2.1 Availability of Jobs

What do engineering students do when they graduate? Fortunately, they have the opportunity to work in their field if they wish. In a recent study, a sample of the 109,200 people receiving baccalaureate degrees in engineering in 1999 and 2000 were surveyed to find out what they were doing in 2001. Ninety-three percent of the recent graduates were working. Of those employed, 84% found jobs in engineering and science (NSF, 2003; see Figure 1). Most of the employed engineers (68%) found jobs in the same discipline as their degree. The bottom line? Trained engineers can usually find jobs as engineers.

2.2 Introduction to Engineering Jobs

Where are engineers employed? The range of jobs performed by engineers is truly amazing. They have optimized devices as simple as the pencil and developed systems as complex as the Space Shuttle.* For example, some engineers work on systems as small as very large scale integration (VLSI)

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*The Space Shuttle *Endeavour*, built to replace the Space Shuttle *Challenger*, was first flown in May 1992. This Space Shuttle has several hundreds of thousands of parts, and it was constructed with the assistance of over 250 subcontractors at a cost of approximately $1.7 billion.

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Key idea: People trained as engineers generally can find jobs as engineers.

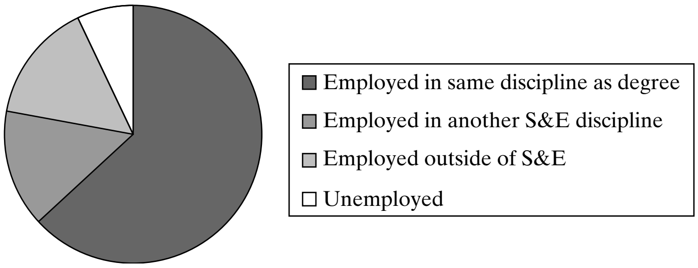
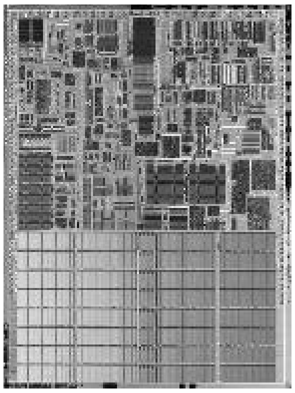


Figure 1. Employment Statistics for Baccalaureate Engineers (S&E = science and engineering)



Intel Corp.'s Itanium® 2 microprocessor contains 221 million transistors in an area less than a square inch (421 mm^2).

chips, with millions of transistors and other circuits on each 0.25-inch square speck of silicon. Engineers are helping to develop *nanomachines*, futuristic mechanical devices consisting of only a few thousand atoms. Others work on systems as large as the 305-meter (1,000-foot) radio telescope near Arecibo, Puerto Rico.

Engineers have done work as helpful as creating assistive devices for the disabled and inventing innovative approaches to clean polluted air. In fact, engineers work on systems as controversial as nuclear weapons and nerve gases.

Arecibo observatory (photo courtesy of the NAIC-Arecibo Observatory, a faculty of the NSF)

With such a range of experiences, how can you make sense of engineering jobs? It is instructive to examine the distribution of engineering jobs in various economic sectors. In 2002, about 1,769,000 engineers were employed in the United States (BLS, 2004), including about 611,000 computer software engineers. About half of these jobs were in manufacturing industries. A little more than one-quarter of the jobs were in service industries. Government agencies at all levels (federal, state, and local governments) employed about 12% of all engineers in 2000.

2.3 Engineers in Industry

Key idea: About half of all engineers work in manufacturing, producing motor vehicles, aircraft, electrical and electronic equipment, and industrial or computing equipment.

Engineers in industry are involved mainly with the manufacture of products. In 2001, there were 1,000 engineers making toys and sporting goods and 57,000 engineers involved in manufacturing electronic components and accessories. Manufacturing accounts for about half of engineering jobs. Most of these jobs are in transportation equipment (mainly motor vehicles and aircraft), electrical and electronic equipment, and industrial equipment (including computing equipment). Other engineers in industry work in nonmanufacturing areas such as construction and mining.

2.4 Engineers in Service

Key idea: About 28% of engineers work in the service sector, primarily as consulting engineers.

Engineers in service act as consultants, contribute to product marketing and sales, or conduct research. The service sector accounts for about 28% of engineering jobs, mostly in engineering and architecture, business services (mainly computer/data processing and personnel supply services), and research and testing services.

Key idea: Many engineers are small business owners.

Most engineering companies are small. In 2001, 59% of engineering firms had fewer than 5 employees, and 35% of the firms employed 5 to 50 people (Rosenbaum, 2002). It is not uncommon to find very small "mom-and-pop" engineering consulting firms.

consulting engineer: an engineer providing professional advice to clients

Consulting engineers may own their own business. About 43,000 engineers in 2000 were self-employed. Most of these engineers worked as consultants.

2.5 Engineers in Government

Government engineers may be employed by federal, state, or local agencies. The military also employs both civilian and active-duty engineers. Government engineers work

Key idea: About 12% of engineers work for government agencies.

for a wide range of agencies, from city engineering offices to the U.S. Army Corps of Engineers to the Peace Corps.

As stated in Section 2.2, about one out of every eight engineering jobs is in government. Over half of these jobs are in the federal government, primarily in such agencies as the Departments of Defense, Transportation, Agriculture, Interior, and Energy and in the National Aeronautics and Space Administration (NASA) (BLS, 2004). Engineers employed by state and local governments typically work in highway and public works departments.

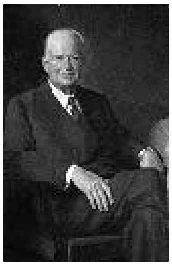
2.6 Other Engineering Jobs

Transportation and public utilities account for another 5% of engineering jobs. Most of these jobs are with electric and telephone utilities. The remaining engineering jobs are mainly in wholesale/retail trade and construction.

2.7 Engineering Education as a Route to Other Fields

Key idea: An engineering education is excellent preparation for many nonengineering professions.

An engineering education provides a strong background in quantitative skills and problem solving. Such tools are highly valued in many fields. Thus, an engineering education is a good start for many nonengineering professions. Trained engineers are well suited to pursue professional degrees in other fields, including law, medicine, business, and education. For example, an engineering background is very desirable for patent and environmental law. Engineers can go on to medical school and contribute to such fields as biomechanics and neurobiology. Many business schools encourage potential students to pursue technical degrees at the undergraduate level. An engineering degree is a fine route to a teaching career in secondary or higher education.



Herbert Hoover

The tools and approaches learned in engineering classes have led to successful careers in other fields. U.S. Presidents Herbert Hoover (mining) and Jimmy Carter (nuclear) were trained as engineers. Other engineers that became politicians include John Sununu (mechanical), Yasser Arafat (civil), Leonid Brezhnev (metallurgical), and Boris Yeltsin (civil).

Several famous entertainers started out as engineers. For example, both *Star Trek* creator Gene Roddenberry (aeronautical) and Academy Award-winning director Frank Capra (chemical) had engineering degrees. Other engineers who landed in entertainment-oriented careers include film directors and Roger Corman (industrial) and Alfred Hitchcock (studied at the School of Engineering and Navigation in London), jazz musician Herbie Hancock (electrical), talk show host Montel Williams (general), and television star Bill Nye, "The Science Guy" (mechanical). For another interesting story of an engineering entertainer, see the *Focus on Nonengineers*.

Engineering careers are not limited to Earth. Nearly all the early astronauts in the Mercury, Gemini, and Apollo programs were engineers. All but four of the 39 U.S. astronaut pilots in the Space Shuttle program in 2004 had engineering degrees.

3 JOB SATISFACTION IN ENGINEERING

3.1 What Does "Job Satisfaction" Mean to You?

As discussed in Section 2.1, people trained as engineers can generally obtain jobs as engineers. Thus, you are not just pursuing a *degree* in engineering, but you are also traveling the road towards a *career* in engineering. One measure of a successful career is a love for the jobs you will have as you progress in your chosen field.

FOCUS ON NONENGINEERS: “IT’S NOT HEDY, IT’S HEDLEY”

Fans of Mel Brooks’s notoriously crude movie *Blazing Saddles* (1974) will recognize the title of this section. The crooked attorney general Hedley Lamarr (played outrageously by Harvey Korman) repeatedly has to remind everyone how to pronounce his name: “It’s not Hedy, it’s Hedley.”

Hedy Lamarr (photo courtesy of Anthony Loder).

So who was Hedy Lamarr, the source of the attorney general’s confusion? And what does she have to do with engineering? Hedy Lamarr was born as Hedwig Eva Maria Kiesler in Vienna in 1913. She made dozens of movies, including the 1933 Austrian–Czech film *Ecstasy*, which featured one of the first nude scenes in a movie. Lamarr married arms manufacturer Fritz Mandl in 1933. To escape the Nazi regime and her domineering husband, Lamarr escaped to London in 1938. There, she met movie mogul Louis B. Mayer. Mayer gave her the stage name we know now and took her to Hollywood. She became a famous actress and pin-up girl in World War II, and she was active in the sale of millions of dollars in war bonds.

But Hedy Lamarr was not just a glamorous film star of Hollywood’s Golden Age. In fact, Lamarr had the temperament, if not the education, of an engineer. At a dinner party shortly after the onset of World War II, Lamarr was talking with her friend, composer George Antheil. Using the analogy of a player piano, Lamarr and Antheil reasoned that communication between a submarine and a torpedo could be made secret if the information was scrambled by hopping it between frequencies. The pair eventually patented the idea. It became U.S. Patent Number 2,292,387, filed June 10, 1941, and issued August 11, 1942, to Hedy Kiesler Markey (her legal name at the time) and George Antheil for a “Secret Communications System.”

The U.S. military decided that the idea of “frequency hopping” was impractical. In fact, given the technology of the time, frequency hopping probably was nearly impossible to implement. The idea, however, would revolutionize communication. The patent expired in 1959 and the concept was generalized as “spread spectrum technology.”* Soon, the technology caught up with the idea. Spread spectrum technology has been used in military applications from the Cuban Missile Crisis to the 1991 Gulf War. It was released to the public domain in the 1980s and is now used in applications as diverse as pagers and traffic signals.

Spread spectrum communication is the basis for the operation of garage door openers, cell phones, and wireless Internet communication. Why? In addition to the security of the signal, spread spectrum technology has a number of advantages. By spreading the signal across a number of frequencies, this communication tool makes efficient use of the clogged radio frequency band. In addition, because the devices transmit only for a short time at any one frequency, the signals appear as background noise rather than interfering with existing transmissions at that frequency. This property allows spread spectrum devices (for example, digital spread spectrum [DSS] cordless telephones) to operate at a higher power (and hence, have a longer range) and with less interference.

It is not an exaggeration to say that Lamarr and Antheil’s idea for defeating Nazism is the cornerstone of modern digital communication. Not bad for a glamorous actress and avant-garde composer. Hedy Lamarr and George Antheil were honored with an International Pioneer Award in 1997 from the Electronic Frontier Foundation. Hedy Lamarr died in 2000, remembered as an actress and inventor.

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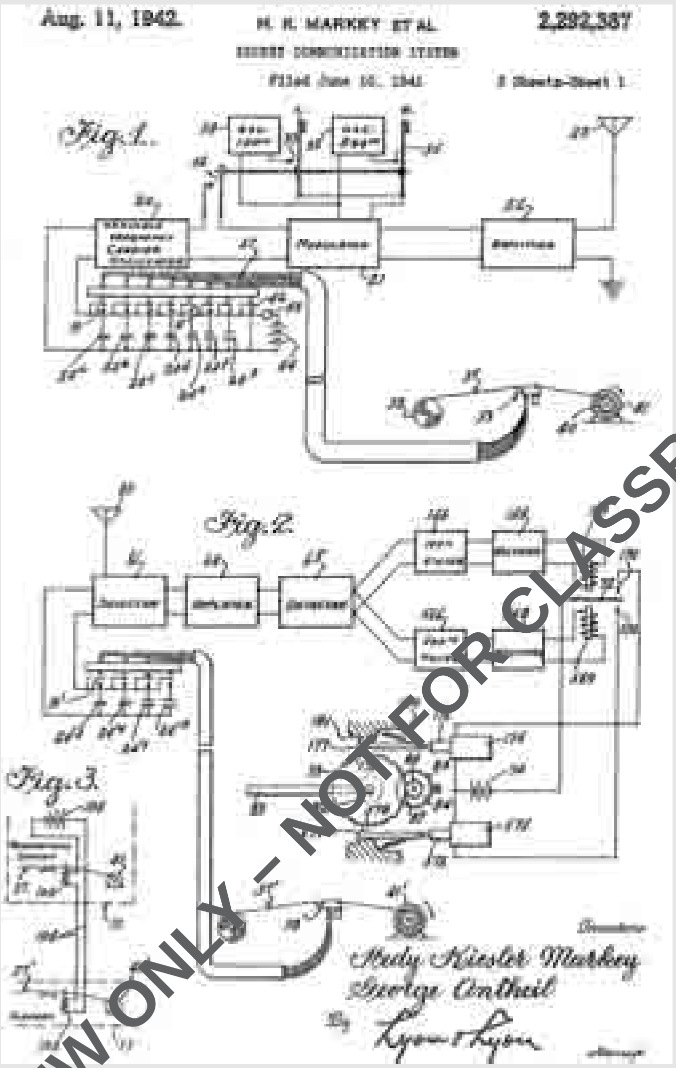
*The term “spread spectrum technology” refers to any technology where information is distributed over a wide signal bandwidth according to a pattern independent of the data transmitted. One way to accomplish this is to use the frequency-hopping approach of Hedy Lamarr and George Antheil.



Hedy Lamarr/George Antheil patent

PONDER THIS

When you get your first engineering job, how are you going to measure your own job satisfaction?

Most people measure their job satisfaction in three categories:

- Accomplishments: what they have contributed to society
- Work environment: independence, responsibility, the degree to which they are challenged by their work, and where they work
- Monetary issues: salary, benefits, and opportunities for promotion

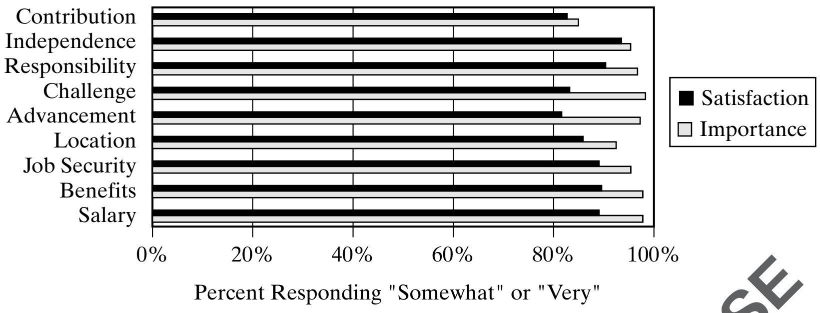


Figure 2. Importance in Job Selection and Level of Satisfaction of Recent Engineering Graduates

Key idea: Job satisfaction includes contributions to society, degree of independence, level of responsibility, intellectual challenge, opportunities for promotion, benefits, and salary.

It is not uncommon for people to have very high expectations of their future careers, only to have their visions squashed by reality. Entry-level engineers also have high expectations. In 2001, the National Science Foundation (NSF) surveyed 1999 and 2000 engineering graduates about their job satisfaction (NSF, 2003). The elements of job satisfaction included contribution to society, degree of independence, level of responsibility, intellectual challenge, opportunities for advancement, location, job security, benefits, and salary. As shown in the gray bars in Figure 2, most factors were very important to the recent engineering graduates. (Figure 2 shows the percentage of respondents that said the factor was "very important" or "somewhat important" to them.)

Key idea: Job satisfaction among engineers is very high.

The good news is that their level of job satisfaction was high. The average job satisfaction rating for the nine factors was 88%. (For scientists in the same survey, the average job satisfaction was 82%.) The entry-level engineers were particularly satisfied with the degree of independence and level of responsibility provided in their jobs.

3.2 Engineering Salaries

Key idea: Engineers are well compensated, with salaries varying by discipline, educational level, and experience.

Compared with other fields, engineers are paid well. Salaries vary by discipline, educational level, and experience. So how much do engineers make? It would be misleading to list detailed salary data here. Information about salaries can become outdated very quickly and should be interpreted with caution. It is almost impossible to know the true average salary of any group as large as the engineering community. Salary surveys invariably cover different populations and may or may not include some benefits. In general, engineers have and continue to be valued in our society. Compensation is expected to remain good for the foreseeable future.

While the higher salaries of engineers are an attraction, avoid choosing a profession (or engineering discipline) strictly on the basis of salary. Your job satisfaction will be low (and your life miserable) if you go for the bucks without listening to your heart.

Key idea: Employers expect to receive more value from you than you are paid.

One final note on salaries: The higher salaries of engineers come with some expectations.

PONDER THIS

What do employers expect of you when they offer you, say, $45,000 as a starting salary?

It means that they expect to receive more than $45,000 worth of value from you. For a company to make money, it must receive more value (in sales or client fees) from you than you are being paid. Remember this fact when you interview for jobs: salaries create an obligation to work responsibly, diligently, and ethically.

4 FUTURE OF ENGINEERING EMPLOYMENT

Key idea: Engineering jobs are expected to grow over 7% from 2002 to 2012, with over about 5% growth in the major engineering disciplines.

The future is good for the employment of engineers. In total, 109,000 engineering job openings are expected from 2002 to 2012. Most of the major engineering disciplines are predicted to show over about 5% growth in that period, with engineering as a whole having a 7.3% job growth. According to the best estimates of the economists, engineers trained today should have reasonable expectations of a job tomorrow.

5 SUMMARY

The present and future states of engineering employment are strong, and students should expect to find jobs in their fields. Engineering jobs may be found in manufacturing (e.g., mainly motor vehicles, aircraft, electrical and electronic equipment, and industrial equipment and computing equipment), services (e.g., consulting services, marketing and sales, and research), government, and other areas (e.g., transportation, public utilities, wholesale/retail trade, and construction).

Engineers are paid well, with salaries varying by discipline and increasing with educational level and experience. While engineering salaries are good, never forget that employers expect you to contribute in value to the company more than they pay you. Job availability and salaries are expected to increase in the future. Finally, an engineering education can lead to rich and rewarding careers in nonengineering fields.

SUMMARY OF KEY IDEAS

- People trained as engineers generally can find jobs as engineers.
- About half of all engineers work in manufacturing, producing motor vehicles, aircraft, electrical and electronic equipment, and industrial or computing equipment.
- About 28% of engineers work in the service sector, primarily as consulting engineers.
- Many engineers are small business owners.
- About 12% of engineers work for government agencies.
- An engineering education is excellent preparation for many nonengineering professions.
- Job satisfaction includes contributions to society, degree of independence, level of responsibility, intellectual challenge, opportunities for promotion, benefits, and salary.
- Job satisfaction among engineers is very high.
- Engineers are well compensated, with salaries varying by discipline, educational level, and experience.
- Employers expect to receive more value from you than you are paid.
- Engineering jobs are expected to grow over 7% from 2002 to 2012, with over about 5% growth in the major engineering disciplines.

Problems

1. For an engineering discipline of your choice (chemical, civil, electrical, industrial, or mechanical engineering), list two jobs from each job sector in Section 2. Which job sector appeals to you and why?

2. Interview practicing engineers from two job sectors listed in Section 2. Write a paragraph explaining how the engineers you interviewed got from their baccalaureate degree to their current job.

3. Which of the job satisfaction criteria discussed in Section 3.1 is most important to you?

4. Describe your ideal engineering job. As a guideline, use the job satisfaction criteria discussed in Section 3.1.

5. Using the Internet, research jobs in the discipline of most interest to you. How closely do the jobs align with the ideal engineering job you described in Problem 4?

6. You have received two job offers: one from Technolico, Inc., at $44,000 per year and one from Engionics at $46,000 per year. What criteria should you use in deciding which job to take?

7. List four questions you would like to ask during an engineering job interview.

8. A small consulting firm wishes to expand. If they hire an entry-level engineer, they can increase their revenue by $4,750 per month. The annual salary for an entry-level engineer in their community is $47,000. Benefits (e.g., health insurance and contributions to retirement accounts) cost 25% of the employee's salary. Can the firm afford to hire an entry-level engineer at the going rate?

9. How much would revenues have to grow for a small consulting firm to justify hiring an entry-level engineer? Assume that the typical annual salary for an entry-level engineer is $48,500 and benefits amount to 30% of the employee's salary.

10. Ask a practicing engineer whether a master's degree in engineering is desirable for engineers in your area.

11. Ask a practicing engineer whether an MBA (master of business administration) is desirable for engineers in your area.

Introduction to Engineering Problem-Solving Tools and Using Data

SECTIONS

OBJECTIVES

After reading this chapter, you will be able to:

- compare the concepts of accuracy and precision;
- round numbers appropriately;
- report numbers to the proper number of significant figures;
- list the important measures of central tendency and explain when to use them;
- list the important measures of variability and explain when to use them.

1 INTRODUCTION

1.1 Engineering Problem-Solving Tools

Engineers use four problem-solving tools. First, engineers collect *data* to test hypotheses, conduct analyses, and do design. Techniques to get the most out of your data are discussed in this chapter. Second, *models* are used. Models are conceptual, mathematical, or physical representations of the engineering system of interest. Engineers use models to verify system performance prior to design. Third, engineers use *computers* to perform calculations and visualize their results. Finally, engineers use feasibility concepts to evaluate alternative designs.

1.2 Using Data

All engineers generate data, use data, and frequently perform calculations involving data. In your engineering curriculum, you will take many classes in mathematics. It is likely that you will take a course or two in probability, statistics, and experimental design. In those courses, you will learn about the characteristics of data and how to manipulate data. In this chapter, a few basic concepts concerning experimental data will be introduced.

2 ACCURACY AND PRECISION

2.1 Introduction

Engineers measure characteristics of the real world. If life were perfect, you could collect data and determine *exactly* the parameter of interest to you. This is almost never the case. As an example, consider a human factors engineering study in which you must determine the distance from a computer user's eyes (modeled by a mannequin) to the computer monitor. The data collection requirements seem

simple: you could easily measure the distance with a ruler or other measuring device. Common experience tells you that if you performed the measurement numerous times, you might get different results. If each one of your studymates made the measurement, you would likely get even more variety in the responses. In spite of the variability, there is one true distance (at least, one true distance when measuring at a fixed scale).

2.2 Accuracy

accuracy: a measure of closeness to the true value

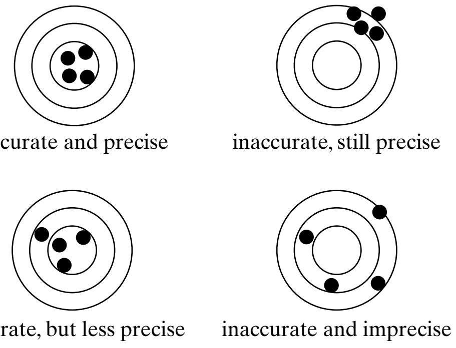
How can you describe how closely your measurements are to the true answer? In this section, the relationship between measured and true values will be discussed in a general way. A more quantitative discussion may be found in Sections 4 and 5. The relationship between measurements and the true value is called ***accuracy***. A measurement is said to be *accurate* if it is near the true value. For example, if the mannequin's eyes are set at 40.0 cm from the monitor, a measurement of 39.9 cm may be accurate and a measurement of 45.6 cm may be inaccurate (depending on the needs of the study).

2.3 Precision

precision: a measure of similarity in a set of values

The relationship between repeated measurements is called ***precision***. A set of measurements is said to be *precise* if the measurements are similar in value. For example, suppose the measurements from the mannequin's eyes to the monitor are 31.6, 31.5, 31.6, and 31.4 cm. This set may be said to be precise (although inaccurate).* An example of accuracy and precision is shown in Example 1.

You may have seen the concepts of accuracy and precision illustrated with a dartboard or archery target. If the goal is to hit the bull's eye, then accurate shots are near the bull's eye and precise shots are clustered together (but not necessarily near the bull's eye). This is shown in Figure 1.



accurate and precise

inaccurate, still precise

accurate, but less precise

inaccurate and imprecise

Figure 1. Accuracy and Precision

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*Be careful about the use of the word "precise." In common usage, "precise" is used to mean "exact" ("That is precisely my point."). In scientific work, use "precise" and "precision" only in reference to repeated measures.

EXAMPLE 1 ACCURACY AND PRECISION

For the human factors example, how would you label the following data sets with regard to accuracy and precision (if the “true” distance from the mannequin’s eyes to the monitor is 40.0 cm)?

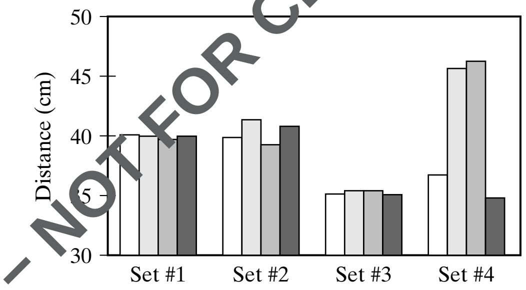
Set #1 = 40.1, 40.0, 39.8, and 40.0 cm
Set #2 = 39.8, 41.4, 39.4, and 40.9 cm
Set #3 = 35.2, 35.3, 35.3, and 35.1 cm
Set #4 = 36.7, 45.6, 46.2, and 34.9 cm

SOLUTION

The answer depends on the needs of the study. A reasonable answer is as follows:

Set #1 = accurate and precise
Set #2 = accurate, but less precise
Set #3 = less accurate, but precise
Set #4 = much less accurate and much less precise

The data are plotted in the following figure:



Note that the concepts of accuracy and precision are easy to see in this figure. More quantitative measures of accuracy and precision will be developed in Sections 4 and 5, respectively.

3 ROUNDING AND SIGNIFICANT DIGITS

3.1 Introduction

The concepts of precision and accuracy do not help you to *record* data and data calculations. A particularly troublesome area of data reporting and calculations concerns the number of decimal places to report. In the computer monitor problem, suppose you and a friend measure the distance from the mannequin’s eye to the monitor. You use a meter stick and find the distance to be 40.6 cm. Your friend uses a yardstick and finds the distance to be 15 11/16 inches. Your friend realizes that the answer is supposed to be reported in centimeters and performs the following conversion:

$$\begin{aligned} \text{distance} &= (15\ 11/16\ \text{in})(2.54\ \text{cm/in}) \\ &= (15.6875\ \text{in})(2.54\ \text{cm/in}) \\ &= 39.84625\ \text{cm} \end{aligned}$$

Thus, your friend reports the distance as 39.84625 cm.

PONDER THIS

Is it really true that your measurement is only accurate to the nearest 0.1 cm, but your friend's measurement is accurate to 0.00001 cm?

Key idea: Do not blindly report the numbers given to you by a calculator or spreadsheet—determine the proper number of digits to report.

The answer is, emphatically, *No! Just because your calculator reports five figures after the decimal point does not mean that the measurement is accurate to five figures after the decimal point.*[*]

3.2 Counting the Number of Significant Digits

significant digits: the number of digits justified by the precision of the data

If reporting all digits is incorrect, how *should* you report measurements and calculation results? To determine the number of decimal places, it is important to understand the idea of ***significant digits*** (or *significant figures*). Determine the number of significant digits of a number by the following procedure (for numbers containing a decimal place):

1. Starting on the *left* side of the number, move *right* until you encounter the first nonzero digit (ignoring the decimal place). Count this first nonzero digit as "one."
2. Continue moving to the right, counting each digit (still ignoring the decimal place). When you reach the last digit of the number on the right, you have counted the number of significant digits.

As an example, count the number of significant digits in the number 0.0504. It is a good idea to mentally separate each digit, ignoring the decimal place. One way to do this is to put each number in a box:

0.	0	5	0	4

Counting the boxes from left to right, the first box containing a nonzero digit is the third box from the left. Number this box "1" and continue counting from left to right until you run out of digits:

	0.	0	5	0	4
Box #			1	2	3

⟶ count in this direction

The last box is the third numbered box. Thus, 0.0504 has three significant digits. How many significant digits are in the number 120.0? Repeat the procedure by separating each digit (ignoring the decimal place):

1	2	0.	0

---

[*] By point of reference, 0.00001 cm = 100 nanometers, about the size of a virus. It is unlikely that a yardstick can measure a distance of about 40 cm to the accuracy of the size of a virus.

Counting the boxes from left to right, the first box containing a nonzero digit is the first box from the left. Number this box "1" and continue counting from left to right until you run out of digits:

	1	2	0.	0
Box #	1	2	3	4

→ count in this direction

The last box is the fourth numbered box. Thus, 120.0 has four significant digits. See Example 2 for more examples of counting the number of significant digits.

3.3 Exceptions to the Rule: Numbers with No Decimal Point and Exact Numbers

Key idea: Avoid writing numbers without decimal points, because such numbers have an indeterminate number of significant digits.

The procedure in Section 3.2 for counting the number of significant digits works for most numbers. The rule implies that leading zeros to the left of the decimal point are ignored. What about numbers with *no* decimal point? Does the number "8" have the same number of significant digits as "8." or "8.0" or "8.00"? Numbers without decimal places are tricky. It is clear from Section 3.2 that "8.," "8.0," and "8.00" have one, two, and three significant digits, respectively. However, *you do not know how many significant digits there are in the number 8 when it is written without a decimal point*.

To avoid this uncertainty, refrain from writing numbers without decimal points. If you wish to indicate three significant figures with the number seven hundred, write it as "700." not "700" (i.e., write it *with* a decimal point). (In addition, *always* include a leading zero when reporting numbers between 1 and −1. It is much clearer if you write "−0.14" or "0.56" than if you write "−.14" or ".56".)

You also can use scientific notation to show the number of significant digits. Count the number of significant digits in a number in scientific notation by applying the procedure of Section 3.2 to the mantissa.* Thus, the numbers "$7. \times 10^2$", "7.0×10^2", and "7.00×10^2" have one, two, and three significant digits, respectively. (Again, mantissas without decimal places are tricky: avoid writing numbers such as "7×10^2".)

What about *exact* numbers? You may wish to do calculations that involve numbers that are exact. Exact numbers have no variability. For example, there are *exactly* 100 cm in a meter, *exactly* three feet in a yard, and *exactly* eight sides in an octagon. In engineering calculations, you may wish incorporate exact numbers into calculations, such as the number of roads in a city, the number of distillation columns in a factory, or the number of capacitors in a circuit.

PONDER THIS

How many significant digits are there in an exact number?

Exact numbers are treated as if they have an *infinite* number of significant digits. This may seem a little strange at first, but as you shall see in Section 3.5, the number of significant digits in exact numbers is ignored in calculations.

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*Numbers in scientific notation have three parts: the base (usually 10), the mantissa (number before the "×" symbol), and the exponent (exponent on the base). Thus, in the number 1.71×10^5, the mantissa is 1.71, the base is 10, and the exponent is 5. The word *mantissa* means "an addition of little importance." In some software packages, "×10" is replaced with an uppercase letter "e." Thus, $1.71 \times 10^5 = 1.71E5$.

EXAMPLE 2 SIGNIFICANT DIGITS

Count the number of significant digits in the following measurements: 43 cm, 4.3 kV, 0.43 Ω, and 0.043 microcurie (0.043 μCi). Count the number of significant digits in the numbers 691, 1.30, and 0.00000500.

SOLUTION

Start with the first nonzero digit from the left and count to the right until encountering the last digits. For example, the measurement "4.3 kV" can be counted as

	4.	3
Box #	1	2

The number "0.00000500" can be counted as

	0.	0	0	0	0	0	5	0	0
Box #							1	2	3

Thus, each number and unit in the set of measurements (43 cm, 4.3 kV, 0.43 Ω, and 0.043 μCi) has two significant digits. Each number in the set of numbers (691, 1.30, and 0.00000500) has three significant digits.

3.4 Reporting Measurements

Key idea: Report one more significant digit than the number of digits you are certain about. The last significant digit is understood to include some uncertainty.

You now know how to *determine* the number of significant digits in numbers. However, the question from Section 3.2 remains: how should you *report* measurements? The usual interpretation of significant digits is as follows: report *one more significant digit than the number of digits you are certain about*. In other words, the last significant digit is understood to be estimated and may include some uncertainty.

An example will help here. Suppose you are weighing concrete test specimens to test the strength of a new concrete formulation. The scale is marked in grams. You interpolate between gram markings to estimate tenths of grams. It would be proper to report a weight of 79.6 g. When another engineer reads this number, he or she will know that there is some uncertainty in the tenths of grams, because it is the last significant digit reported.

3.5 Rounding and Calculations

Always report your calculations with the number of significant digits consistent with the data. Determining the number of significant digits involves two steps: deciding which digits to drop and deciding what to do with the digits you report. The latter process is called ***rounding***.

rounding: adjusting the value of certain digits to comply with the appropriate number of significant digits

There are two simple rules for rounding:

1. If the digit to be dropped is less than 5, then write the last digit retained as it is.
2. If the digit to be dropped is greater than or equal to 5, then increase the last digit retained by one.*

---

*Sometimes, a different convention is used if the digit to be dropped is equal to 5. Some people write the last digit retained as the nearest even digit if the digit to be dropped is equal to 5. For example, if you determine that three significant digits are appropriate, you would round 0.6225 to 0.622 and 1.235 to 1.24 in this system.

For example, if you determine that four significant digits are appropriate, you would round 95.673 to 95.67 (since the digit dropped, 3, is less than 5). Similarly, if you determine that five significant digits are appropriate, you would round 0.0124457 to 0.012446 (since the digit dropped, 7, is greater than 5).

How do you determine the appropriate number of significant digits in a calculation? Two rules will suffice here:

1. When multiplying or dividing numbers, report the result to the number of *significant digits* of the value with the smallest number of significant digits.
2. When adding or subtracting numbers, report the result to the number of *decimal places* of the value with the smallest number of decimal places.

Key idea: The reported value is based on the smallest number of *significant digits* in the calculation for multiplication and division and on the smallest number of *decimal places* in the calculation for addition and subtraction. Exact numbers do not affect the number of digits reported.

It is important to note the difference between how numbers are reported in different calculations. In multiplication and division, the reported value is based on the smallest number of *significant digits* in the calculation. This rule implies that the product or division of numbers cannot be more precise than the least precise number. For example, your calculator may report:

56.122/2.31 = 24.2952381 (*Warning*: Too many digits reported)

PONDER THIS

How would you round the results of the calculation of 56.122/2.31 = 24.2952381?

You round the result to 24.3, because the smallest number of significant digits in the numbers on the left side of the equation is three ("2.31" has three significant digits).

In addition and subtraction, the second rule says that the reported value is based on the smallest number of *decimal places* (numbers to the right of the decimal place) in the calculation. As an example, your calculator may report

23.52 + 4.215 + 6.1 = 33.835 (*Warning*: Too many digits reported)

PONDER THIS

How would you round the results of the calculation of 23.52 + 4.215 + 6.1 = 33.835?

You round the sum to 33.8, because the number "6.1" has only one digit to the right of the decimal point. Note that the sum is reported to three significant digits, even though one of the numbers on the left side (the number "6.1") has only two significant digits.

What about exact numbers in calculations? Exact numbers play no role in determining the number of digits reported.

PONDER THIS

Why should exact numbers not affect the number of reported digits in multiplication and division?

Recall from Section 3.3 that *exact numbers are treated as having an infinite number of significant digits*. Thus, exact numbers do not affect the number of reported digits in multiplication and division. Why? Exact numbers can *never* have the smallest number of significant digits and can never control the number of digits reported.

In addition and subtraction, it also makes sense that exact numbers should not play a role in determining the number of digits reported. For example, suppose you are trying to convert a temperature reading from Kelvin to Celsius. A temperature of zero Kelvin (0 K) is defined to be exactly −273.16°C. Thus, 298.103 K is equal to $-273.16 + 298.103 = 24.943$ K. You report this temperature to three decimal places because the number "−273.16" is exact and does not affect the number of decimal places reported.

Finally, rounding is best performed on the final answer, not on intermediate calculations. If you round intermediate calculations, rounding errors may accumulate.

4 MEASURES OF CENTRAL TENDENCY

4.1 Introduction

Engineers usually take a more quantitative approach to the ideas of accuracy and precision than that presented in Section 2. To determine accuracy, you may wish to use one measure as representative of a set of data. This is called a measure of the *central tendency* of the data or the *average* (from the Arabic *‘awariyah* meaning damaged merchandise, because the word "average" was originally applied to the process of proportionally distributing expenses for damaged goods during sea transport).

4.2 Arithmetic Mean

arithmetic mean: the sum of all values divided by the number of values $= \frac{1}{N}\sum_{i=1}^{N} x_i$

There are many ways to take the average of a set of data. The most common measure is the ***arithmetic mean*** (often just called the *mean*). The arithmetic mean is calculated by summing all the values and dividing by the number of data points. For example, if the fuel efficiency of an innovative automotive engine was measured to be 56.2, 61.4, 55.2, and 60.9 miles per gallon (mpg), then the arithmetic mean would be

$$(56.2 + 61.4 + 55.2 + 60.9 \text{ mpg})/4 = (233.7 \text{ mpg})/4 = 58.4 \text{ mpg}$$

(Why was the answer reported to one decimal place? Each number to be summed was reported to one decimal place, so the sum should be reported to one decimal place. The number 4 is exact and does not affect how the result is reported.) If each data point is designated x_i and there are N data points ($x_1, x_2, x_3, \ldots, x_N$), then the arithmetic mean is

$$\text{arithmetic mean} = \frac{x_1 + x_2 + x_3 + \cdots + x_N}{N} = \sum_{i=1}^{N} x_i$$

The uppercase sigma (see Appendix B) is read, "the sum from i equals 1 to i equals N of . . . ."

At first glance, it appears that the arithmetic mean is the *only* reasonable way to determine an average. However, the arithmetic mean can be misleading and is not always appropriate. Can you think of a situation where the arithmetic mean is ***not*** the best measure of central tendency?

THOUGHTFUL PAUSE

Take a guess at the mean wealth of eyeglass-wearing men in Washington state with the initials WHG who were born in 1951.

Now guess the mean wealth of this group if *one* member, Microsoft President Bill Gates, is excluded. The exclusion of Bill Gates would probably decrease the arithmetic mean of the wealth significantly.

Key idea: The arithmetic mean is sensitive to extreme values in the data set.

Similarly, note what happens to the arithmetic mean if you change *one* data point in the fuel efficiency data. If the fuel efficiencies were 56.2, 61.4, 55.2, and *20.9* mpg (rather than 56.2, 61.4, 55.2, and *60.9* mpg), then the arithmetic mean changes from 58.4 mpg to 48.4 mpg. These exercises demonstrate that the *arithmetic mean is sensitive to extreme values*. In other words, the largest and smallest values in the data set strongly affect the arithmetic mean.

4.3 Median

median: the middle data point when the values are listed in numerical order

To avoid the influence of extreme values, the median sometimes is used as a measure of central tendency. The ***median*** of a data set is the middle data point when the values are listed in numerical order. (For an odd number of data points, the median is the middle value when ordered. For an even number of data points, the median is the arithmetic mean of the two middle values when ordered.)

Say the engineering library has ten very old personal computers with hard-drive storage capacities of 1.2, 4.5, 6.4, 5.2, 6.4, 5.0, 2.3, 3.4, 6.3, and 8.2 gigabytes (1 gigabyte = 1 GB = 10^9 bytes). To determine the median storage capacity, order the values (8.2, 6.4, 6.4, 6.3, 5.2, 5.0, 4.5, 3.4, 2.3, and 1.2 GB). Since there is an even number of values, take the arithmetic mean of the middle two values (5.2 and 5.0 GB). The median amount of storage capacity is then 5.1 GB. (You may wish to confirm that the arithmetic mean amount of storage capacity is 4.9 GB. This is similar to the median, since there are no really extreme values here.) As another example, find the median value of 5.62, 4.1, and 6.2:

Values: 5.62, 4.1, 6.2

Ordered values:

4.1	5.62	6.2
smallest		largest

Median: 5.62

(use the middle value, since the number of values is odd)

4.4 Geometric Mean

geometric mean: the product of the values raised to the 1/N power = $(x_1x_2x_3\ldots x_N)^{1/N} = \left(\prod_{i=1}^{N} x_i\right)^{1/N}$

There are several other types of less commonly used averages. The ***geometric mean*** is the product of the values raised to the 1/N power $(x_1x_2x_3\ldots x_N)^{1/N}$, or, equivalently, the Nth root of the product of the values:

$$\text{geometric mean} = (x_1x_2x_3\ldots x_N)^{1/N} = \sqrt[N]{x_1x_2x_3\ldots x_N}$$

You can use uppercase pi (Π) to read "the product of . . . " (just as Σ means "the sum of . . . ").

Thus,

$$\text{geometric mean} = \left(\prod_{i=1}^{N} x_i\right)^{1/N}$$

You can show that the logarithm of the geometric mean of a set of positive numbers is equal to the arithmetic mean of the logarithms of the numbers (see also Problem 10).

The geometric mean sometimes is used as a measure of central tendency with values that change over several orders of magnitude. For example, in environmental engineering, treated wastewater can contain no more than a specified number of a certain kind of microorganism. Since microorganism concentrations can vary greatly, the geometric mean is regulated. If the data for one week are 400, 100, 250, 100, 15, 20, and 15,000 organisms per 100 milliliters, then the seven-day geometric mean is as follows:

$$(400 \times 100 \times 250 \times 100 \times 15 \times 20 \times 15{,}000)^{1/7}$$

or 240 organisms per 100 milliliters.

4.5 Harmonic Mean

harmonic mean: the reciprocal of the arithmetic mean of the reciprocals of the values = $\dfrac{N}{\sum_{i=1}^{N} \frac{1}{x_i}}$

The ***harmonic mean*** is the reciprocal of the arithmetic mean of the reciprocals of the values:

$$\text{harmonic mean} = \frac{1}{\frac{1}{N}\sum_{i=1}^{N}\frac{1}{x_i}} = \frac{N}{\sum_{i=1}^{N}\frac{1}{x_i}}$$

The harmonic mean is used when the *reciprocals* of the data are important. For example, computer speeds often are assessed by benchmark tests, where the computation speeds (expressed in millions of instructions per second or MIPS) for several tasks are recorded. The computation *time* is more important than the computation *speed* for most computer users. The computation time is inversely proportional to the computation speed (speed = number of operations/time, so time = number of operations/speed). Thus, the appropriate measure of central tendency for computational speed is the harmonic mean.

As an example, suppose that five benchmark programs execute at 30, 700, 15, and 13,000 MIPS. The harmonic mean is

$$\frac{4}{\frac{1}{30\text{ MIPS}} + \frac{1}{700\text{ MIPS}} + \frac{1}{15\text{ MIPS}} + \frac{1}{13{,}000\text{ MIPS}}} = 39\text{ MIPS}$$

The harmonic mean is influenced most strongly by the *smallest* values. For example, if the *largest* computation speed was doubled from 13,000 to 26,000 MIPS, the harmonic mean remains unchanged at 39 MIPS. However, if the *smallest* computational speed was doubled from 15 to 30 MIPS, the harmonic mean increases from 39 MIPS to 59 MIPS.

4.6 Quadratic Mean

quadratic mean (root mean square, RMS): the square root of the arithmetic mean of the squares of the values = $\sqrt{\frac{1}{N}\sum_{i=1}^{N}x_i^2}$

The ***quadratic mean*** (commonly called the ***root mean square, RMS***) is the square root of the arithmetic mean of the squares of the values:

$$\text{quadratic mean} = \text{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}x_i^2}$$

The quadratic mean is used when an important property is proportional to the *square* of a measured value. For example, suppose a mechanical engineer bombards a surface with high-energy particles to learn more about the surface properties of the material. The information to be gathered depends on the energy of the particles. The engineer may be more interested in the quadratic mean velocity (RMS velocity) of the particles, rather than the arithmetic mean, because the energy of the particles is proportional to the velocity squared. (Recall that the kinetic energy = $\frac{1}{2}mv^2$, where m = mass and v = velocity.)

4.7 Mode

mode: the most frequently occurring value in a data set

Finally, the ***mode*** of a data set is the most frequently occurring value in a data set. In the hard-drive storage capacity example (Section 4.3), the mode is 6.4 GB, since that value is present at a higher frequency (2 out of 10 values) than any other (all others present at one out of ten values). An example of how to select the most appropriate measure of central tendency is given in Example 3.

EXAMPLE 3 MEASURES OF CENTRAL TENDENCY

Select and calculate the most appropriate measure of central tendency for the diameters of catalyst particles used in ammonia synthesis. A particle size analysis of 400 catalyst particles revealed 100 particles with diameter 5.4 μm, 100 particles with diameter 10.6 μm, 100 particles with diameter 7.5 μm, and 100 particles with diameter 8.4 μm. You are interested in the particle diameter, surface area, and surface-to-volume ratio (*S/V*).

SOLUTION

For the particle diameter, either the mean or median is appropriate, since the distribution is narrow. The mean of the particle diameters is $[(100)(5.4\ \mu\text{m}) + (100)(10.6\ \mu\text{m}) + (100)(7.5\ \mu\text{m}) + (100)(8.4\ \mu\text{m})]/400$ or **8.0 μm**. The median of the particle diameters is the arithmetic mean of 7.5 μm and 8.4 μm or **8.0 μm**. (Note the number of significant figures through this problem.)

Surface area is proportional to the diameter squared, so the quadratic mean of the particle diameters is the appropriate type of mean. The quadratic mean of the particle diameters is $\{[(100)(5.4\ \mu\text{m})^2 + (100)(10.6\ \mu\text{m})^2 + (100)(7.5\ \mu\text{m})^2 + (100)(8.4\ \mu\text{m})^2]/400\}^{1/2}$ or **8.2 μm**.

S/V is proportional to the reciprocal of the diameter, so the harmonic mean of the particle diameters is the appropriate type of mean. The harmonic mean of the particle diameters is $400/[(100)/(5.4\ \mu\text{m}) + (100)/(10.6\ \mu\text{m}) + (100)/(7.5\ \mu\text{m}) + (100)/(8.4\ \mu\text{m})]$ or **7.5 μm**.

(*Note:* The surface area and *S/V* also can be calculated directly and the arithmetic mean of their values calculated.)

5 MEASURES OF VARIABILITY

5.1 Introduction

Precision is a qualitative indicator of the variability of the data. There are three common *quantitative* measures of data variability: variance, standard deviation, and relative standard deviation.

Before developing the formulas for these measures, it is important to review two important types of data sets. If you examine all possible members of some group, then the measures of central tendency and variability are called ***population*** measures. For example, if you measured propulsion characteristics of all Space Shuttle engines, you could calculate the population mean of the propulsion characteristics.

population: all possible members of a group

sample: selected members of a group

In many cases in engineering, you can examine only a few members of the population. If so, label your measures ***sample*** measures. For example, you may determine the failure rate of a handful of circuit boards from a production line and calculate the sample mean of the failure rate. (Why test only a handful? If you tested *all* the boards to failure, there wouldn't be any left to sell.) If you have n members of the sample and N members of the population (where $n \leq N$), then you can define

$$\text{sample (arithmetic) mean} = \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i, \text{ and}$$

$$\text{population (arithmetic) mean} = \mu = \frac{1}{N}\sum_{i=1}^{N} x_i$$

Note that different symbols are used for the sample and population means.

5.2 Variance

variance: a measure of data variability proportional to the sum of the squares of the differences between each data point and the mean

The formulas for the population mean and sample mean look similar. However, the differences between the sample and population measures of *variability* are more pronounced. The ***variance*** is one measure of data variability. The variance is proportional to the sum of the squares of the differences between each data point and the mean. The *sample variance* is given by

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$$

The *population variance* is given by

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2$$

(Note that the sample variance is calculated by dividing by $n - 1$, while the population variance is calculated by dividing by N.) Why square the difference between the data and the mean? Squaring makes all the terms in the summation positive. Thus, contributions to the variance from data points *less* than the mean do not cancel out contributions from data points *greater* than the sample mean.

The variance has one big disadvantage as a measure of variability. To illustrate the problem, calculate the sample mean of the fuel efficiencies discussed in Section 4.2. The sample mean was 58.4 mpg. The sample variance is

$$\begin{aligned} s^2 &= [(56.2\text{ mpg} - 58.4\text{ mpg})^2 + (61.4\text{ mpg} - 58.4\text{ mpg})^2 + \\ &\quad (55.2\text{ mpg} - 58.4\text{ mpg})^2 + (60.9\text{ mpg} - 58.4\text{ mpg})^2]/3 \\ &= 10.1\ (\text{mpg})^2 \end{aligned}$$

Is $10.1\ (\text{mpg})^2$ big or small? It is hard to tell, because of the strange units of the variance. The units of the variance are the squares of the units of the observations.

5.3 Standard Deviation

standard deviation: a measure of data variability with the same units as each data point and equal to the square root of the variance

A more easily interpreted measure of data variability is the ***standard deviation***. The standard deviation is the square root of the variance. Thus, the sample standard deviation is $s = (s^2)^{1/2}$ and the population standard deviation is $\sigma = (\sigma^2)^{1/2}$. For example, the sample standard deviation for the fuel efficiency example is

$$s = [10.1\text{ miles}^2/\text{gallon}^2]^{1/2} = 3.2\text{ mpg}$$

The standard deviation makes it clear that the variability is fairly low: the sample standard deviation is small compared with the sample mean.

5.4 Relative Standard Deviation

relative standard deviation (RSD or standard error): a dimensionless measure of data variability and equal to the standard deviation divided by the mean

The mean and standard deviation can be compared even more directly in the final common measure of variability: ***relative standard deviation (RSD***, also called the ***standard error***). The relative standard deviation is the standard deviation divided by the mean. It is usually expressed as a percentage. For the fuel efficiency data, the RSD is

$$(3.2\text{ mpg})/(58.4\text{ mpg}) = 0.055\text{ or }5.5\%$$

This reaffirms the observation that the variability in the data is fairly low. Another example of calculating the measures of variability is given in Example 4.

EXAMPLE 4 MEASURES OF VARIABILITY

Calculate the relative standard deviations for the volumes of the Great Lakes and the lengths of all the pencils in the Western Hemisphere.

The volumes of the Great Lakes are as follows: Superior (11,800 km^3), Michigan (4,800 km^3), Huron (3,500 km^3), Erie (500 km^3), and Ontario (1,600 km^3). Using the pencils in my desk as examples, the lengths are 18.3 cm, 17.0 cm, 13.2 cm, 16.5 cm, and 18.5 cm.

SOLUTION

Since the data for all the Great Lakes are known, use population statistics. Thus, $\mu = 4{,}400$ km^3, $\sigma = 3{,}969$ km^3, and RSD $= \boldsymbol{\sigma/\mu = 0.89}$ **or 89%**. (Remember to divide by $N = 5$ for σ^2.)

Since the data for the pencils are samples, use sample statistics: $\bar{x} = 16.7$ cm and $s = 2.1$ cm, so RSD $= \boldsymbol{s/\bar{x} = 0.13}$**, or 13%**. (Remember to divide by $n - 1 = 4$ for s^2.)

5.5 Variability and Data Collection in Engineering

In engineering, variability leads to uncertainty. For example, increased variability in a parameter such as Young's modulus means more uncertainty about the stability of a structure. More uncertainty leads to more conservative designs. More conservative designs are more expensive. For example, if you are uncertain about the properties of a capacitor, then you may specify an overly large capacitor to account for the uncertainty. As a result, variability leads to higher costs.

Key idea: Variability increases uncertainty, leading to higher costs. Engineers collect data to reduce uncertainty.

How do engineers reduce uncertainty? Simply put, *engineers collect data to reduce uncertainty*. Two examples will demonstrate the relationship between data collection and uncertainty reduction. Suppose your firm is hired to design a waterproof cover for a baseball infield. You might design the cover with the assumption that the bases are spaced 90 feet apart. Are the bases exactly 90 feet apart? No, it is possible that they might be off by a tiny distance. However, the uncertainty regarding the base path distance is very small. In addition, the cost of overdesign (i.e., the cost of making the cover a little too big) is also very small. Therefore, the cost of actually measuring the base path distances probably is not outweighed by the reduction in uncertainty that the measurements would bring.

Now imagine you are designing the steel columns in a high-rise building. The columns transmit the force generated by the structure's mass to the foundation. Is it worthwhile to test the mechanical properties of the steel columns? The answer might very well be *yes*. While the cost of collecting the data is high, the potential payoff is very high. If you have to design for uncertain structural properties, then you might have to specify many additional columns. In addition, the cost of failure (in this case, the cost of collapse) is extremely high. Another example of how engineers pay to reduce uncertainty is shown in the *Focus on Variability: Paying to Reduce Uncertainty*.

safety factor: a multiplier of a design parameter used to account in part for uncertainty

Uncertainty in design sometimes is expressed by a ***safety factor***. Design parameters sometimes are multiplied by safety factors to account for uncertainty. For example, steel buildings are designed with a safety factor of 2, while wooden buildings are designed with a safety factor of 6. Why the difference? The structural properties of wood are more variable than the structural properties of steel.*

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*As the examples in the text show, safety factors are determined in part by the uncertainty in materials properties and the cost of overdesign. Safety factors also are influenced by the variability in loads and by the cost of failure. For example, the cables in high-speed elevators (which experience variable loads and for which the cost of failure is high) are designed with a safety factor of 11.9.

FOCUS ON VARIABILITY: PAYING TO REDUCE UNCERTAINTY

This chapter was devoted to how to *use* data. Perhaps a more fundamental question should be asked: why do engineers gather data in the first place? After all, data collection—whether a phone call or an hour on the Internet or two year's worth of laboratory research—costs money. The simple answer from the text is that engineers collect data to reduce uncertainty. When engineers pay for data collection, they are really paying to reduce uncertainty. So when should you collect data? *You collect data only when the benefits of reducing uncertainty outweigh the cost of data collection.*

You sometimes can quantify both the cost of collecting data and the degree of uncertainty reduction. Consider the case of simple random sampling. In many cases, it is common to collect a small number of samples relative to the total possible number of samples (using the symbols in Section 5.1: $n \ll N$). From the samples collected, it is possible to estimate the standard deviation of the sample mean. For example, if you collected five samples on ten occasions, you could calculate ten different sample means. Using those ten values, you could calculate the variance of the sample mean.

One result from statistics is that the variance of the sample mean $[\text{var}(\bar{x})]$ is equal to the population variance divided by the number of samples (σ^2/n):

$$\text{var}(\bar{x}) = \sigma^2/n$$

Rearranging terms yields

$$n = \sigma^2/\text{var}(\bar{x})$$

This equation tells you that you need to collect twice as many samples in a given population to reduce the variance in the sample mean by half. In other words, decreasing $\text{var}(\bar{x})$ by a factor of two means increasing n by a factor of two. In addition, the equation tells you that an inherently more variable population (i.e., larger σ^2) will require more samples to maintain the same variance in the sample mean.

Suppose you are working on a new aircraft design and need to test the tensile strength of an aluminum alloy. How many alloy samples should you test? Say, from previous work, you know that $\sigma = 0.3$ ksi (tensile strength is measured in thousands of pounds per square inch, or ksi). Each test costs \$25. By reducing the uncertainty in $\bar{x}$, you increase the benefits. Suppose that the relationship between benefits and variability is given by

$$\text{benefits (in \$)} = 2{,}000(0.3 - \text{sd}(\bar{x})]$$

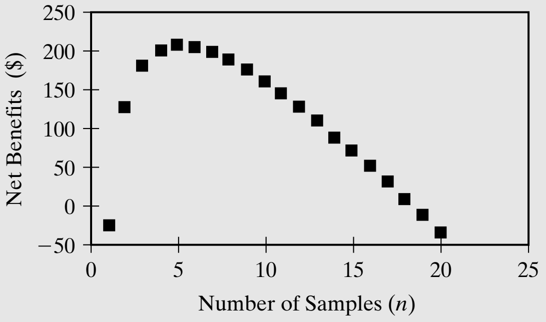
where $\text{sd}(\bar{x})$ is the standard deviation of the sample mean in ksi. You know that

$$\text{sd}(\bar{x}) = [\text{var}(\bar{x})]^{1/2} = (\sigma^2/n)^{1/2} = \sigma/n^{1/2}$$

The cost of testing n samples (in \$) is $25n$, since the tests cost \$25 each. Thus,

$$\begin{aligned}\text{net benefits} &= \text{benefits} - \text{costs} \\ &= 2{,}000(0.3 - \text{sd}(\bar{x})] - 25n \\ &= 2{,}000(0.3 - \sigma/n^{1/2}] - 25n.\end{aligned}$$

The net benefits are plotted as a function of n in the accompanying figure. Note that collecting a *small* number of samples is undesirable: the sample cost, although small, is not outweighed by the very small reduction in uncertainty. (A negative value for net benefits means that the costs are larger than the benefits.) Similarly, collecting a *large* number of samples is undesirable: the large sample cost is not offset by the corresponding reduction in uncertainty. Net benefits are maximized by collecting five samples in this case.



6 SUMMARY

Engineers generate and use data. Data may have errors, described qualitatively by the concepts of precision and accuracy. Calculated values should be presented with an appropriate number of significant digits (usually ***not*** the number given by your calculator or spreadsheet). Use measures of central tendency and variability to summarize your data and quantify data variability.

SUMMARY OF KEY IDEAS

- Do not blindly report the numbers given to you by a calculator or spreadsheet—determine the proper number of digits to report.
- Avoid writing numbers without decimal points, because such numbers have an indeterminate number of significant digits.
- Report one more significant digit than the number of digits you are certain about. The last significant digit is understood to include some uncertainty.
- The reported value is based on the smallest number of *significant digits* in the calculation for multiplication and division and on the smallest number of *decimal places* in the calculation for addition and subtraction. Exact numbers do not affect the number of digits reported.
- The arithmetic mean is sensitive to extreme values in the data set.
- Variability increases uncertainty, leading to higher costs. Engineers collect data to reduce uncertainty.

Problems

1. Describe whether the following measures are more related to accuracy or precision:
   a. The range of scores on the midterm exam
   b. Free-throw shooting percentages
   c. Tolerance values on spark-plug gaps
   d. Length of a cold medication capsule
   e. Reproducibility of the lengths of cold medication capsules

2. The subtraction of two values can result in a loss in the number of significant digits. Give an example of this phenomenon.

3. Find three numbers in this text outside of this chapter. Determine the number of significant digits in each number and explain your reasoning.

4. Consider two resistors having resistance R_1 and R_2. If the resistors are in series (i.e., connected end-to-end), the overall resistance R is given by $R = R_1 + R_2$. If the resistors are in parallel (i.e., the current is split between the resistors), then $1/R = 1/R_1 + 1/R_2$.
   a. What kind of mean of R_1 and R_2 would you use to calculate the overall resistance of resistors in series?
   b. What kind of mean of R_1 and R_2 would you use to calculate the overall resistance of resistors in parallel?

5. Using the *Help* functions in your favorite spreadsheet software, find and report the spreadsheet functions used to calculate the arithmetic mean, geometric

mean, harmonic mean, median, mode, sample standard deviation, and population standard deviation.

6. Using the data in Section 4.2, how does *median* change when one fuel efficiency value is changed? Does this make sense?

7. Measure the heights of ten students as samples of the larger student population. Calculate the variance in their heights.

8. For each of the following situations, state the most appropriate type of mean:
    a. The mean of the interest rates for three years (i_1, i_2, and i_3), if you are interested in the interest rate i over the entire three-year period. [*Hint*: You want the most appropriate type of mean of i_1, i_2, and i_3 to describe i, where $(1 + i)^3 = (1 + i_1)(1 + i_2)(1 + i_3)$.]
    b. The mean speed of four legs of an automobile trip, if you are interested in the mean speed of the entire trip.
    c. The mean frequencies of the three A notes nearest to middle C on a piano. (*Hint*: The frequencies of the A notes nearest middle C are 220, 440, and 880 Hz, where 1 Hz = 1 hertz = 1 cycle/s.)

9. Can the geometric mean ever be greater than the arithmetic mean?

10. The geometric, harmonic, and quadratic means are related to the arithmetic mean in a way that helps in calculating their values. It is possible to find three functions so that

$$f(\text{geometric mean}) = \text{arithmetic mean of } f(x_i)$$
$$g(\text{harmonic mean}) = \text{arithmetic mean of } g(x_i)$$
$$h(\text{quadratic mean}) = \text{arithmetic mean of } h(x_i)$$

where f, g, and h are the functions and the x_i are the data. Another way to write this is

$$\text{geometric mean} = f^{-1}(\text{arithmetic mean of } f(x_i))$$
$$\text{harmonic mean} = g^{-1}(\text{arithmetic mean of } g(x_i))$$
$$\text{quadratic mean} = h^{-1}(\text{arithmetic mean of } h(x_i))$$

where f^{-1}, g^{-1}, and h^{-1} are the inverses of f, g, and h, respectively. The inverse of a function means that $f^{-1}(f(x)) = x$, $g^{-1}(g(x)) = x$, and $h^{-1}(h(x)) = x$. For example, if $f(x) = e^x$, then $f^{-1}(x) = \ln(x)$ because $\ln(e^x) = x$.

a. Find a function f so that geometric mean $= f^{-1}(\text{arithmetic mean of } f(x_i))$.
b. Find a function g so that harmonic mean $= g^{-1}(\text{arithmetic mean of } g(x_i))$.
c. Find a function h so that quadratic mean $= h^{-1}(\text{arithmetic mean of } h(x_i))$.

Engineering Models

1 INTRODUCTION

To facilitate analysis and design, engineers often rely on models. There are several different types of engineering ***models***.

To some people, the phrase "engineering model" conjures up an image of a hastily drawn sketch of a Rube Goldberg machine on a napkin (see Figure 1). This is an example of a *conceptual model*. Conceptual models will be discussed in more detail in Section 3.2.

To others, the term "engineering model" evokes images of clay cars on pedestals or small airplanes in wind tunnels or miniature supertankers suspended in wave tanks. These are examples of *physical models* and will be discussed further in Section 3.3.

Finally, "engineering model" may bring to mind page after page of densely written mathematical formulas. This is an example of a *mathematical model*. More details on mathematical models may be found in Section 3.4. Each type of model will be illustrated with the following problem: predict the time required to reach the engineering building from your apartment.

2 WHY USE MODELS?

Why will you use models as an engineer? Models serve a number of roles in engineering. First, models aid in organizing ideas about engineered systems. In particular, conceptual models are a useful way to enumerate the important elements of a system.

Second, models can be used to simulate expensive or critical systems prior to construction. Physical models often are used prior to assembly. It is now possible to design even large engineered systems by computer.

SECTIONS

OBJECTIVES

After reading this chapter, you will be able to:

- explain why engineers use models;
- list the types of models used by engineers;
- solve engineering problems using models and data;
- explain how models and data interact.

model: a conceptual, mathematical, or physical representation of an engineering system

Key idea: Types of engineering models include conceptual, physical, and mathematical models.

"what if" scenario: a question (usually probed by models) regarding how a system will respond to a set of conditions

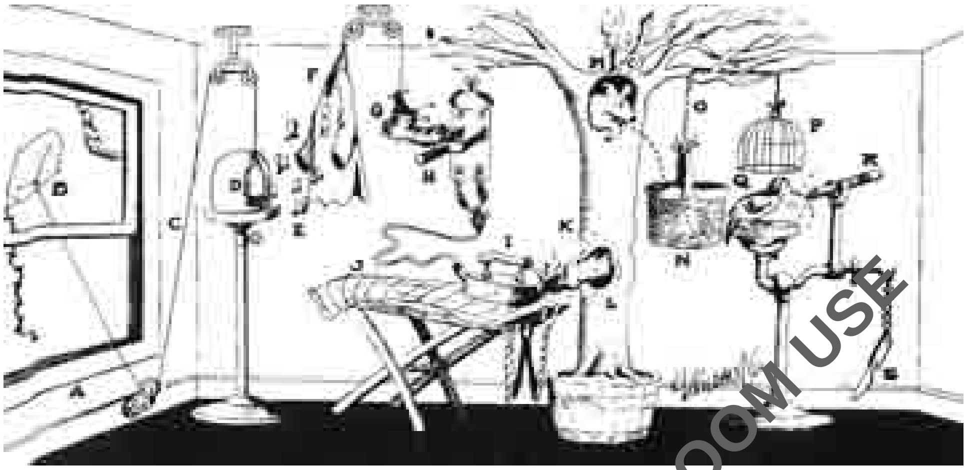


Figure 1. A Rube Goldberg Pencil Sharpener. Reuben (Rube) Lucius Goldberg (1883–1970) was a Pulitzer prize–winning cartoonist. He is known for his drawings of incredibly complicated machines designed to perform very simple jobs. The term "Rube Goldberg" refers to a complex solution to a simple problem. (Image courtesy of Rube Goldberg Inc.)

PONDER THIS

What does the phrase "engineering model" mean to you?

Key idea: Engineers use models to organize ideas, simulate expensive or critical systems prior to construction, and probe the response of a system to a large number of conditions.

Third, models aid in probing the response of a system to a large number of conditions. This use of models is sometimes referred to as a ***"what if" scenario***. Examples of "what if" scenarios include "What if the primary braking system fails on the Maglev (magnetically levitated) train?" and "What if a voltage spike occurs in a DVD player?" By way of another illustration, suppose you have a mathematical model for the steps involved in the construction of a high-rise apartment building. You could use the model to determine the effects of delays on the project completion time. (Delays may result from adverse weather, delivery delays, or labor strikes.) In this way, models can be used for prediction of future conditions.

3 TYPES OF MODELS

3.1 Introduction

As stated in Section 1, engineers use three types of models: conceptual, physical, and mathematical models. Each model type will be explored in more detail in this section.

3.2 Conceptual Models

conceptual (descriptive) model: a model showing the main elements and how they interact, including *boundaries* (which define the system in space and time), *variables* (elements that may change), *parameters* (or constants: elements that do not change), and *forcing functions* (external processes that affect the system)

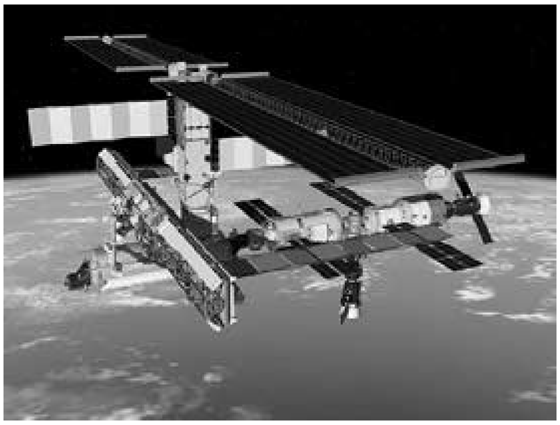
boundaries: the part of the model that defines the system in space and time

variables: elements of the system that may change

A ***conceptual model*** (also called a ***descriptive model***) contains the main elements of the model and how they interact. Almost all modeling efforts begin with a conceptual model of the system. Conceptual models are often summarized in a sketch or diagram. A conceptual model should include the following elements of the system to be modeled: boundaries, variables, parameters, and forcing functions.

Boundaries define the system. The system must be defined in both space and time. For example, the boundaries of a model for the movement of a pollutant through groundwater would include the area under investigation (spatial boundaries) and time period being modeled (temporal boundaries). The space and time domain described by the model boundaries is sometimes called the *control volume*.

Variables are elements of the system that may change. For example, in modeling life support systems for the International Space Station (ISS), variables would include



Artist's rendering of the International Space Station. The solar panel wings are 11.9 m × 34.2 m (39 ft × 112 ft) each. (Image courtesy of NASA/JPL.)

the size of the crew and the water usage rate. The crew size and water usage rates are expected to change over time.

Variables can be divided into two types. *Independent variables* serve as inputs to the model. In the ISS example, the crew size is an independent variable. *Dependent variables* are calculated by the model. For the ISS example, dependent variables include the size of the air cleaning system (called the atmosphere revitalization subsystem) and the capacity of the water treatment system (called the water recovery and management subsystem).

As the names imply, dependent variables *depend* on independent variables. For example, the sizes of the ISS subsystems depend on the crew size.

parameters: elements of the system that do not change

Parameters (also called *constants*) are system elements that do not change. If you were modeling the velocity of a water droplet in a decorative fountain, parameters would include gravitational acceleration, water density, and water viscosity (if density and viscosity are constant over the spatial and temporal domain of interest). In some types of mathematical models, the values of some parameters are changed to best fit the data (see Section 4). These parameters are called *adjustable parameters*: they are not functions of the variables, but are changed in the mathematical modeling process.

forcing functions: external processes that affect the system but are not modeled explicitly

Conceptual models also should include external processes that affect the system. These processes are called ***forcing functions*** (or *inputs*). Forcing functions are external to the model at hand and not modeled explicitly. If you were modeling the water level in a reservoir behind a hydroelectric dam, then the forcing functions might include rainfall and evaporation.

The boundaries, variables, parameters, and forcing functions combine to form the conceptual model. A conceptual model of the time-to-school problem is shown in Figure 2. In this case, a model is developed for commuting by bicycle.

The system boundaries are listed in the sketch title and include the spatial path (e.g., Main Street to University Avenue to Engineering Lane) and the time (year-round). The model is designed to calculate the speed at any time during the commute (also called the *instantaneous speed* and shown in the thickly outlined box in Figure 2). The total commuting time, the model output, will be calculated from the instantaneous speed. Thus, time is the independent variable and instantaneous speed and total commuting time are the dependent variables. Note that the dependent variable is expected to change over the course of the system boundaries and should be modeled.

Parameters include information about the route (i.e., the number of stop signs and the hill slope). Forcing functions include the bike condition, traffic, weather, and initial fatigue (i.e., fatigue at the beginning of your commute). The conceptual model shows

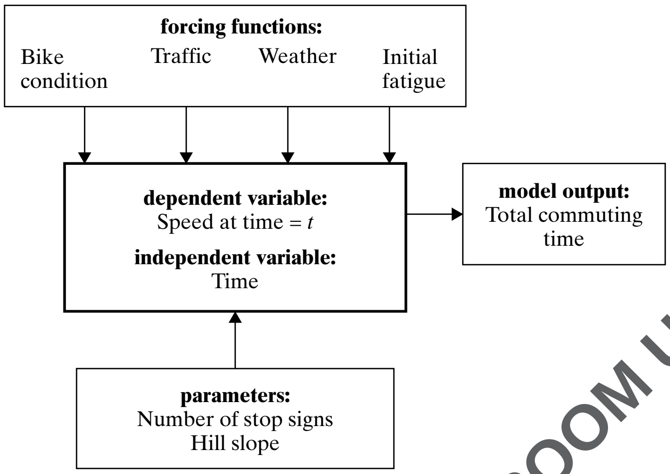


Figure 2. Conceptual Model for the Time-to-School Problem

that the forcing functions will influence the instantaneous speed. This, in turn, will affect the time required to complete the trip. Another example of a conceptual model is presented in Example 1.

3.3 Physical Models

physical model: a (usually) smaller version of the full-scale system

mock-up: a full-size physical model

Physical models are often used for evaluating proposed solutions to engineering problems. A ***physical model*** usually is a smaller version of the full-scale system. (A full-size physical model is called a ***mock-up***.) Physical models are typically used with large engineering projects, from the Great Pyramids to automobiles to the Space Shuttle.

EXAMPLE 1 CONCEPTUAL MODELS

Develop a conceptual model for the design of a wooden pedestrian bridge over a river.

SOLUTION

A conceptual model for a wooden pedestrian bridge over a river would include the following items:

1. Boundaries:
   spatial boundaries (e.g., a river crossing a location), temporal boundaries (e.g., design life)
2. Independent variables:
   number of pedestrians crossing the bridge over time, properties of wood that change over time
3. Dependent variables:
   design elements (e.g., deck, trusses, railings, piers)
4. Parameters:
   wood properties that do not change over time, gravitational acceleration
5. Forcing functions:
   weather, cost constraints

A wind tunnel is an example of a physical engineering model. Conditions of an aircraft in flight can be simulated by placing a physical model of the aircraft in a wind tunnel and moving the air past it. Knowledge of fluid mechanics is used to correct for the size of the model and wind tunnel conditions to provide a good prediction of how the full-size aircraft will perform in flight. Other examples of physical models include rotating hydrodynamic laboratories (to study the effect of the Earth's rotation on the movement of water in large water bodies), laboratory robotic systems (to study interferences in automated materials-handling systems), and rapid mixing devices (to simulate chemical reactions and separations in the synthesis of plastics).

To develop a physical model for the commuting example, consider transportation to school by skateboard. You could build bench-scale physical models of the terrain and skateboard. This would allow you to perform experiments to estimate the travel time. The success of the model (i.e., its ability to predict the actual commuting time) would depend on how well the physical model mimicked friction, air resistance, and other elements of the system.

3.4 Mathematical Models

Mathematical models commonly are used in engineering evaluations. ***Mathematical models*** are built on the logical and quantitative relationships between model components. If the model is valid, then the real system can be probed by altering the independent variables and observing the model output.

mathematical model:
a representation of the logical and quantitative relationships (usually mathematical expressions) between model components

Mathematical models may be further subdivided into deterministic and stochastic models. In a ***deterministic model***, the input *determines* the output. Typically, a deterministic model provides a *single answer for a given set of inputs*. For example, the equation $t = d/v$ is a simple model describing the time t required for an object to travel a distance d at a constant velocity v. The model is deterministic: any combination of d and v determines a single value of t. The model $t = d/v$ is an accurate representation of the motion of a satellite in space.

deterministic model:
a mathematical model which provides a single answer for a given set of inputs

PONDER THIS

Would a simple mathematical model (such as $t = d/v$) accurately predict the time required to commute to school by bus?

This simple mathematical model would fail in many instances because it assumes a constant velocity. It does not take into account acceleration, deceleration, time spent at traffic lights or stop signs, or time spent at bus stops. A deterministic model sophisticated enough to include all factors may be so complex that it has little value.

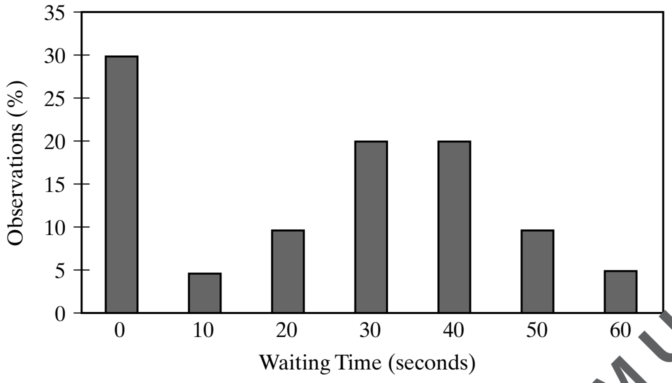


Figure 3. Hypothetical Distribution of Stoplight Waiting Times for a Time-to-School Stochastic Model

stochastic (or probabilistic) model: a mathematical model which provides a distribution of outputs for a given set of inputs

Stochastic models (from the Greek *stochos*, meaning target, aim, or guess) have different outputs, each with their own probability, for each set of inputs. Stochastic models have variables or parameters with probability distributions. For example, imagine that your commute to school passes through only one intersection and the intersection is controlled by a traffic light. You carry a stopwatch with you for a year and record your waiting time at the traffic light. Since you reach the traffic light at a random time in its cycle, your waiting time is expected to show a *distribution* of values, say between zero (if you hit a green light) and one minute (if you hit the light as it turns yellow). An example of a distribution of waiting times is shown in Figure 3. You could incorporate the distribution of waiting times into a stochastic model.

The stochastic model output would also be a distribution of commuting times, each with its own probability of occurrence. In other words, the output of the stochastic model could state, “There is a 50% probability that the commuting time will be greater than 20 minutes.” Compare this statement with the output of a deterministic model, which might read, “The expected commuting time is 23 minutes.” Other examples of mathematical models are given in Examples 2 and 3.

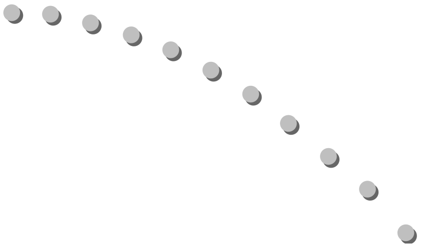
In engineering applications, mathematical models usually have a basis in theory. For example, suppose you are designing a new way to airlift food supplies to flood victims. You want to know how far the food crates will fall in a given time. Starting with basic definitions, you can derive the following common kinematic expression:

$$d = {}^{1}\!/_{2}gt^2$$

where d = distance fallen, g = gravitational acceleration, and t = time.

empirical model: a mathematical model based on observations, not theory

The equation $d = {}^{1}\!/_{2}gt^2$ is derived by theory. Suppose you had sought the relationship between the distance fallen and the time by a series of experiments. By analyzing the experimental data, you might come up with the following relationship: d is proportional to t^2, or $d = kt^2$, where k is a constant. The model $d = kt^2$ is an ***empirical model***.



Trajectory of a falling object (vertical distance fallen is proportional to t^2)

Empirical models are based on observations, not theory. Most engineers are more comfortable using models with theoretical underpinnings. However, empirical models also are useful and may lead to research designed to provide the theory to support the observations.

EXAMPLE 2 DETERMINISTIC MATHEMATICAL MODEL

You are developing new polychromatic lenses for sunglasses. Polychromatic sunglasses darken when exposed to ultraviolet light. The glass in the lenses contains silver chloride (AgCl). You find from experiments that the degree of darkening of the lenses is proportional to both the thickness of the lens (d) and the concentration of AgCl in the layer (C). Further experiments show that when d and C are both doubled, the degree of darkening increases by fourfold. Develop a mathematical model for the degree of darkening of the lenses.

SOLUTION

The degree of darkening is proportional to the lens thickness d and AgCl concentration C. There are two possible models to describe this behavior:

$$\text{Model \#1: darkening} = ad + bC$$
$$\text{Model \#2: darkening} = edC$$

where a, b, and e are constants.

Both models describe the observation that the degree of darkening of the lenses is proportional to both d and C. However, recall that other experiments showed that the degree of darkening increased fourfold when d and C both were doubled. Model #1 predicts that the degree of darkening will only double when d and C both are doubled. Model #2 correctly predicts the behavior of the system when both d and C are doubled. Thus, **Model #2 correctly predicts the observations**.

Note: Model 2 is analogous to the Beer–Lambert Law of absorbance.

EXAMPLE 3 STOCHASTIC MATHEMATICAL MODEL

A nonprofit organization has asked you to help them evaluate the ticket price for a carnival ride at a charity event. For safety reasons, the riders must be at least 54 inches tall. You anticipate that 20% of the fair customers will be unable to ride the roller coaster because of the height constraint. The tickets for the ride cost \$1 and the ride costs \$7 per hour to operate. During a particular one-hour time period, 10 customers visited the charity event. What is the probability that the revenues collected during the hour will equal or exceed the operational costs?

SOLUTION

Systems of this sort follow a binomial distribution. If the proportion of eligible riders to the total population is p, then the probability (P) that n out of N people are eligible to ride is

$$P = \binom{N}{n} p^n (1-p)^{N-n}$$

Here,

$$\binom{N}{n} = \frac{N!}{n!(N-n)!},$$

where $N! = N(N-1)(N-2)\cdots(2)(1)$. ($N!$ is read "N factorial," with $0! = 1$.)

In this example, $p = 1 - 0.20 = 0.80$ and $N = 10$. The number of eligible riders is n ($n = 0, 1, 2, \ldots, 10$). The revenue is

$$\text{revenue} = (\text{ticket price})(\text{number of eligible riders}) = (\$1)(n) = n \text{ (in dollars)}$$

The probability that there will be exactly n eligible riders (and therefore, exactly n dollars taken in during the hour) is

$$P = \binom{10}{n} 0.8^n \, 0.2^{10-n}$$

The revenue and probabilities of occurrence for each value of n are listed in the following table:

Number of Eligible Riders per Hour (n)	Revenue (dollars per hour)	Probability that Exactly n Riders Will Be Eligible
0	0	1.02×10^{-7}
1	1	4.10×10^{-6}
2	2	7.37×10^{-5}
3	3	0.000786
4	4	0.00551
5	5	0.0264
6	6	0.0881
7	7	0.201
8	8	0.302
9	9	0.268
10	10	0.107

Revenues will equal or exceed \$7 per hour only when 7, 8, 9, or 10 riders are present each hour (i.e., only when $n = 7$, 8, 9, or 10). The P values for $n = 7$, 8, 9, and 10 are 0.201, 0.302, 0.268, and 0.107, respectively. The probability that $n = 7$ or 8 or 9 or 10 is the sum of the probabilities with $n = 7$, 8, 9, and 10. Summing these values, **the probability that the revenue will equal or exceed the operational costs of \$7 per hour is 0.879 or about 88%.**

Note: If there are only eight visitors per hour ($N = 8$), then the probability that the revenue will equal or exceed the operational costs decreases to about 50%. Of course, if only six or fewer people enter the charity event every hour, then the probability of generating \$7 per hour drops to zero.

3.5 Other Kinds of Models

As computing power increases, the line between mathematical and physical models is being blurred. Computer-controlled milling machines now make it possible to quickly turn mathematical models into physical models. One name for this approach is "3-D printing." As the name implies, engineers may soon be able to "print" prototypes at their desktops as easily as they print reports.

In some cases, mathematical models coupled with computer-controlled milling machines allow engineers to bypass physical models completely. For example, the Boeing 777, first flown in June 1994, was the first aircraft to be designed without physical models. For more information, see *Focus on Models: Mathematical or Physical Model?*

FOCUS ON MODELS: MATHEMATICAL OR PHYSICAL MODEL?

BACKGROUND

Physical models often give engineers a sense of comfort. A model of a bridge or skyscraper sitting on a table can reduce the anxiety over whether the parts really can come together to make a whole. On the other hand, a large-scale physical model (especially a full-scale mock-up) can be very expensive. Engineers must decide whether a physical model is economically feasible; that is, whether the value of the information produced by the physical model exceeds its cost. For many years, engineers have sought other modeling tools that could provide the "comfort level" of a physical model at less expense.

Rapid changes in computing power have created opportunities for replacing some large-scale physical models with mathematical models. A good example is the design of the Boeing 777 series of jetliners. With a wingspan of 60 m and a length of about 64 m, the Boeing 777-200 is the world's largest twinjet airliner. Clearly, the design and assembly of such a large, sophisticated aircraft was a formidable challenge.

(Image courtesy of Boeing Commercial Airplane Group.)

COMPUTER-AIDED MANUFACTURING

Prior to the 777, aircraft parts were manufactured and assembled in large assembly buildings. If parts did not fit, change orders were issued to redesign and remanufacture the part. The Boeing 777 was preassembled digitally using solid, three-dimensional parts generated by computer. The computing power necessary for this effort was extremely high. Over 1,700 workstations were linked to a mainframe cluster of four IBM mainframe computers; this was the largest mainframe installation of its kind in the world at the time.

The innovative design approach had a number of advantages over traditional design/assembly methods. The approach allowed engineers to identify parts-fitting problems without the extensive use of physical models. In addition, design and manufacturing operations could occur concurrently. In fact, a number of parts for the craft were made by metalworking machines controlled directly from the design software. This approach, called *computer-aided design/computer-aided manufacturing* (CAD/CAM), greatly sped up the time from design to construction of the first aircraft.

A Boeing engineer designing a portion of the 777 (Image courtesy of Boeing Commercial Airplane Group.)

DIGITAL CLAY

The replacement of computer models for physical models is not limited to aircraft. Some automobile manufacturers have adopted "digital clay": computer representations of prototypes instead of clay models. The use of computer models allows designers all over the world to work on the same new car around the clock. The result is a cheaper, faster design. Volvo used digital clay to design a new station-wagon concept car. The company saved $100 million and cut the design time in half.

Returning to the CAD/CAM process, did Boeing use physical models or mathematical models for the 777? The answer is not readily apparent. Without a solid mock-up, you might say that the design used a very sophisticated mathematical model. However, when solid parts are generated digitally and allowed to interact, it is easy to argue that the design tool was as close to a physical model as you can get without the use of a milling machine. The design of the 777 represents the latest step in the blurring of the differences between mathematical and physical models. You can imagine a day where all physical models are holograms and the term "mathematical model" is no longer in use.

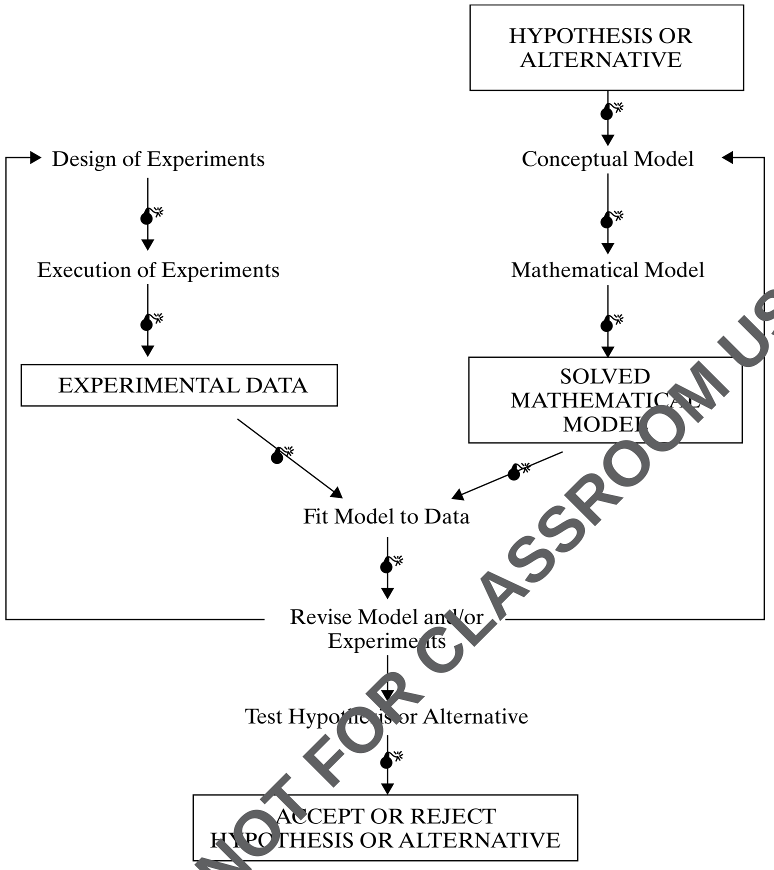


Figure 4. Interplay of Models and Data

4 USING MODELS AND DATA TO ANSWER ENGINEERING QUESTIONS

4.1 Interplay of Models and Data

Data collection is an important part of hypothesis testing and alternatives evaluation. The interplay of models and data is illustrated in Figure 4.

There are several steps to using models and data to answer questions. First, develop a conceptual model (see the upper right corner of Figure 4). An example conceptual model for the commuting problem was shown in Figure 2.

Second, translate the conceptual model into a mathematical model. A reasonable mathematical model might contain both deterministic elements (e.g., $t = d/v$) and stochastic elements (e.g., waiting time at traffic lights).

Third, solve the mathematical model. Note that experimental data may be needed to solve the mathematical equations. Why? Experiments may provide parameters needed for the model. As you may know from past experience, errors may occur during the solution of mathematical equations.

Key idea: Data are used to determine model parameters, and models influence the design of data collection activities.

On a parallel path with model development, you may gather data. Data may be used to determine model parameters (discussed in Section 4.3) or to compare model output with measured values. For example, you might measure the time required to reach school under a number of conditions and compare the measured values with the times predicted by the model. Note that *the model influences the design of experiments*.

For example, your model may include parameters such as hill slope and the number of stop signs. Thus, procedures must be developed to measure these parameters.

The interplay between modeling and data gathering is the engineer's friend. Data can point out errors in the model. A carefully constructed model may lead to the remeasurement of key parameters. The process shown in Figure 4 may have to be iterated several times until the model gives satisfactory results. The iteration process is the way that engineers refine their view of engineering problems and solutions.

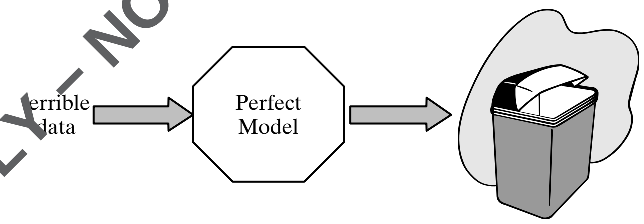
If the model fit is not satisfactory (see Section 4.4), then revise the model. In some cases, the experiments may require revision as well. If the model is revised incorrectly, errors can occur on the next iteration. For example, imagine that the output of the commuting model does not fit the data. After some thought, you conclude that wind resistance must be included in the model to account for the discrepancies. If the real culprit is an incorrect formulation of the waiting time probabilities, then the model revisions may not help.

4.2 Potential Errors

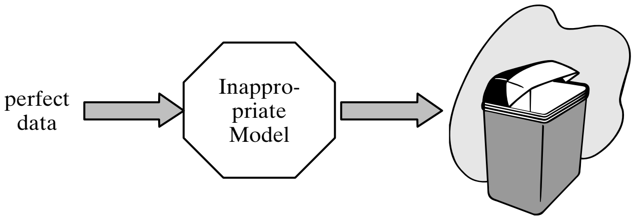
The bombs in Figure 4 indicate where errors could occur. The first chance for error comes in the formulation of the conceptual model. If the conceptual model is incomplete (i.e., if important variables, parameters, or forcing functions are left out), then the model will be a poorer representation of reality. In general, *models are limited in their usefulness by their scope and input data*. If the commuting time is influenced significantly by road construction and road construction is *not* included in the model, then the model will likely not predict the commuting time accurately. Similarly, if you make an error in measuring the hill slope, then the model output may be useless. In other words, we apply the term ***GIGO*** (garbage in, garbage out).

Key idea: Models are limited by their scope (i.e., the elements included or excluded) and the input data.

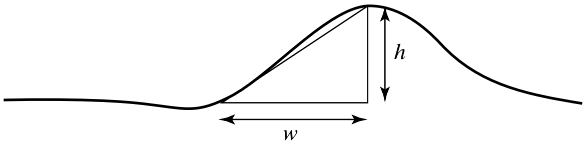
GIGO (garbage in, garbage out): the idea that model output will be meaningless if the model input data are poor



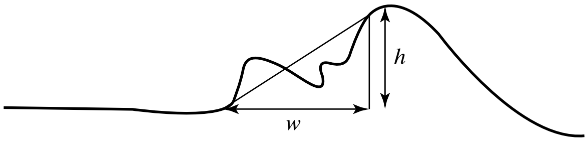
Errors also can creep in if the selected mathematical model is incompatible with the conceptual model. For example, if the conceptual model included the elements of acceleration and deceleration, then a constant-velocity model (such as $t = d/v$) would be inappropriate.



Errors can arise in experiments as well (see the bombs in Figure 4). Experiments can be improperly designed. For example, suppose you chose to determine the length of a road up a hill by measuring the hill height and hill length and by using basic trigonometry. This design is inappropriate if the hill is undulating.



length of road ≈ $(h^2 + w^2)^{\frac{1}{2}}$



length of road ≠ $(h^2 + w^2)^{\frac{1}{2}}$

The next step is to execute the experiments to gather the data. Again, errors can occur through improper execution. In the bicycling-to-school example, the stopwatch may be slow or the surveying equipment may be incorrectly calibrated.

4.3 Model Fits

Key idea: Fit the model to the data; **never** fit the data to the model.

Assuming the model and experimental errors are small, you now can compare the model output with the measured values. It is critical at this stage to *fit the model to the data rather than the data to the model*. **Never** exclude data because they do not fit your preconceived notions of what the data should look like. In other words, do not reject data just because the data does not match the model.[*]

What is meant by "fitting the model to the data"? Fitting a model means finding the values of the adjustable parameters so that the model output matches the experimental data as closely as possible. This process is called ***model calibration***.

model calibration: the process of finding the values of the adjustable parameters so that the model output matches the experimental data as closely as possible

There are a number of fitting tools used by engineers to calibrate models. In this text, a numerical approach will be introduced. Before discussing the fitting method, it is necessary to think about how you will know when the model output matches the data satisfactorily. A common approach is to formulate a function that describes the error in the model prediction and then pick adjustable parameter values to minimize the function. The objective then becomes to minimize the error. (The error function becomes the ***objective function***.) Say, for example, that the deterministic model has one independent variable x, one dependent variable y, and one parameter m. From experiments, you have n pairs of x and y values. The x values are denoted $x_1, x_2, \ldots, x_n$ and the y values are denoted $y_1, y_2, \ldots, y_n$. Since the model is deterministic, each value of x (i.e., each x_i) will give one predicted value of y (usually denoted $\hat{y}_i$ and pronounced "why eye hat").

objective function: a mathematical statement of the success of the project

One possibility for an objective function is the sum of the differences between the model predictions and the data. This is called the *sum of the errors* (or SE). For the n data points (i.e., n pairs of x_i and y_i), SE is given by

$$\text{SE} = \sum_{i=1}^{n} (y_i - \hat{y}_i)$$

An example of computing SE is given in Figure 5. For the data in Figure 5: $\sum_{i=1}^{3} (y_i - \hat{y}_i) = -3 + 2 + 0 = -1$.

---

[*] While you should not *reject* data that do not fit the preconceived model, sometimes it is appropriate to *question* data that do not fit the model. Models can be used to identify data that do not fit preconceived notions. If repeated measurements show that the original data are in error, then the original data are rejected. If the original data are *not* in error, then the model must be revised.

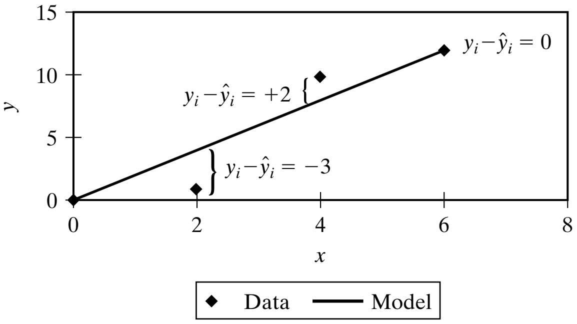


Figure 5. Example of Computing SE

PONDER THIS

Is SE a good measure of the differences between the model predictions and the experimental data?

SE is **not** a good measure of how well the model fits the data. Why? In SE, the “negative” errors (i.e., $y_i - \hat{y}_i$ less than zero) will cancel out “positive” errors (i.e., $y_i - \hat{y}_i$ greater than zero). For example, consider the data and model output in Figure 6. The model is $y_i = mx_i$. Model output is shown for $m = 2$. For this value of m, SE $= 0$ because the negative errors and positive errors cancel out. Even though SE $= 0$, it is clear from Figure 6 that the model $y_i = 2x_i$ is not a “perfect” model for the data.

There are many possible objective functions where the positive and negative errors do not cancel out (see Problem 2). A commonly used objective function is the *sum of the squares of the errors*, ***SSE***:

SSE: sum of the squares of the errors (square of the differences between the model output and data)

$$\text{SSE} = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \tag{1}$$

To fit a model to data, the mathematical problem becomes “Find the set of adjustable parameter values that minimize the SSE.”

To illustrate the use of SSE, consider an exciting new field of engineering: the use of *fractal geometry* to describe the dimensions of irregular objects. In common objects, the area (A) increases proportionally to the square of a characteristic length (l). Examples

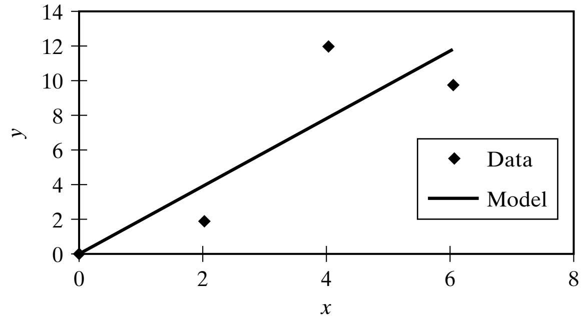


Figure 6. Example Model and Data to Illustrate Model Fit

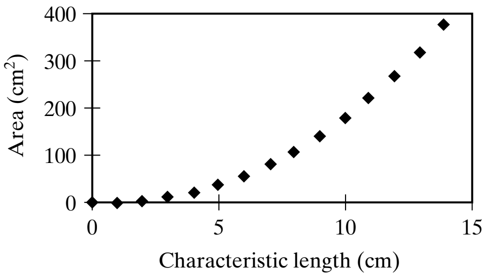


Figure 7. Data for Fractal Example

include circles (where $A = \pi r^2$; r = radius), spheres (where the surface area = $4\pi r^2$), squares (where $A = s^2$; s = side), cubes (where the surface area = $6s^2$), and equilateral triangles (where $A = \frac{\sqrt{3}}{4}s$). With fractal objects, A increases proportionally to l raised to the power n, where n is not necessarily equal to 2. Suppose you measure the area of a family of fractal objects and plot the area against the characteristic length (see Figure 7).

PONDER THIS

What is your model for the relationship between *l* and *A*?

The model is A = (proportionality constant)l^n. Suppose you know from other data that the proportionality constant is equal to 1. Thus, $A = l^n$. How would you find n? One approach would be to vary n and calculate the SSE. You can do this easily with a spreadsheet. Values of SSE are plotted against n in Figure 8. Note that the units of SSE are the units of the dependent variable squared.

PONDER THIS

What is your estimate of *n* from Figure 8?

Key idea: Select the values of the adjustable parameters to minimize the objective function (i.e., minimize SSE).

From Figure 8, SSE is minimized at n = 2.2–2.3. As shown in this example, the *values of the adjustable parameters should be selected so that SSE is minimized*.

The graphical approach of determining the values of the adjustable parameters that minimize SSE works well when your model has one adjustable parameter. The approach becomes more cumbersome with two adjustable parameters and virtually impossible to visualize with more than two adjustable parameters. A common approach to calibrating models containing more than one adjustable parameter is called *regression analysis*.

4.4 Using Calibrated Models

model fits: comparison of model output to the calibration data set

During model calibration, the values of the adjustable parameters are determined. In this process, the values of the dependent variables are calculated where data exist. For example, in the crate-drop example of Section 3.4, the values of the distance that the crate fell would be calculated for each time at which data were collected. These data are sometimes called the *calibration data set*. The model outputs for the calibration data set are called ***model fits***. You *expect* the model fits to be close to the data, because you are using the data to fit the adjustable parameters.

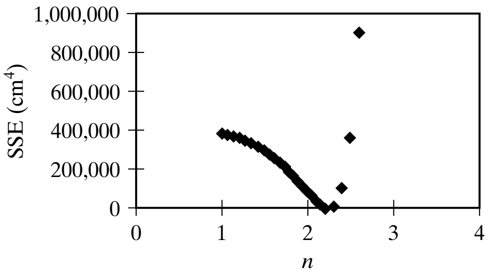


Figure 8. Variation of SSE with n in the Fractal Problem

model predictions: comparison of model output to data outside the calibration data set

If you compare the calibrated model output to other data (i.e., data outside the calibration data set), the model outputs are called ***model predictions***. Be sure to differentiate between model fits and model predictions in your engineering work. We want our models to be *predictive*; that is, they should predict data outside the calibration data set (but they have some limitations, as shown in Section 4.6).

4.5 Determining Model Fit

Another important issue in using models is determining how well the model fits the data. In fact, you already know one way to look at model fits: SSE. Unfortunately, SSE has a problem. It has units of (units of y)^2, so the magnitude of SSE depends on the units of y. Say you have a model relating the current in a photocircuit with light intensity. The photodiode produces a current in amps equal to a constant times the light intensity in watts. You calibrate the model twice with the same data set: once with current in amps and once with current in milliamps. The values of the SSE will be different even though the model is the same, as illustrated below:

Photodiode example: Data in watts and amps
model: current (A) = a (light intensity in watts)

Light Intensity (W)	Measured Current (A)	Predicted Current (in A, a = 0.3)	Error = measured − (A) predicted	Square of Error (A^2)
0	0	0	0	0
1	0.2	0.3	−0.1	0.01
2	0.6	0.6	0	0
5	1.7	1.5	+0.2	0.04

SSE = 0.05 A^2

Photodiode example: Data in mW and mA
model: current (mA) = a (light intensity in mW)

Light Intensity (mW)	Measured Current (mA)	Predicted Current (in mA; a = 0.3)	Error = measured − predicted (mA)	Square of Error (mA^2)
0	0	0	0	0
1,000	200	300	−100	10,000
2,000	600	600	0	0
5,000	1,700	1,500	+200	40,000

SSE = 50,000 mA^2

As this example shows, SSE would be more useful if it is dimensionless. One way to make SSE dimensionless is to compare your model with the simplest model for your dependent data.

PONDER THIS

What is the simplest possible model for *any* data?

The simplest model for a dependent variable y is $y = \text{constant}$. A reasonable value of the constant is the arithmetic mean of the y values. Thus, the simplest model is

$$y = \bar{y}$$

A more useful measure of model fit would be

(SSE for your model)/(SSE for the simplest model), or

(SSE for your model)/(SSE for the model $y = \text{mean } y$)

In mathematical terms, this new measure is

$$\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

***correlation coefficient* (r^2):** a dimensionless measure of the degree of fit of a model to data ($r^2 > 0.9$ is good)

This new measure is equal to zero when the model is perfect ($SSE = 0$) and is equal to one when the model is no better than the simplest model ($y = \text{mean } y$). This is okay, but it would be nice to have a measure that is equal to one when the model is perfect and is equal to zero when the model is no better than the simplest model. This is accomplished by defining the ***correlation coefficient*** r^2:

$$r^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{2}$$

The correlation coefficient is a very valuable measure of the degree of fit of *any* model. It is dimensionless and near one if the model fits the data well. You can verify for the data in Figure 6 that r^2 is equal to 0.98, indicating a good fit ($r^2 > 0.9$ generally represents a good fit of the model to the data).

4.6 Are Engineering Models Real?

Key idea: When using models, remember that (1) the final model is only as good as the underlying conceptual model and resulting mathematical model, (2) models should not be used outside their calibration range, (3) engineers should not be misled by a good model fit, and (4) model output must be interpreted.

It is easy to become overly enamored with models and model output. Sometimes engineers come to believe that the calibrated model represents the truth and that data and model interpretation just get in the way.

You should remember four points about using engineering models. First, the final model is only as good as the underlying conceptual model and resulting mathematical model. As discussed in Section 4.2, models cannot predict behavior missing from the conceptual model.

Second, take great care not to use models outside the range of the independent variable for which the model has been calibrated. As an example, consider the prediction of the trajectory of a projectile (Figure 9). At short times, the height appears to be proportional with time. An extrapolation of the data at short time (≤ 6 seconds) is

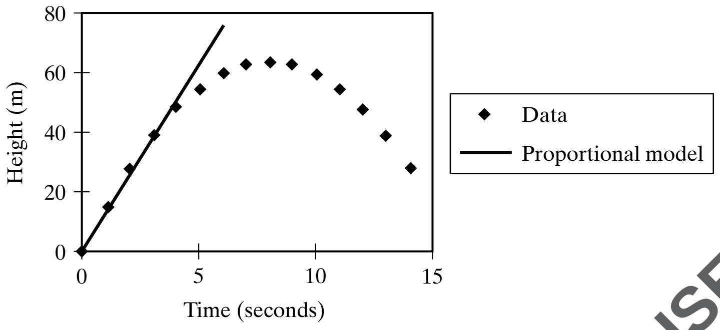


Figure 9. Example of an Extrapolated Model

shown by the line in Figure 9. The proportional model fits the data used to calibrate the model well. However, extrapolation of the model output *beyond* six seconds gives the wrong picture of the flight of the projectile. Predictions made by the proportional model outside the range of calibration could be disastrously wrong.

Third, do not be misled by good model fit. It is incorrect to assume that the model is "good" just because it fits the data. The classic example of an incorrect but good-fitting model is the Ptolemaic model of the galaxy. Claudius Ptolemy (ca. 100–ca. 170) proposed in the second century that the Earth was the center of the universe. The motion of the planets was described by circular orbits called *epicycles* as the planets orbited the Earth. More and more layers of epicycles were added to explain the observations as measurement techniques improved. In its final form, the Ptolemaic model was a mishmash of epicycles based on a flawed premise (i.e., an Earth-centered universe), but it fit the observed data remarkably well. In fact, the Copernican Sun-centered model (after Nicholas Copernicus, 1473–1543), although correct, did not fit the observations as well as the Ptolemaic model! The bottom line: do not assume that good-fitting models are "real."

Fourth, model output must be interpreted. Models are only part of the analysis or design process. It is important to realize that you must use the results of models *in conjunction with other information* to make conclusions about alternatives. The "other information" may be other types of feasibility.

5 SUMMARY

Engineers often rely on models to conduct analysis or to evaluate alternatives. Models are used to organize ideas, simulate expensive or critical systems prior to construction, and probe the response of a system to a large number of conditions ("what if" scenarios).

Three types of models are used in engineering. First, *conceptual models* contain the main elements of the model (boundaries, variables, parameters, and forcing functions) and how they interact. Second, a *physical model* is usually a smaller version of the full-scale system. Finally, *mathematical models* represent systems in terms of logical and quantitative relationships and are of two types. *Deterministic models* provide one output for each set of inputs. *Stochastic models* contain variables or parameters with probability distributions and therefore predict a probability of a certain outcome with a given set of inputs.

Models and data interact. As mentioned earlier, model parameters may be measured through experiments. In addition, models may identify key variables and parameters, thereby influencing the design of experiments. If the model predictions do not match the measured values satisfactorily, then both the model and experiments may need to be revised. Although numerous opportunities for errors exist, the interplay of models and data aids in developing models that adequately describe natural and engineered systems.

When using models, remember that the final model is only as good as the underlying conceptual model and resulting mathematical model. In addition, take great care in using models outside the range of the independent variable for which the model has been calibrated. Finally, do not be misled by good model fit in interpreting model results.

SUMMARY OF KEY IDEAS

- Types of engineering models include conceptual, physical, and mathematical models.
- Engineers use models to organize ideas, simulate expensive or critical systems prior to construction, and probe the response of a system to a large number of conditions.
- Data are used to determine model parameters, and models influence the design of data collection activities.
- Models are limited by their scope (i.e., the elements included or excluded) and the input data.
- Fit the model to the data; **never** fit the data to the model.
- Select the values of the adjustable parameters to minimize the objective function (i.e., minimize SSE).
- When using models, remember that (1) the final model is only as good as the underlying conceptual model and resulting mathematical model, (2) models should not be used outside their calibration range, (3) engineers should not be misled by a good model fit, and (4) model output must be interpreted.

Problems

1. Develop a conceptual model for a device to screen airline passengers for concealed weapons. Include the boundaries, variables, parameters, and forcing functions.
2. List two objective functions other than SSE where the positive and negative errors do not cancel out. Discuss the advantages and disadvantages of your objective functions compared with SE and SSE.
3. Use the Internet to find a picture and description of a bridge of interest to you. Build a physical model of the bridge using everyday materials (e.g., Popsicle sticks). What characteristics of the actual bridge does your bridge model well? What characteristics of the actual bridge does your bridge model poorly?
4. Develop a mathematical model to calculate how deeply a ship will sit in the water. (*Hint*: Perform a force balance, where the buoyancy force is proportional to the mass of water displaced by the ship. Develop your model for a specific geometry of the ship.)
5. Collect data of the height and weight of 10 friends. Develop an empirical model relating their height and weight.

6. For the data below, find the slope and intercept relating two hardness scales for steel, the Brinell number and the Vickers number. Calculate the correlation coefficient and comment on the applicability of the linear model for the data given.

Brinell Number	**Vickers Number**
780	1,150
712	960
653	820
601	717
555	633

7. Thermistors are semiconductors used for measuring temperature. The electrical resistance of a thermistor changes with temperature. One model for the effect of temperature on a specific thermistor is $R = 2{,}252e^{4000\left(\frac{1}{T}-\frac{1}{298.16}\right)}$, where R is the resistance in ohms and T is the temperature in K. You can verify that this thermistor has a resistance of 2,252 Ω at 25°C = 298.16 K. For the data below, calculate the correlation coefficient for the model and decide whether the model fits the data well or not.

Temperature (°C)	**Resistance (Ω)**
0	7,850
10	4,400
20	2,900
30	1,500
40	1,000

8. The number of transistors on processor chips has doubled every 18 months or so for at least the last 30 years. This doubling sometimes is called *Moore's Law* (after Intel founder Gordon Moore). For the data on Intel processors below, determine the doubling time that minimizes the SSE. Decide whether the model (with your fitted doubling time) fits the data well or not.

Processor	**Year of Introduction**	**Number of Transistors**
4004	1971	2,250
8008	1972	2,500
8080	1974	5,000
8086	1978	29,000
286	1982	120,000
386	1985	275,000
486 DX	1989	1,180,000
Pentium	1993	3,100,000
Pentium II	1997	7,500,000
Pentium III	1999	24,000,000
Pentium 4	2000	42,000,000

9. One example of 3-D printing (Section 3.5) is printable prescription lenses. Printable lenses, developed by Saul Griffith (winner of the 2004 Lemelson–MIT Student Prize), may be used to provide low-cost eyeglasses for less-developed regions. Write a short report about printable prescription lenses.
10. What is the difference between stochastic and deterministic models? Give an example of each in the engineering field of your choice.

Introduction to Technical Communications

1 INTRODUCTION

Some people think the term *technical communications* is a contradiction in terms. Technical information, they say, is just numbers. They may snicker that engineers are not always natural after-dinner speakers. Why spend your time on the presentation side of things when some engineers are more comfortable grinding out the numbers?

People with these attitudes are sadly misinformed. Engineering often results in complex answers that need to be communicated simply and effectively. The truth is that *engineering work has no impact unless the message is delivered successfully*.

Technical presentations also must "tell a story." The conclusions of the story, of course, must be supported by data and solid reasoning. In evaluating your own technical writing or technical presentations, it is always important to ask yourself, Has the audience understood my story?

The purpose of this chapter is to introduce you to the importance of technical communications (Sections 2 and 3) and present ground rules common to all technical communication (Sections 4 through 9). In Section 4, the important questions you should answer before you start writing your report or technical talk will be discussed. Some techniques for organizing the presentation material will be presented in Section 5. In Sections 6, 7, and 8, you will learn in detail the ways that data are presented, including the design and construction of tables and figures. Section 9 discusses creativity in technical presentations.

You will notice some new terminology in this chapter. The recipients of the presentation will be referred to simply as the "audience," since the recipients could be either *readers* of your technical document or *listeners* of your technical talk. The word "presentation" will include both written documents and technical talks.

SECTIONS

OBJECTIVES

After reading this chapter, you will be able to:

- explain why technical communication skills are important to engineers;
- list common misconceptions about technical communication;
- discuss how the presentation goals, the target audience, and the constraints shape technical communication;
- devise an outline for a technical presentation;
- use tables and figures to communicate technical information effectively.

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2 ROLE OF TECHNICAL COMMUNICATION IN ENGINEERING

2.1 Technical Communication as a Professional Skill

Your interest in engineering may have been fueled by the important role of engineers in society and the challenges that engineers face every day. Take a moment to make a mental list of what engineers do.

PONDER THIS

What activities do engineers perform?

Key idea: Technical presentations must tell a story; always ask yourself whether the audience understood your story.

Your list may include activities such as designing, modeling, testing, building, and optimizing. While most engineers do at least one of these activities *some* of the time, all engineers communicate *all* the time. In a real sense, engineering is not engineering until you, the engineer, successfully communicate the results to someone else. Technical communication is not effective unless the audience understands the message you wish to deliver.

2.2 Technical Communication and Employment

Key idea: Strong technical presentation skills aid in obtaining a job and in advancing a career.

If you remain unconvinced of the importance of technical communication, consider a more practical reason to improve your communication skills. Engineering faculty frequently receive telephone calls requesting information about students (or former students) applying for jobs. Nearly every potential employer asks two questions: Can the person *write* effectively? Can he or she *speak* well? Potential employers ask these questions because they know that engineers spend a great deal of their time communicating. The result of a survey of graduates from the University at Buffalo's School of Engineering and Applied Sciences showed that respondents spent an average of *64% of their working hours* on written communication, oral presentations, and other oral discussions. To compete for employment opportunities, engineers must develop strong technical communication skills. Technical excellence is necessary (but not sufficient) to secure a good job in today's employment market.

Technical communication skills affect not only your ability to get a job, but also your ability to progress in your profession. In a survey cited by Paradis and Zimmerman (1997), over half of the research and development engineers and scientists polled (and 71% of the managers) knew of cases where technical communication skills had a serious impact on a person's career. Respondents to the University at Buffalo survey indicated that good technical communication skills can make the difference between receiving a raise and not receiving a raise. Good technical communication skills are prerequisites for success in your career.

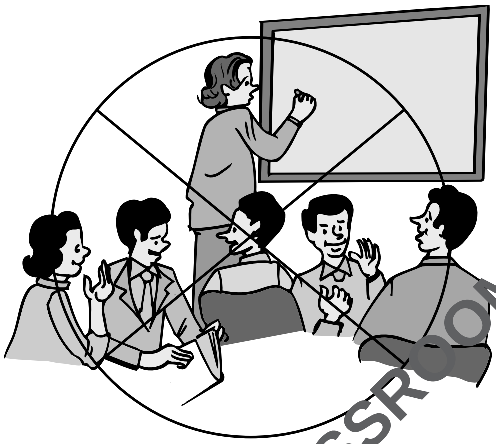
3 MISCONCEPTIONS ABOUT TECHNICAL COMMUNICATIONS

Few areas of the engineering profession are more poorly understood or more underappreciated than technical communication. Common misconceptions are discussed in the next several sections.

3.1 Misconception #1: Technical Communication Is Inherently Boring

Key idea: Technical communication is a creative process.

Some people feel that engineers excel in dry facts and even drier numbers. How can an engineer possibly communicate creatively? The truth is that designing effective communication strategies is one of the most creative activities in engineering. Technical communication does not mean linking dull facts to form a sleep-inducing document or boring oral presentation. Today, engineers have many tools at their disposal for communicating ideas: everything from sketches on the back of a napkin to 3-D visualization techniques to Internet-based teleconferencing. Effectively communicating technical work is a challenging part of the optimization process that lies at the heart of engineering. Creativity in technical communication is discussed in more detail in Section 9.



Technical talks are *not* inherently boring.

3.2 Misconception #2: Engineering Communication Is Passive

Key idea: Technical communication is usually meant to be persuasive.

Many people think of technical communication as flat and one-sided. In this view, technical speakers and writers lay out a smorgasbord of facts that the audience records passively (as in a poorly designed lecture). In truth, much technical communication is both interactive and *persuasive*. Engineers often try to convince others of their point of view. Facts and figures rarely speak for themselves. They require thoughtful presentation to convince people of their worth.

3.3 Misconception #3: Technical Communication Is Best Left to Nonengineering Specialists

Key idea: Engineers can benefit from communication specialists, but the engineer must take responsibility for making sure the correct message is delivered.

In your career, you will benefit from working with many other professionals. Engineers often work collaboratively with communication specialists, such as technical writers and graphic designers. However, *you as the engineer are always responsible for making sure that the technical information is communicated clearly and concisely to the intended audience*. Remember, all your work (whether in a homework assignment or the design of a multimillion-dollar facility) is for naught if the intended audience does not understand your message. Taking control of the message is as important as taking control of the design calculations.

3.4 Misconception #4: Good Technical Communicators Are Born, Not Made

Key idea: All engineers can improve their technical communication skills.

It is true that not all of us will mesmerize* our audiences each time we stand before them or each time we put pen to paper. However, each of us can improve our speaking and writing skills *every time* we set out to communicate with our peers and others. Specific steps for honing your technical communication skills will be presented in Sections 4 through 9. Whatever level of comfort you have now with public speaking and technical writing, *know that you can improve your communication skills throughout this semester, throughout your university days, and throughout your career*.

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*The word "mesmerize" comes from the Austrian-born physician Friedrich Anton Mesmer (1734–1815), who popularized the idea that doctors could induce a hypnotic state by manipulating a force he called "animal magnetism."

4 CRITICAL FIRST STEPS

Before you write a single word of a technical presentation, three elements must be identified clearly: the goals of the presentation, the target audience, and the constraints on the presentation. Each of these elements will be discussed in more detail in this section.

4.1 Presentation Goals

Key idea: Before preparing a technical presentation, write down the goals of the presentation.

One of the most important activities in the design of any technical talk or document is the identification of the *presentation goals*. It is absolutely critical to know what you are trying to accomplish in a presentation. The presentation will fail unless its goals are identified. Why? First, you cannot decide what information should be presented (or how to present it) unless you have described the objectives thoughtfully. Second, you need to know the goals to evaluate whether or not you have communicated the ideas successfully. In fact, *every* engineering project requires objectives so that the success of the project can be determined at its conclusion.

You should write out the presentation goals. For example, you might write, "The goal of the lab write-up is to tell the professor about the experimental methods employed, the results obtained, and the answers to the three discussion questions." This goal allows you to decide what should go in the lab write-up and how the material should be prioritized. Also, you now have a tool to judge whether your write-up was successful. You could compare the completed lab report with the goal to see if you met the goal. Remember, *a goal not written down is just a dream*.

4.2 Target Audience

target audience: the intended recipients of the information to be presented

The presentation goal should identify the ***target audience***. The target audience consists of the intended recipients of the information you are presenting.

PONDER THIS

What is the target audience of this text?

Although professors order the text and professionals may read it, the target audience of this text is freshman engineering students.

As with presentation goals, identification of the target audience is critical to the success of your presentation. In your career, you will give oral and written presentations to many audiences, including colleagues (i.e., fellow engineers), managers, elected officials, students, and the general public. You must keep the background and technical sophistication of the target audience in mind when developing your presentation material. For example, you would not use the same approaches to communicate a bridge design to a city council as you would to communicate the same ideas to a professional engineering society.

Key idea: Identify the target audience (and their technical sophistication, interests, and backgrounds) before preparing a technical presentation.

The interests and backgrounds of the audience are as important as their technical sophistication. Each audience member will interpret the presentation through his or her own point of view. To engage the audience fully, you must know the backgrounds of its members. As an example, consider the choices available to an engineer presenting an idea for a new computer design. For an audience of managers and corporate executives, she may wish to emphasize the low cost and high profit margin of the new personal computer. For fellow engineers, she would likely focus on the technical specifications and performance data. Subtle changes often can make the presentation match the interests and background of the audience more closely.

4.3 Constraints

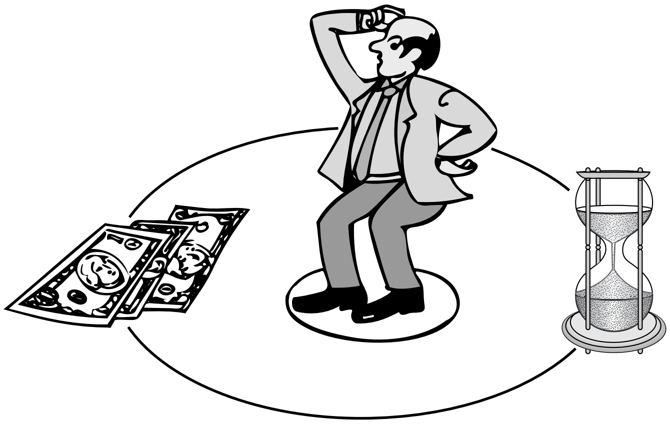
Identification of *constraints* on the presentation also is important. Engineering, like life, is a constrained optimization problem. Similarly, technical presentations almost always are

Know your audience

Key idea: Before preparing a technical presentation, quantify the constraints on the presentation (i.e., length limits, your time, and other resource limitations).

constrained. Common constraints are *presentation length* (page limits for written documents or time limits on oral presentations) and *resource limitations* (e.g., your time or money for photographs or specialized graphics). It is very important to heed the presentation length constraints. In oral presentations, going well over or under the allotted time limit is rude and unprofessional. With technical documents, many engineering proposals (and term papers) have gone unread because they exceeded the imposed page limit.

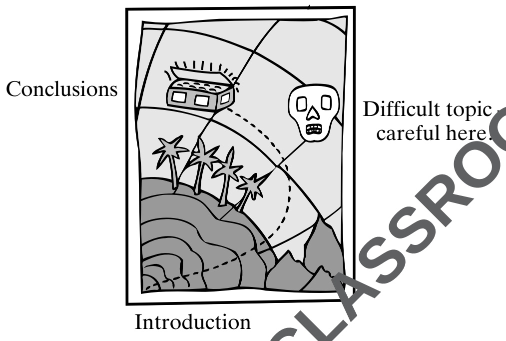
The resources required for technical presentations cannot be ignored. As a student, you know you must allocate time for *writing* a term paper as well as time for reading about the term paper topic. Similarly, practicing engineers learn to budget time for report preparation. Other resources required to produce a high-quality technical document (or oral presentation) include money for personnel, graphics creation, printing, reproduction, and distribution.



Common constraints on technical communication: time and money

5 ORGANIZATION

Once you have identified the goals, target audience, and constraints, you can begin to write the presentation. Technical documents and talks can be made or broken on their degree of organization. In a well-organized presentation, the audience always knows where in the presentation they are and where they are going. There are two keys to creating an effectively organized presentation: *structuring the material* and *showing your structure* to the audience.



Organization is the map that guides your audience through the presentation.

5.1 Outlines

outline: a list of the major headings and subheadings in the presentation, showing the order of the main ideas and showing the secondary topics supporting the main ideas

The primary tool used to structure a presentation is the ***outline***. An outline is a structured (or hierarchical) list showing the skeleton of the presentation. An example is shown in Example 1.

The purpose of the outline is to divide the presentation into manageable pieces. An outline shows three elements of the presentation:

- The main ideas (listed in the outline as major headings)
- The order of the main ideas
- The secondary topics (subheadings) that support and flesh out the main ideas

The main ideas, of course, depend on the goal of the presentation and the audience.

EXAMPLE 1
OUTLINE

Write an outline for a technical presentation on computer-aided manufacturing (CAM) in the production of aircraft.

SOLUTION

An example outline, with the parts of the outline labeled, is as follows:

Computer-Aided Manufacturing (CAM) in Aircraft Production

I. Introduction [major heading]
II. Background
    A. History [subheading]
    B. Contemporary examples
    C. Current problems

III. Use of CAM in Aircraft Production
    A. CAM principles
    B. Applications
        1. potential barriers [subheading]
        2. examples
    C. Future trends
IV. Conclusions

Key idea: To organize a presentation, structure the material using an outline and show the structure to your audience.

The outline is a wonderful tool for organizing a presentation. It shows at a glance the relationships between parts of the document or talk. The outline helps you to see if the presentation is balanced; that is, whether the level of detail in a certain part of the presentation corresponds to the importance of that part in achieving your goals. The outline also helps determine the needs for more data or more presentation tools (i.e., more tables and figures). An outline can be changed easily as the presentation evolves. In fact, as the outline is annotated (that is, as more levels of subheadings are added), the document or oral presentation will nearly write itself.

signposting: indicators used to show the audience where they are in the presentation

5.2 Signposting

Organizing a presentation is only half the battle. You also must *let the audience know* that you are well organized. Showing the audience that you are organized is called ***signposting***. An example of signposting is the headings used in this text. The consistency of the headings tells you where you are in the text:

Chapter title: 32 point Futura font, with the initial letters capitalized

Example: Introduction to…

Section titles: 11-point Copperplate30ab font, all caps

Example: 5 ORGANIZATION

Subsection titles: 11-point Futura Book font, initial letters capitalized

Example: 5.2 Signposting

6 USING TABLES AND FIGURES TO PRESENT DATA

Nearly every technical presentation you develop will contain data. The number of ways of presenting quantitative information is limited only by your imagination. However, some data presentation tools are more appropriate in a given situation than others.

6.1 Use of Tables and Figures

The two main ways to present numbers are *tables* and *figures*. Tables are used when the *actual values are important*. For example, a table would be an excellent way to show the estimated construction, operation, and maintenance costs for three polymer extruder designs. In this case, the exact costs are important and the audience wants to see the numbers.

Key idea: Use tables when actual values are important; use figures to show trends in the data.

On the other hand, figures are used to *show trends in the data*: that is, to show the relationships between variables. For example, suppose you collect data on the movement of an artificial limb in response to stimuli of varying voltage. A figure would be an appropriate way to show the trend in the dependent variable (here, the limb movement) as a function of the independent variable (here, the applied voltage).

6.2 Common Characteristics of Tables and Figures

Key idea: Tables and figures should have a number (by which they are referred to in the text) and a short, descriptive title.

While tables and figures are very different, they share several features. First, every table and figure in a technical document must have a number. Many numbering schemes are possible (e.g., "Table 1" or "Figure 4.2" or "Table II" or "Figure C"), but table and figure numbers are essential in technical writing. Why number your tables and figures? A number allows the figure or table to be *referred to* from the text. For example, in the text, you may write

> In Figure 2.3, the average wait time at the stoplight is plotted against the daily pedestrian traffic.

Remember, *do not include a table or figure in a technical document that is not referred to by number in the text*.

Second, every table and figure in a technical document must have a title. Titles are needed to give the audience a short description of the content of the table or figure. Titles should be concise and descriptive. They need not be complete sentences. Examples of table and figure titles are listed in Table 1. The numbers and titles appear together either at the top or bottom of the table or figure. Commonly (but not universally), table titles are placed at the *top* of tables and figure titles are placed at the *bottom* of figures. (Note that Table 1 has a number and title located together at the top of the table. Also, Table 1 was referred to in the text, so you knew when to look at it.)[*]

Key idea: Tables and figures must be interpreted in the text.

Third, tables and figures must be *interpreted*. This means that you should discuss the table or figure in the text. To continue the example at the beginning of Section 6.2, you may write

> In Figure 2.3, the average wait time at the stoplight is plotted against the daily pedestrian traffic. Note that the average wait time increases from baseline only when the pedestrian traffic exceeds 150 people per day.

Many inexperienced technical writers make the mistake of simply throwing the data at the audience rather than *presenting* the data. They write

> The data from the first study are shown in Figure 2.3. A second study was conducted in May 2005.

You included the table or figure for a reason. To satisfy that reason (and help you achieve your presentation goals), you need to guide the audience through the interpretation of the data in your tables and figures.

Key idea: Include units in the row or column headings of tables and the axes of figures.

Fourth, units must be listed for all data in tables and figures. In tables, units usually accompany the column or row headings. In figures, the axes must be labeled with units shown. You may want to take a moment and look through this text for examples of tables and figures with units in the headings or axis labels.

TABLE 1 Examples of Poor and Improved Table and Figure Titles

Poor Title	Problems with Poor Title	Improved Title
Table 2: Experimental Data	too vague: what data will the table contain?	Table 2: Ergonomic Data for Three Automobile Seat Designs
Figure 4.2: Problems with Acid Rain	insufficient detail: figure titles usually list the dependent and independent variables	Figure 4.2: Effects of pH on the Survivorship of Brown Trout in Lakes Receiving Acid Rain
Figure A.32: Current vs Voltage	insufficient detail: lists *only* the dependent and independent variables without putting the information in context	Figure A.32: Current–Voltage Curves for Four Electrode Configurations

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[*] The astute reader will notice that some pictures in this text have no title and are not referred to in the text. An example is the cartoon labeled "Know your audience" in Section 4. The use of such pictures for illustrative purposes is common in textbooks and reflects the fact that the target audience of the text is students.

7 TABLES

Key idea: In tables, list the independent variables in the leftmost columns.

As stated previously, tables are used to present data when the actual values are important. Tables should be limited to the minimum number of columns needed to show the relevant data. In general, independent variables are listed in the first or leftmost columns, with dependent variables listed in the columns to the right.

With today's software, it is easy to create tables with myriad types of lines, shadings, colors, and font styles. However, these devices should be used sparingly and consistently. Each table has a goal; "bells and whistles" should be used only to make your point clearer.

An example table is given in Table 2.

PONDER THIS

Critique Table 2.

Table 2 is well constructed. Note that it is numbered and has a descriptive title. The independent variable (reinforcing bar type) is listed first. Units are given for all data (i.e., for every column). Lines are used minimally and mainly serve to separate the table from the surrounding text.

To demonstrate the importance of the order of the columns, examine Table 3. Table 3 contains the same data as Table 2, but the column order has been changed. Note how difficult it is to interpret Table 3. Even though the most important information probably is the weight, placing a dependent variable first does not communicate the information very effectively.

Table 4 demonstrates the potential for distractions in table design. The use of many fonts, lines, and types of shading adds little to the message and can be distracting.

TABLE 2 Characteristics of Standard Steel Reinforcing Bars

[*Caution:* Table may contain errors! See text for discussion.]

Type	Diameter (in)	Weight (lb/ft)
#2	0.250	0.167
#3	0.375	0.376
#4	0.500	0.668
#5	0.625	1.043
#6	0.750	1.502

TABLE 3 Characteristics of Standard Steel Reinforcing Bars

[*Caution:* Table may contain errors! See text for discussion.]

Weight (lb/ft)	Type	Diameter (in)
0.167	#2	0.250
0.376	#3	0.375
0.668	#4	0.500
1.043	#5	0.625
1.502	#6	0.750

TABLE 4 Characteristics of Standard Steel Reinforcing Bars

[*Caution*: Table may contain errors! See text for discussion.]

Type	Diameter (in.)	Weight (lb/ft)
#2	0.250	0.167
#3	0.375	0.376
#4	0.500	0.668
#5	0.625	1.043
#6	0.750	1.502

8 FIGURES

Key idea: Use scatter (*x*–*y*) plots when the independent variable is continuous.

Recall that figures are used when the relationships between variables are important. There are three common types of figures used in technical presentations: scatter (or *x*–*y*) plots, bar charts, and pie charts.

8.1 Scatter Plots

scatter (x–y) plot: a type of plot using symbols or lines that is employed when the independent variable is continuous

Key idea: In general, use symbols for data and lines for calculated values (i.e., model output).

The ***scatter plot*** (or ***x*–*y* plot**) is the most common type of graph in technical work. It is used when the *independent variable is continuous*; that is, when the independent variable could take any value. Examples of continuous variables are time, flow, and voltage. In the scatter plot, the independent variable is plotted on the *x*-axis (also called the *abscissa*) and the dependent variable is plotted on the *y*-axis (also called the *ordinate*). In general, symbols are used for data and lines are used for calculated values (i.e., for model fits or model predictions). An example of a scatter plot is shown in Figure 1.

PONDER THIS

Critique Figure 1.

In Figure 1, the independent variable (vapor pressure) is continuous. Thus, a scatter plot is appropriate. Note the important elements: figure title (here, at the bottom of the figure), axis titles with units, tick marks (small lines) near axis labels, and symbols that represent data. If more than one dependent variable were plotted, a legend would

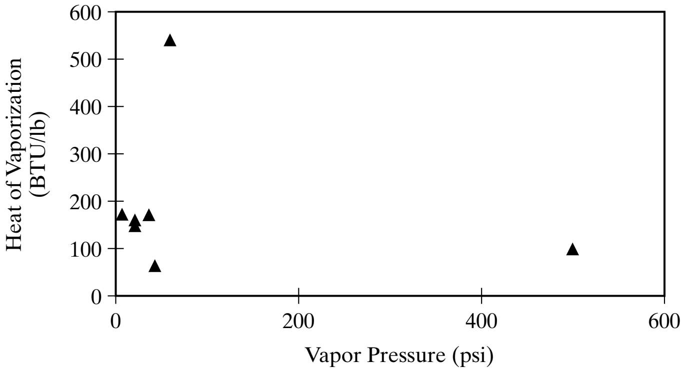


Figure 1. Heat of Vaporization of Some Common Refrigerants [*Caution*: Figure may contain errors! See text for discussion.]

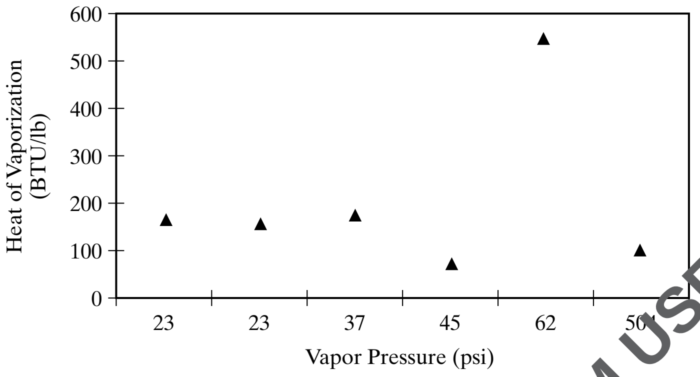


Figure 2. Heat of Vaporization of Some Common Refrigerants [*Caution*: Figure may contain errors! See text for discussion.]

Key idea: Use the line chart type carefully in technical presentations (or, better yet, avoid it completely).

be necessary. Note that *a legend is not necessary if only one dependent variable is plotted*. (Legends are discussed with bar charts in Section 8.2.)

One final note on scatter plots. Most common graphing programs (including Microsoft Word, Microsoft Excel, Corel WordPerfect, and Corel QuattroPro) have a figure type (also called a *chart type*) called "line." With the line chart type, the *x* data points are spaced evenly, *regardless of their values*. The data in Figure 1 are replotted as a line chart in Figure 2. Notice that the relationship between heat of vaporization and vapor pressure appears to be distorted in the line chart. There are almost no cases where the line type is the *best* way to present technical data. It is recommended that *you avoid the line chart type completely*.

8.2 Bar Charts

bar chart: a type of plot using bars that is employed when the independent variable is not continuous

Key idea: Use bar charts when the independent variable is not continuous.

Bar charts are used when the independent variable is discrete (i.e., not continuous). Discontinuous independent variables are common in engineering. For example, you may wish to show how the properties of magnets vary with material type or how energy efficiency varies with industry category. The type of material or category of industry is a discrete variable and the use of a bar chart is appropriate.

legend: a listing of the property represented by each symbol, bar, or line

An example of a bar chart[*] is given in Figure 3. Note the descriptive title, inclusion of units, and tick marks on the *y*-axis. Tick marks generally are not used on the *x*-axis in bar charts with vertical bars, since the tick marks would interfere with the bars. Note also in Figure 3 that two *y*-axes are used. Multiple *y*-axes are useful when the independent variables have different units or vastly different scales.

In Figure 3, two variables are plotted; therefore, a legend is required. A ***legend*** tells the audience the meaning of each symbol, bar, or line. In this case, the legend tells you that the white bar represents the resistivity and the black bar represents tensile strength.

Key idea: In figures, select the axis ranges to encompass all the data without distorting the relative values.

In both scatter and bar charts, you must select the ranges of the axes carefully. Clearly, the ranges must be selected to encompass all data. In addition, it is generally a good idea to start the *y*-axis at zero.[†] Why? Starting at zero gives the audience a better view of the relative values of your data. In Figure 3, for example, it is obvious that the tensile strength of silver is about twice that of gold. If the data are replotted using smaller ranges for the *y*-axes, a skewed view of the relative resistivities and tensile strengths is created (see Figure 4). For example, the tensile strength of silver appears to be about five times that of gold in this figure.

---

[*] The common name for the plot in Figure 3 is a bar chart. Some software packages call it a *column chart* if the bars are vertical and a *bar chart* if the bars are horizontal.

[†] Do not, of course, start the *y*-axis at zero if you have negative *y* values. Also, avoid starting the *y*-axis at zero if the *y* values cluster around a large value.

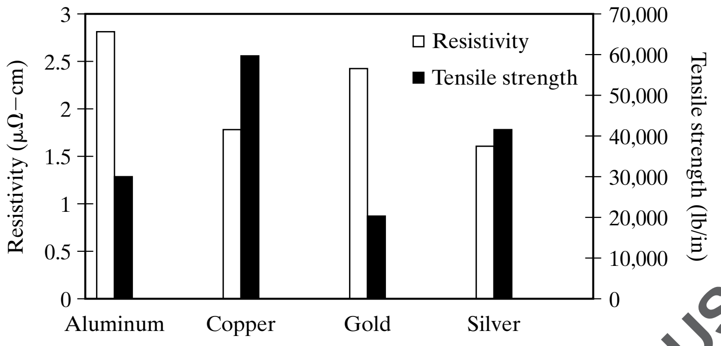


Figure 3. Physical Properties of Conductors

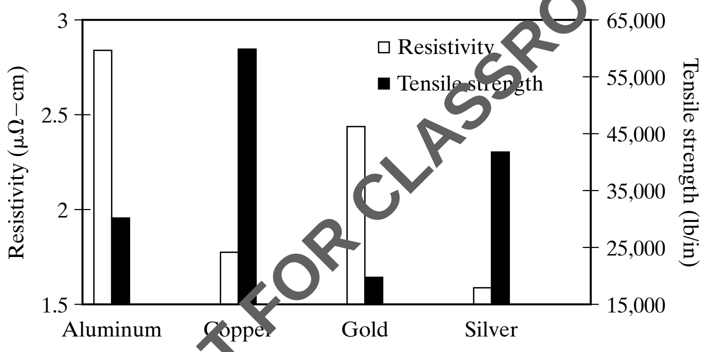


Figure 4. Physical Properties of Conductors [*Caution*: Figure may contain errors! See text for discussion.]

Key idea: Do not accept the default table or figure produced by the software without questioning whether it meets your objectives.

This lesson can be extrapolated. In general, *do not let the software pick the look of your tables and figures*. Always look critically at the default table or figure produced by the software package. Use your judgment: edit tables and figures to best meet your presentation goals.

pie chart: a type of plot using pie slices that is employed to show the relative contributions of several factors to a whole.

Key idea: Use pie charts to show relative contributions.

8.3 Pie Charts

Pie charts are used to show the relative contributions of several factors to a whole. In most cases, pie charts are used to show percentages. Thus, pie charts have no independent variable. Although pie charts are not used very frequently in engineering, they can show the relative importance of discrete factors very effectively.

An example of a 3-D pie chart is shown in Figure 5. The slices of the pie may be defined with a legend or labels.

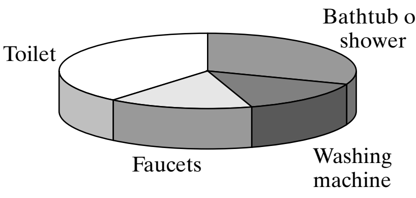


Figure 5. Water Use in the Home

An example of how the design of a figure may influence engineering decision making is shown in the *Focus on Figures: Of Plots and Space Shuttles*.

FOCUS ON FIGURES: OF PLOTS AND SPACE SHUTTLES

The explosion of the Space Shuttle *Challenger* on the cold morning of January 28, 1986, rocked the world. Subsequent investigation into the disaster pointed to the likely cause: hot gases from fuel combustion bypassed two seals, leading to the destruction of the booster segment and the loss of the lives of all seven astronauts. The booster segments were sealed with O-rings made out of a rubber-like material called Viton®. The two O-rings (primary and secondary) protected the segments from the combustion gases. The primary O-ring was closest to the fuel.

The *Challenger* disaster is often discussed as an example of engineering ethics. Although some facts are in dispute, it is clear that some of the engineers involved vigorously argued that the launch should be aborted. Why? The temperature at launch was forecasted to be much lower than previously experienced. Like typical rubber, the flexibility of Viton (and thus its ability to seal against the enormous pressures at launch) is dependent on temperature.

It has been argued (Tufte, 1993) that the available data, if plotted in the most meaningful way, would have provided overwhelming evidence for aborting the launch. According to this argument, the engineers were remiss in not presenting the data in the most powerful way. In other words, technical communication problems may have contributed to the launch and loss of *Challenger*. This point of view has been strongly challenged by the engineers involved (Robison et al., 2002). The arguments and counterarguments are complex and cannot be summarized in this short section. The interested reader is urged to read the cited papers. The purpose here is to show how data presentation can lead and mislead the engineer.

To appreciate the importance of how the data were plotted, it is necessary to understand what data were available at the time. There are several indicators of O-ring damage. One indicator is soot marks made by blackened grease as it blows through the primary O-ring. Soot is a very bad sign, indicating that the primary O-ring has been breached and the shuttle health depends only on the remaining secondary O-ring. The size of the soot marks (for shuttle launches with measurable soot) are shown as a function of ambient temperature at launch in Figure 6. Based on these data, would you recommend launching at the launch temperature of 26°F on January 28, 1986?

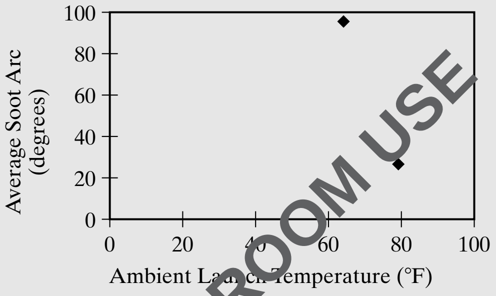


Figure 6. Influence of Temperature on Soot Including Only Data Where Soot Was Observed

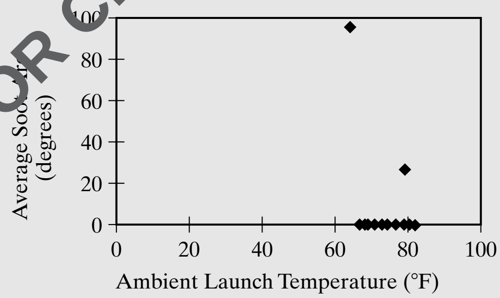


Figure 7. Influence of Temperature on Soot Including All Available Data

Based on the data plotted in Figure 6, you *might* conclude that a launch at 26°F is inadvisable. Although there *appears* to be a trend that soot area increases with decreasing temperature, two data points are hardly enough to justify a quantitative relationship. The picture becomes even cloudier when all available data are included (Figure 7). Note that no soot was observed at many launch temperatures between the values shown in Figure 6. Does the trend appear weaker now?

Results of the testing of isolated rockets revealed no soot at O-ring temperatures between 47 and 50°F (see Figure 8). How would the rocket test data influence your decision to launch?

History proved that the advice not to launch was justified. It is impossible to know with certainty whether a plot such as Figure 7 or Figure 8 would have enhanced the argument of the engineers. Rather than a clear-cut lesson in technical communications, we are left with a tragedy.

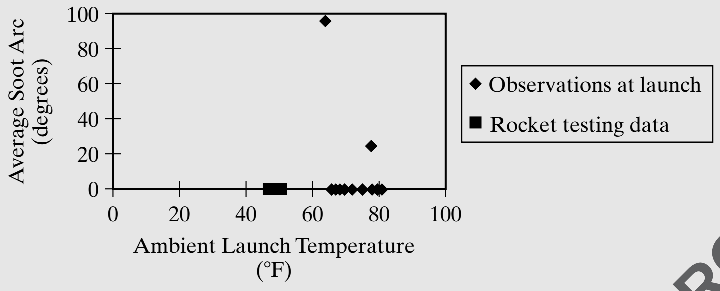


Figure 8. Influence of Temperature on Soot Including All Available Data and Rocket Testing Results

9 CREATIVITY IN TECHNICAL PRESENTATIONS

This chapter has emphasized the need for structure in technical presentations and has introduced numerous rules. However, please do not forget that technical communication is a creative process. Much of the creativity in technical presentations is focused on two areas: conciseness and thinking visually.

9.1 Creative Conciseness

When in doubt, favor conciseness over verbosity in technical presentations. Simply filling the page or presentation time with words is always obvious and insulting to the audience. In addition, calculations, data, or analysis that are necessary, but secondary to the main points being made, can be very distracting. In a written document, they may be best placed in an appendix.

Finding the right degree of conciseness is not easy. Technical presentations, like homemade bread, are hard to digest if they are too dense. To use another food analogy: wine can be very pleasant. It can be distilled into a complex brandy. Overdistill and you end up with ethanol: harsh and undrinkable. Often a dense presentation can be made more palatable by building in repetition and explanatory text.

The idea of conciseness also applies to figures. Consider the three plots of the same data in Figure 9. The top panel is a typical figure produced by the built-in plotting software of a word processing program.

PONDER THIS

What unnecessary elements do you see in the top panel of Figure 9?

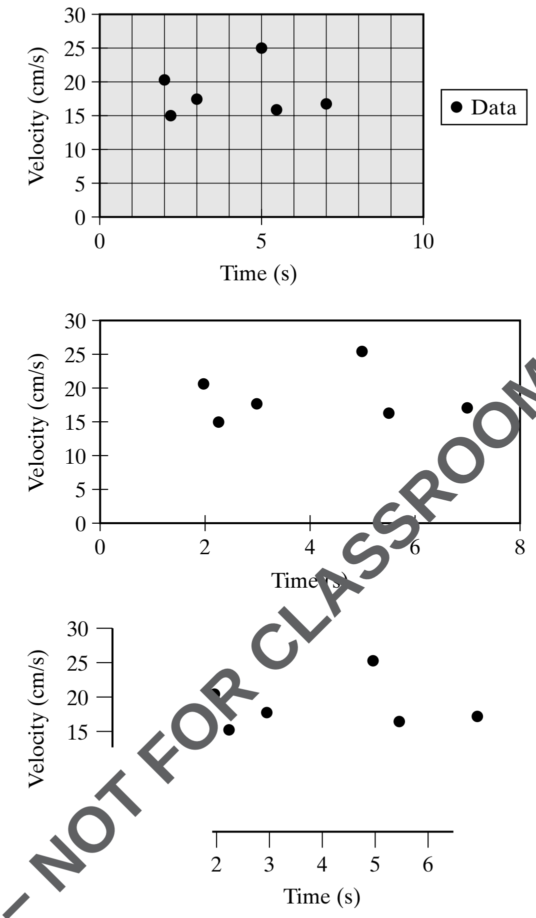


Figure 9. Example of Conciseness in Figures [*Caution*: Figure may contain errors! See text for discussion.]

The extraneous graphical elements in the top panel of Figure 9 include background color, grid lines, and legend. (No legend is needed, since there is only one set of symbols.) A clearer presentation (middle panel of Figure 9) is produced by eliminating the extraneous elements. In the bottom panel of Figure 9, nearly all extraneous lines have been removed. For most engineers, the bottom panel is on the verge of being too abstract: perhaps too much information has been removed. Figure 9 shows that some redundancy is needed to best communicate the information.

9.2 Thinking Visually

Another important creative element in technical presentations is the ability to *think visually*. The layout of the page or the slides can help make your points or distract the audience from your goal.

For more details (and fascinating examples), peruse the books by Edward Tufte listed in the references (Tufte, 1983, 1990). These are truly amazing and beautiful books that will greatly influence your thinking about the design of figures and tables.

10 SUMMARY

Technical communication is important in turning engineering ideas into reality. In addition, good technical communication skills are essential for obtaining an engineering job and advancing in the engineering profession.

Engineers must take responsibility for communicating their ideas and their work to a large and varied audience. As an engineer, you should think about technical communications as a creative and persuasive engineering tool. You must take control of the message, ask yourself if your message is understood, and seek to improve your communication skills at every opportunity.

Several general aspects of technical presentations (i.e., technical writing and technical speaking) were discussed in this chapter. Before putting pen to paper, you should take several steps. First, always identify the goals of the presentation, the target audience, and the constraints of the presentation. Second, organize the material to be presented. This can be done by using an outline to structure the information. Be sure to show your structure to the audience. Third, use the proper technique to present data. Tables are used when the actual values are important, while figures are used to show trends in the data. Every table and every figure in a technical document must have a number and a descriptive title. In addition, every table and figure must be referred to from the text of a written document, and its main points must be summarized.

Be sure to use the most appropriate type of figure: scatter (x–y) plots when the independent variable is continuous, bar charts when the independent variable is not continuous, pie charts to show relative proportions, and line charts almost never. Look critically at the default table or figure produced by software and ask how it could be modified to best meet *your* presentation goals.

SUMMARY OF KEY IDEAS

- Technical presentations must tell a story; always ask yourself whether the audience understood your story.
- Strong technical presentation skills aid in obtaining a job and in advancing a career.
- Technical communication is a creative process.
- Technical communication is usually meant to be persuasive.
- Engineers can benefit from communication specialists, but the engineer must take responsibility for making sure the correct message is delivered.
- All engineers can improve their technical communication skills.
- Before preparing a technical presentation, write down the goals of the presentation.
- Identify the target audience (and their technical sophistication, interests, and backgrounds) before preparing a technical presentation.
- Before preparing a technical presentation, quantify the constraints on the presentation (i.e., length limits, your time, and other resource limitations).
- To organize a presentation, structure the material using an outline and show the structure to your audience.
- Use tables when actual values are important; use figures to show trends in the data.
- Tables and figures should have a number (by which they are referred to in the text) and a short, descriptive title.

- Tables and figures must be interpreted in the text.
- Include units in the row or column headings of tables and the axes of figures.
- In tables, list the independent variables in the leftmost columns.
- Use scatter (x–y) plots when the independent variable is continuous.
- In general, use symbols for data and lines for calculated values (i.e., model output).
- Use the line chart type carefully in technical presentations (or, better yet, avoid it completely).
- Use bar charts when the independent variable is not continuous.
- In figures, select the axis ranges to encompass all the data without distorting the relative values.
- Do not accept the default table or figure produced by the software without questioning whether it meets your objectives.
- Use pie charts to show relative contributions.

Problems

1. Identify the goals, target audience, and constraints for the following types of communication:
   a. Two roommates discussing how to divide the telephone bill
   b. A review article on the avian flu virus in a newsmagazine
   c. A NASA news briefing on the evidence of water on Mars
2. Write an outline for a research paper on career opportunities in the engineering field of your choice.
3. Discuss whether you would use a figure or a table to present the following data. If you choose a figure, state which type of figure you would use.
   a. The chemical composition (in percent by weight) of a concrete formulation
   b. Operation and maintenance costs of three pavement types
   c. Effect of fiber-optic cable length on the transmission of photons
   d. Percentage of zebra mussels killed under a specified treatment regime
4. Figure titles often are missing or incomplete in the popular press. Find two data figures in a newspaper or newsmagazine. Critique the figure titles and then write your own.
5. Find two data tables in a newspaper or newsmagazine. Critique and write your own table titles. Edit the table, if necessary, following the principles discussed in this chapter.
6. Some people refer to line charts as “bar charts with symbols.” Explain this definition of line charts.
7. Write Newton’s Second Law of Motion in a concise form for a technical audience and in a more expansive form for a general audience.

8. Pick a figure in this text, critique it, and improve upon its design. State why your design is an improvement.
9. Interview a practicing engineer and write a paragraph about the importance of technical communication in his or her professional life.
10. Explain the differences and similarities between technical communication and written or oral presentations you did in high school in nontechnical courses.

Written Technical Communications

1 INTRODUCTION

In this chapter, written technical communications will be discussed in much detail. Organization is the key to good technical communication. Thus, most of the chapter (Sections 2 and 3) is devoted to the organization of written documents. Grammar and spelling issues are reviewed in Section 4. Section 5 provides details on the types of engineering documents you will write, from formal reports to casual email.

2 OVERALL ORGANIZATION OF TECHNICAL DOCUMENTS

2.1 Introduction

The key to good written and oral presentations is organization. Technical documents must be organized on several levels. In this section, the general organization of technical documents will be discussed. Organization at the paragraph, sentence, and word levels is the subject of Section 3.

2.2 General Organization Schemes

Outlines should be used to develop organized presentations. What headings and subheadings should be employed? Clearly, the details of the outline will depend on the goal of the presentation and nature of the technical work. Although every technical report is different, several elements are common to many technical presentations. Important elements found in many technical presentations are given in Table 1. The common elements are as follows:

SECTIONS

OBJECTIVES

After reading this chapter, you will be able to:

- list the elements of technical documents;
- organize a technical document;
- identify common grammatical and spelling errors in technical documents;
- proofread technical documents;
- write an effective technical document.

Key idea: Organize technical documents from the largest to smallest scale: outline level, paragraph level, sentence level, and word level.

Key idea: Common elements of technical documents include the abstract (or executive summary), introduction/background/literature review, methods, results, discussion, conclusions/recommendations, and references.

Key idea: The abstract should contain a summary of each element of the report.

- Abstract
- Introduction/Background/Literature Review
- Methods/Modeling
- Results
- Discussion
- Conclusions/Recommendations
- References

Each of the common elements will be illustrated with a report on a laboratory exercise conducted to test the conservation of momentum.

2.3 Abstract

Technical documents typically begin with an *abstract*. The purpose of the abstract is to provide a brief summary of the remainder of the document. The abstract should include the important points from each element in the document. An extended abstract (often written for nontechnical audiences) is sometimes called an *executive summary*.

A properly written abstract should be a miniature version of the entire technical document. The word *abstract* comes from the Latin *abstractus*, meaning drawn off. In a true sense, think of the abstract as being *drawn off of the whole document*. Thus, an abstract should include the following sections:

- An introduction (with enough background material to show the importance of the work),
- A statement on the methods or models employed,
- A short summary of the results and their meaning, and
- Conclusions and recommendations.

For the lab report on the conservation of momentum, the abstract might read as follows:

> **Abstract**
>
> The purpose of this lab was to test the law of conservation of momentum. Experiments were conducted with disks designed to remain together after collision. The masses and velocities of the disks were measured before and after collision. On average, the total momentum of the system after the collision was 101% of the total momentum before the collision. The calculated momentums were interpreted to be consistent with the conservation of momentum law.

TABLE 1 Elements in a General Technical Document

Section Title	Purpose
Abstract or Executive Summary	Summarizes the entire report, including all other elements
Introduction or Background or Literature Review	Brings the reader to the topic of the report; may give project history and/or a review of the appropriate technical literature
Methods or Modeling	Describes study approach, methods used, and model development (if any)
Results	Presents the results, including "raw" data with trends indicated but little interpretation of the data
Discussion	Interprets of the results
Conclusions and Recommendations	Summarizes main points and gives suggestions for further work, often in a list format
References	Lists references cited (may be in an appendix)

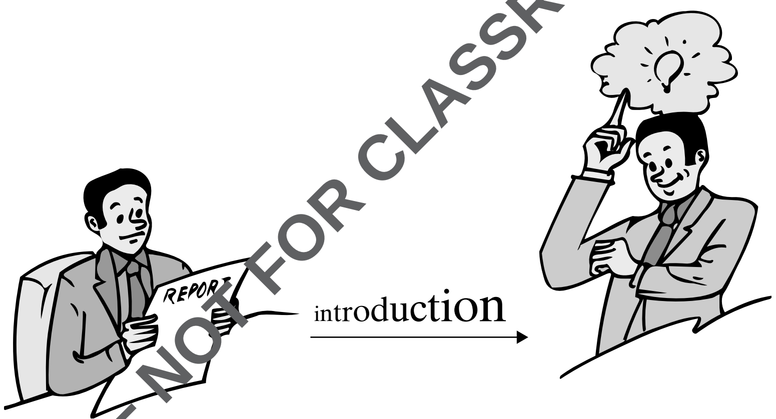
Note that the abstract contains all the elements of the full report: introduction (first sentence), methods (second and third sentences), results (fourth sentence), and conclusion (last sentence).

2.4 Introduction

Key idea: The introduction should take the reader from the report title to an understanding of why the report was written.

The next element is the *introduction*. In writing the introduction section, assume that the reader knows only the information in the title of the report. After reading the introduction, the reader should have a good idea of the *motivation* for the report (i.e., why the report was written).

In some cases, the introduction section may be fairly long. It may include a discussion of the project history, a review of pertinent technical literature, and a presentation of the goals and objectives of the work. On other occasions, the introduction is short and the other material is placed in separate sections (i.e., a background or a literature review section or a goals/objectives section).



The introduction section takes the reader from the title to an appreciation of why the document was written.

For the lab report on the conservation of momentum, the introduction might read as follows:

> **Introduction**
>
> Science and engineering are founded on a number of conservation laws. One example is the conservation of momentum. Momentum is the product of the mass of an object and its velocity. The law of conservation of momentum states that the momentum of a closed system remains unchanged.
>
> The conservation laws are impossible to prove experimentally because of error. However, the data collected in a well-planned experiment should be consistent with the conservation laws. In this lab, a comparison was made between the momentum calculations from laboratory data and the law of conservation of momentum.

2.5 Methods

Key idea: In the methods section, justify the study approach, present data collection techniques, and discuss data analysis methods.

The introduction is usually followed by a section on the *methods* employed in the study. The methods section should describe three elements of the work. First, the methods section should justify the *study approach*. In most engineering studies, there are many ways to achieve the study goals.

PONDER THIS

How many ways can you think of to "test" the law of conservation of momentum?

For example, you could explore the conservation of momentum law under controlled conditions with billiard balls or model cars or hockey pucks. You also could collect data in the real world. For example, a visit to a county fair would allow you to make measurements using bumper cars or the demolition derby. Even in this simple example, there are many ways to test the hypothesis of interest. As an engineer, you *choose* to follow a certain approach. It is important to justify your choice.

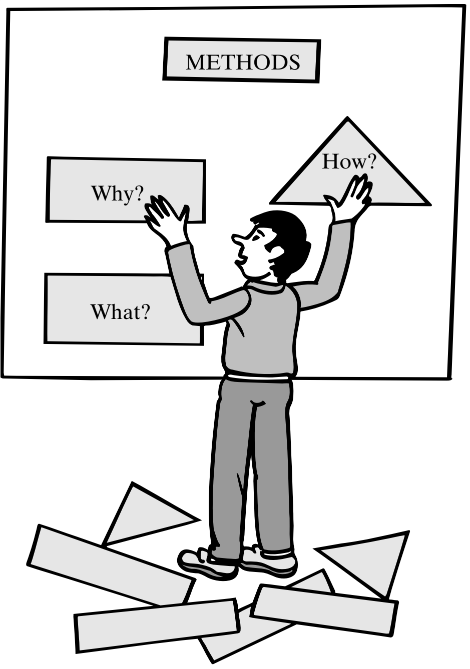
Second, the methods section should discuss the techniques involved in data collection. For experimental work, this means describing the measurement methods. For modeling studies, this means presenting the models developed specifically for your study.

Third, the methods section should discuss the approaches used to analyze the data. For example, suppose you measured temperature using a thermistor. A thermistor is a resistor that has a resistance related to temperature in a known fashion. In a study using a thermistor, it may be necessary in the methods section to describe how the temperature was calculated from electrical measurements.

The three parts of the methods section can be summarized as follows:

- *Why* did you do the work? (study approach)
- *How* did you do the work? (experimental procedure)
- *What* did you do with the work? (data analysis)

Often, the information about experimental set-up can be communicated most effectively by drawings or photographs. It should be noted that in some technical fields, information on methods is placed in an appendix rather than in the body of a report.



Elements of a methods section

For the lab report on the conservation of momentum, the methods section might read as follows:

> **Methods**
>
> Data collection was performed in a laboratory setting to enhance reproducibility. Tests were conducted on an air table to minimize friction.
>
> Six experiments were conducted. For each experiment, the masses of two plastic disks were recorded. The disks were 5 cm in diameter and 0.5 cm thick. The rims of the disks were covered with a strip of Velcro tape to allow the disks to stick together upon impact. The disks were positioned about 2 m apart. One disk was propelled by hand towards the other disk. Disk velocities were measured immediately before and after collision.
>
> Masses were determined with a Model 501 balance. To measure disk velocities, a digital video camera (VideoCon Model 75) capable of recording images at 30 frames per second was positioned above the initially stationary disk. The sides of the air table were marked in 0.1 cm increments. Images were examined frame by frame, with the instantaneous velocity calculated as (distance traveled between frames) divided by (time between frames). The velocities of the disks were averaged over one second prior to and after collision.
>
> The average momentum was calculated as $p = mv$, where m represents mass and v denotes velocity.

In this example, the study approach is presented and justified in the first paragraph. The second paragraph gives the overall experimental procedure, with the measurement details in the third paragraph. The fourth paragraph outlines the data analysis approach.

2.6 Results and Discussion

Key idea: In the results section, present the results and note the general trends.

Key idea: Interpret data in the discussion section.

The results section comes next. In this section of the typical engineering report, the results are *presented* but not *interpreted*. The general trends shown by the data in tables and figures should be highlighted as the data are presented.

In the results section, there is generally little interpretation of the data. Data interpretation comes in the *discussion* section. Here, elements of the results section are combined and interpreted to reach the main conclusions of the engineering study. Often, data are compared with predictions from models in the discussion section. In a design report, alternative designs may be compared and a final alternative selected in this section.

> *In a results section:*
>
> The measured force values are shown against mass in Figure 1. The measured force (in newtons) increased nearly linearly with the increase in mass (in kg).

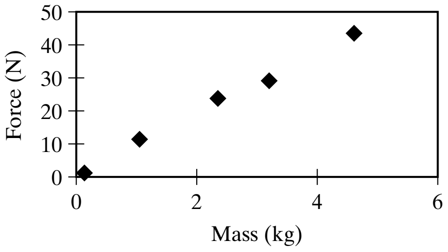


Figure 1: Dependency of Measured Force Values on Mass

In a discussion section:

Measured forces are compared with model predictions in Figure 2. The experimental results were consistent with the model, $F = ma$.

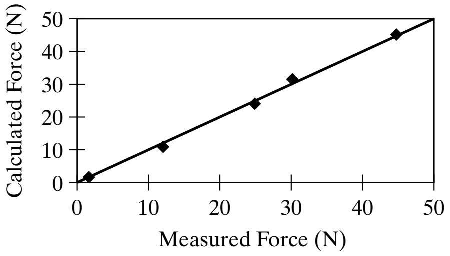


Figure 2: Comparison of Measured Forces and Model Results
(Line is calculated force = measured force)

The division between the results and discussion sections is not always clear cut. In fact, the results and discussion sections usually are combined in short reports. To illustrate the difference between the results and discussion sections, consider a large report on the effects of fatigue on the performance of assembly line workers. In the results section, the data on fatigue measures and performance measures might be reported. General trends (for example, that time to completion of critical tasks decreased as the level of fatigue increased) may be noted. More detailed interpretation of the data would be placed in the discussion section, where, for example, the predictions of a performance model might be compared with the data collected in the study.

For the conservation of momentum lab report, the results and discussion sections probably would be combined because the scope of the report is small. Example results and discussion sections are separated here for illustrative purposes.

Results

Measured masses and mean velocities from the six experiments are shown in Table 1. Note that the measured masses of the single disk (before collision) are similar, as expected. In addition, the measured masses of the coupled disks (after collision) are nearly double the masses of the single disk. By inspection of the data in Table 1, it appears that the velocity decreased by nearly a factor of two as the mass increased by about a factor of two.

TABLE 1 Measured Mass and Mean Velocity Data

	Before Collision		After Collision	
Experiment	**Mass (g)**	**Mean Velocity (cm/s)**	**Mass (g)**	**Mean Velocity (cm/s)**
1	2.5	99	5.0	51
2	2.5	102	5.1	48
3	2.4	96	4.9	48
4	2.5	93	5.0	45
5	2.6	102	5.1	51
6	2.5	105	5.1	54

Discussion

The calculated momentum values before and after collision are listed in Table 2. Note that the calculated momentum values before and after collision are nearly equal. As shown in the fourth column of Table 2, the momentum after collision averaged 101% of the momentum before the collision.

TABLE 2 Calculated Momentum Values (p) Before and After Collision

Expt.	p **Before Collision (g-cm/s)**	p **After Collision (g-cm/s)**	**(**p **After)/(**p **Before) (%)**
1	250	260	104
2	260	240	92
3	230	240	104
4	230	230	100
5	270	260	96
6	260	280	108
mean			101

The approach used in this lab was to compare two momentum values. Therefore, it is important to estimate the uncertainty in the mass and velocity measurements. The precision of the mass measurements can be estimated by the precision of the balance (given by the manufacturer as ±0.01 g). The instantaneous velocity was calculated as (distance traveled between frames) divided by (1/30 second per frame). The distance traveled was rounded to the nearest 0.1 cm, since the scale of the side of the table was marked in 0.1-cm increments. A difference of 0.1 cm over 1/30 s represents $(0.1\text{ cm})/(1/30\text{ s}) = 3$ cm/s. The uncertainty in velocity (3 cm/s) represents about 1.2% of the average velocity of 250 cm/s. Thus, the difference of 1% between momentum values before and after collision is not unreasonable. Given the uncertainty, the data collected are consistent with conservation of momentum during the collision of two disks.

2.7 Conclusions and Recommendations

Key idea: Conclusions and recommendations are often in list form and should be written very carefully.

The last main section of a typical engineering report is the *conclusions and recommendations* section. The conclusions and recommendations must be among the most carefully worded sections of an engineering report, since many readers may turn here first. Conclusions and recommendations often appear in a list format. The conclusions should stem directly from the discussion. In other words, no *new* information should be presented in the conclusions.

The recommendations section is a critical part of an engineering report. Why? Recall that engineers often select intelligently from among alternatives. The preferred alternative often is highlighted in the recommendations section.

An example of a conclusions section is given next.

Conclusions

An experimental study was conducted to explore the conservation of momentum law as applied to a collision of two discs on an air table. The momentum after the collision averaged 101% of the momentum before the collision. The experimental results were consistent with the conservation of momentum.

2.8 References

Key idea: Although many reference formats are acceptable, the references must be complete and consistent.

The last section of a technical report (often found in an appendix) is a list of references. There are many acceptable formats for listing references in technical material. The guiding rules are that the references should be *complete* (so that the reader can find the referenced material easily) and *consistent* (i.e., use the same format for all books or journals cited). Following are some examples of reference formats:

For books:

Author's last name, author's initials (for second authors, initials followed by name), book title in bold, publisher's name, publisher's location, publication date.

Example: Keller, H. **The Story of My Life**. Doubleday, Page & Co., New York, NY, 1903.

For journal articles:

Author's last name, author's initials (for second authors, initials followed by name), article title, journal name in bold italic, volume number, issue number in parentheses, page range, date.

Example: Dallard, P., A. J. Fitzpatrick, and A. Flint. The London Millennium Footbridge. ***Structural Engineer***, **79**(22), 17–35, 2001.

For Web pages:

Author's last name, author's initials (for second authors, initials followed by name), article title, URL, date visited in parentheses.

Example: Anon., Standard Contract Documents, http://www.nspe.org/ejcdc/home.asp (visited March 21, 2005).

bibliography: a list of useful sources of information, including sources not cited in the text (as contrasted with the references, in which only cited material is listed)

Be careful about the differences between a list of references and a ***bibliography***. A reference list consists only of the material cited in the text. A bibliography lists all useful sources of information, even if they are not specifically cited in the text. For examples, please see the References appendix of this text.

2.9 Signposting in Technical Writing

As discussed in Section 2.2, a good technical presentation is well organized and the organization is clear to the audience. The idea of showing the audience where you are in a technical presentation is called *signposting*. A common mistake in technical writing is to give the reader page after page of text with no guide to the content of the text.

Key idea: Use section headings or numbering schemes as signposts in technical documents.

In technical documents, signposting is usually accomplished in one of two ways. First, you may use *section headings* to show the readers where they are in the document. The divisions described in Section 2.1 (e.g., Introduction, Methods, Results, and so on) may be good section headings. Be sure to use a consistent theme to show the hierarchy of the headings. For example, major headings might be left aligned, while subheadings are indented. Or major headings might be all in capital letters, while subheadings are in initial caps.

Second, you can signpost with a *numbering scheme*. Numbers are an excellent way to show the hierarchy of headings. For example, a major section may be given a number (e.g., "3. Assessment of Alternatives"), with subheadings listed as sections under the number (e.g., "3.1 Soldered Joints Alternative"). Hierarchy can be shown by the numbering scheme (4, 4.1, 4.1.1, or I, I.A, I.A.1, or others), indentation, or use of boldface fonts.

Regardless of the system used, signposting *must be applied consistently*. If you use a bold font with initial caps with second-level subheadings, then use a bold font with initial caps with *all* second-level subheadings. Your readers will rely on your signals. Do not confuse the reader with inconsistent signposting.

3 ORGANIZING PARTS OF TECHNICAL DOCUMENTS

3.1 Paragraph Organization

topic sentence: the first sentence in a paragraph in which the purpose of the paragraph is stated

Beyond organizing the overall presentation, each paragraph also should be structured. Each paragraph should tell a complete story and be structured by sentence. The paragraph should begin with a ***topic sentence***. The topic sentence states the purpose of the paragraph. Each following sentence should *support the topic sentence*. Paragraphs should end with a *concluding sentence*, which summarizes the main points of the paragraph. Thus, each sentence in the paragraph has a specific purpose.

PONDER THIS

Reread the previous paragraph and evaluate whether it is structured correctly.

3.2 Sentence Organization

Key idea: Each sentence should express a single idea.

A sentence is a grammatical structure containing a subject and a verb. Sentences should express a *single idea*. There are two common problems with sentences in technical documents: overly long sentences (with more than one idea) and too short sentences (lacking a subject or verb). Avoid using conjunctions (e.g., *and*, *but*, *or*, *nor*, *for*, *so*, or *yet*) to combine disparate ideas into one sentence. Consider the following sentence:

> Design parameters were calculated by standard procedures and all results were rounded to three significant figures.

This sentence contains two ideas. It should be split into two sentences at the word *and*:

> Design parameters were calculated by standard procedures. All results were rounded to three significant figures.

sentence fragment: an incomplete sentence (usually lacking a subject or verb)

Sentences can be *too short* if they do not include both a subject and a verb. Incomplete sentences are called ***sentence fragments***. A common sentence fragment in technical writing creeps in when stating trends. For example,

> The higher the temperature, the shorter the annealing time.

PONDER THIS

Why is the sentence fragment "The higher the temperature, the shorter the annealing time" *not* a sentence?

This fragment has no verb and thus is not a sentence. Try to avoid such constructions in your technical writing. Say instead: "Annealing time decreased as the temperature was increased."

3.3 Word Choice

Key idea: Choose words to make your writing concise, simple, and specific.

The lowest level of organization is the choice of words. In choosing words to form sentences, try to be as *concise*, *simple*, and *specific* as possible.

Concise writing means that you should use the minimum number of words to express the thought clearly. To write concisely, avoid long prepositional phrases. Examples of common wordy phrases and suggested substitutions are listed in Table 2.

TABLE 2 Examples of Long Prepositional Phrases to Be Avoided (adapted from Smith and Vesiland, 1996)

Wordy Prepositional Phrase	Possible Substitute
due to the fact that . . .	because . . .
in order to . . .	to . . .
in terms of . . .	reword sentence and delete phrase[a]
in the event that . . .	if . . .
in the process of . . .	delete, or use "while" or "during"
it just so happens that . . .	because . . .
on the order of[b] . . .	about . . .

[a] *Example*: The sentence "In terms of energy use, Alternative 3 was lowest" could be rewritten as "Alternative 3 had the lowest energy use."

[b] This phrase sometimes is used to indicate an order of magnitude (i.e., a power of 10), as in the following sentence: "On the order of 10,000 bolts were employed in the construction project."

For example, instead of writing

> In order to find the optimum temperature, we conducted experiments.

it is preferable to write

> To find the optimum temperature, we conducted experiments.

Although the general public sometimes feels that technical writing is impenetrable, written technical communication should be *simple*. In other words, use simple words to express your ideas as clearly as possible. Avoid sentences such as

> System failure mode was encountered on three sundry occasions.

Instead, write more clearly:

> The system failed three times.

Key idea: Avoid making up new words or new uses of words in conventional technical writing.

A common and annoying device used to make writing sound more technical is the use of nouns as verbs. One way this is accomplished is by adding the suffix *-ize* to almost any noun (e.g., initialize, prioritize, customize, and the like). Writers are converting nouns into verbs with increasing frequency. For example, a nationwide company offering photocopying services used to advertise itself as "The new way to office." (What does "to office" mean?) In your writing, avoid making up new verbs from nouns.

The heart of technical writing is its *specificity*. Make your writing specific by avoiding general adjectives such as *many*, *several*, *much*, and *a few*. Quantify your statements when you can:

> Engine temperatures were 5°C above normal.
>
> **not**
>
> Engine temperatures were several degrees above normal.

4 GRAMMAR AND SPELLING

Important ideas about spelling and grammar will be reviewed in this section. The purpose of this discussion is not to provide you with a comprehensive list of the rules of grammar, but rather to identify common trouble spots in technical writing.

There are no excuses for errors in grammar or spelling in technical writing. The most important rules are reviewed here. Problem words will be discussed at the end of this section. For more details, please examine any of the excellent books listed in the bibliography at the end of the text.

You should be aware that there is some disagreement on several grammatical rules. It is important to differentiate firm rules from one writer's opinion. It is frustrating to learn and use one approach from a mentor, only to have it totally dismantled by another mentor. When in doubt about the feedback you have received, always ask questions.

4.1 Subject–verb match

Key idea: Make sure that the subject and verb agree in number (i.e., they must be both singular or both plural).

The subject and verb must match in number. In other words, use plural forms of verbs with plural nouns and singular forms of verbs with singular nouns. For example, you should write

> The contacts of the integrated circuit were corroded.
>
> **not**
>
> The contacts of the integrated circuit was corroded.

The subject of the sentence is plural ("contacts") and thus a plural verb ("were") is required.

In most cases, the "subject–verb match" rule is simple. However, some sticky situations arise. For example, is the noun "data" plural or singular? In most technical literature, the word *data* is considered to be a plural noun. (Formally, it is the plural of the noun *datum*.) A growing number of technical writers consider *data* to be singular when referring to a specified set of data. The safe bet is to treat *data* as a plural noun:

The data fall within two standard deviations of the mean.

not

The data falls within two standard deviations of the mean.

If you wish to use a singular noun, use *data set*:

The data set was larger last year.

4.2 Voice

voice: person or people doing the action

Key idea: Use a consistent voice, with preference for the active voice.

In grammar, ***voice*** refers to the person (people) or things doing the action. There are two general voices: active and passive. In the active voice, the subject is identified. In the passive voice, the person performing the action is not identified (either directly or by category).

There is some difference of opinion about which voice is best for technical writing. In general, the active voice is preferred. Why? In engineering, you usually want to know who did the action. You should write

Field technicians backfilled the soil.

not

The soil was backfilled.

The passive voice is appropriate when the identity of the person doing the action is obvious or unimportant. Thus, you will find the passive voice used in many engineering reports where the subject already has been identified. For example, the passive voice was used in the conservation of momentum example in Section 3. Regardless of the voice used, be consistent and use the same voice throughout.

Although the active voice is preferred, you should always avoid the use of the first person in technical writing. For example, write

XYZ Engineering personnel developed an ergonomic design.

or

We developed an ergonomic design.

not

I developed an ergonomic design.

4.3 Tense

Tense refers to when the action occurred. In technical writing, use the present tense unless describing work done in the past. Thus, write

Key idea: Generally use the present tense, unless describing work done in the past.

Values were calculated by a nonlinear optimization algorithm.

This is in the past tense, since the calculation took place in the past. On the other hand, you might write

The results indicate the importance of the new quality assurance procedures.

Use the present tense here, since the results and their interpretation exist now.

4.4 Pronouns

Key idea: Avoid the use of gender-specific pronouns.

Pronouns are substitutes for nouns. Examples of pronouns include *he*, *she*, *it*, *they*, and *them*. An all-too-common problem with pronouns in technical (and nontechnical) writing is *gender bias*. In the older technical literature, scientists and engineers were identified as males. It used to be common to write

An engineer must trust his abilities. **[*incorrect*]**

This construction is ***not*** proper, as it implies that all engineers are men.

One approach to remedying this situation is the use of the pronouns *they* or *their* in place of *he* and *his*. This leads to the statement

An engineer must trust their abilities. **[*incorrect*]**

Unfortunately, the solution is grammatically incorrect.

THOUGHTFUL PAUSE

What is wrong with the statement, "An engineer must trust their abilities"?

In this case, the subject ("an engineer") is singular and the pronoun ("their") is plural. A much better solution to gender-specific pronouns is to rework the sentence completely so that the subject and pronouns match in number:

Engineers must trust their abilities.

Key idea: Use *who* as a pronoun for human subjects, *that* for specific nonhuman subjects, and *which* for nonhuman subjects in clauses set off by commas.

Another common problem is the proper use of the pronouns *who*, *that*, and *which*. When in doubt, use *who* for human subjects and *that* or *which* for nonhuman subjects. The pronoun *that* is used in reference to a specific noun while *which* adds information about a noun and usually is used in clauses set off by commas. Thus,

The engineer *who* was on site had the contract documents.

The human subject takes the pronoun *who*. On the other hand,

The bolt *that* ruptured was installed improperly.

Here, use *that* in referring to a specific bolt. (We are discussing a particular bolt: the bolt that ruptured.) Finally,

The submitted proposal, *which* was missing page three, was thrown in the garbage can.

In this case, use *which* to add information in a separate clause. Often, you can avoid *who*, *that*, and *which* problems by incorporating the information as an adjective. For the examples just presented, you could write

The on-site engineer had the contract documents.

The ruptured bolt was installed improperly.

The submitted proposal was missing page three. It was thrown in the garbage can.

4.5 Adjectives and Adverbs

adjective chain: a long list of modifiers to a noun (to be avoided)

Adjectives modify nouns and adverbs modify verbs. Avoid using long lists of adjectives, sometimes called ***adjective chains***. In adjective chains, it is often difficult to identify the noun. Consider the sentence:

High-grade precut stainless steel beams were specified.

The beam characteristics are clearer if the sentence is rewritten:

Precut beams made of high-grade stainless steel were specified.

split infinitive: insertion of a word between *to* and the verb (to be avoided)

Adjective and adverb *placement* also can be problematic. You should avoid placing an adverb between the word *to* and the verb. This construction is called a ***split infinitive***. For example, you should write

The gear ratio was designed to drive the system efficiently.

not

The gear ratio was designed to efficiently drive the system.

Key idea: With adjectives and adverbs, avoid adjective chains and make sure the adverb or adjective modifies only the verb or noun you intend to modify.

Having railed against them, it should be noted that split infinitives are a tricky construction. The rule against split infinitives appears to stem from Latin, where splitting an infinitive is impossible. Place an adverb between *to* and the verb only to emphasize the adverb or to produce a sentence that sounds better. For example, there is a split infinitive in the phrase

> To boldly go where no one has gone before …

However, it sounds better (at least to many people) than

> To go boldly where no one has gone before …

Adjectives should be located next to the nouns they modify. Consider the following two sentences:

> They only constructed three prototypes.
> They constructed only three prototypes.

In the first sentence, *only* modifies *constructed*: they only *constructed* the prototypes, they did not construct and test the prototypes. In the second sentence, *only* modifies *three* (which, in turn, modifies *prototypes*): they constructed only *three* prototypes, rather than four prototypes. Make sure that the adverb (or adjective) modifies only the verb (or noun) you intend to modify.

4.6 Capitalization and Punctuation

Many neophyte technical writers find it necessary to use nonstandard capitalization and abbreviations. Please do not give in to this temptation. Few words in technical writing are capitalized. As suggested by Smith and Vesilind (1996), you usually capitalize the names of organizations, firms, cities, counties, districts, agencies, and states. In general, do not capitalize general references to these entities. Thus, you can write

> The City of Rochester contracted for engineering services.

Here, capitalize "city" because it is specific to Rochester, New York, but

> The city council met for three hours.
> **or**
> The federal government will meet the deadline.

Do not capitalize "city" and "federal" because they are general adjectives here. In addition, the titles of engineering reports are capitalized, and official titles of people are capitalized when they precede the names of the people (but not when they follow the name).

Key idea: Avoid nonstandard capitalization and abbreviations.

Standard abbreviations for scientific and engineering units and parameters should be used. If in doubt, define an abbreviation *the first time it is used*. There is no need to capitalize the words as an abbreviation is defined. Thus, write

> The standard operating procedure (SOP) was followed.
>
> **not**
>
> The Standard Operating Procedure (SOP) was followed.
>
> **and not**
>
> The SOP was followed.

The last construction is improper if using the abbreviation for the first time, but desirable if the abbreviation *SOP* already has been defined in the document.

Common nontechnical abbreviations include the following:

> e.g. (*exempli gratia* = for example)
> i.e. (*id est* = that is)
> etc. (*et cetera* = and so forth), and
> et al. (*et alia* = and others)

(*Note*: The last term is ***not*** abbreviated et. al or et. al.) These common abbreviations sometimes are italicized (e.g., *e.g.*) to indicate their non-English origins.

Commas should be used to define clauses and separate items in a list. Usually, a comma is used even before the last item in a list. For example,

> Materials included wood, steel, and concrete.

If the items in a list are long (or the items include commas or conjunctions), use semicolons to separate them:

> Materials included wood, natural materials, and fiber; steel and concrete; and thermoplastic resins.

4.7 Spelling

Key idea: Never assume a document is free of errors because it passes the spell checker.

There is no room for spelling errors in technical documents. One misspelled word could destroy an otherwise strong document. The fundamental rule of spelling is *Never, never, never trust your spell checker*. Spell-checking software is a good first start, but you must learn to proofread your writing very carefully. Spell checkers miss misspellings that result in another word (e.g., house/horse, dear/deer). A proofreading example is given in Section 4.10.

4.8 Citation

plagiarism: using someone else's words or ideas without proper credit

You are professionally and morally obligated to give credit when you use ideas from other people. Taking someone else's words or ideas without credit is called ***plagiarism***. Plagiarism is defined in the University at Buffalo University Standards and Administrative Regulations as

> copying or receiving material from a source or sources and submitting this material as one's own without acknowledging the particular debts to the source (quotations, paraphrases, basic ideas), or otherwise representing the work of another as one's own.

Key idea: Make sure you give credit (by use of a citation) when presenting someone else's words or ideas.

Students who plagiarize are subject to disciplinary action. Engineers who plagiarize can lose their professional licenses.

Plagiarism is not just copying *words* from someone else. Plagiarism also means taking another person's *ideas* without giving them due credit. Always read your work carefully to make sure that you have not inadvertently included someone else's ideas "without acknowledging the particular debts to the source."

Credit is shown by *citing the work from which the material was taken*. There are many citation styles. One style (employed in this text) is to list the author's name and publication date in parentheses following the material cited, as in "Smith (2002)." Numbers, usually written as superscripts (e.g., Smith^2), may be used with a numbered reference list.

paraphrase: to rewrite an idea in your own words

In nearly all cases, you ***paraphrase*** the material (i.e., rewrite it in your own words). On rare occasions (when the original words are required), it may be necessary to quote the words exactly. Quotation should be done sparingly and the citation always must be given. Indicate a direct quotation by the use of quotation marks or by doubly indenting the material. Examples of paraphrasing and quotation are shown in Example 1.

EXAMPLE 1 PARAPHRASING AND QUOTATION

Use the following material, from Paradis and Zimmerman (1997), in a paragraph, and cite it properly:

"Long sentences, often amounting to more than 30 words, are usually too complicated. Determine the main actions of the sentence. Then sort these into two or more shorter sentences."

SOLUTION

Here are several citation options:

1. Paraphrase with citation (preferred approach):

   Long sentences should be broken up into smaller sections according to their main actions (Paradis and Zimmerman, 1997).

2. Quotation using quotation marks with citation:

   Overly long sentences can be problematic. According to Paradis and Zimmerman (1997): "Long sentences, often amounting to more than 30 words, are usually too complicated. Determine the main actions of the sentence. Then sort these into two or more shorter sentences."

3. Quotation using indentation with citation:

   > Overly long sentences are confusing to the reader. Several approaches have been developed to identify and eliminate run-on sentences. For example,
   >
   >> Long sentences, often amounting to more than 30 words, are usually too complicated. Determine the main actions of the sentence. Then sort these into two or more shorter sentences. (Paradis and Zimmerman, 1997).

The following approach is plagiarism because the work is paraphrased but no citation is given **[*Warning*: This material is not cited properly!]**

> Long sentences—some can be up to 30 words long—should be subdivided. To do this, find its main actions and create a shorter sentence for each main action.

4.9 Other Problem Areas

In addition to the rules discussed previously, several other words and phrases cause problems in technical writing. Most of the words and phrases listed below were found in Strunk and White (1979) or Smith and Vesiland (1996):

affect/effect: These two words cause many difficulties in technical writing, but the rule regarding their use is simple. The word *affect* is almost always a *verb*. The word *effect* is almost always a *noun*. Thus, write "The effects of temperature were noted" (*effects* is a noun) and "Temperature affected the results" ("affected" is the verb).*

among/between: Use *between* when two people or things are involved and *among* when more than two or more people or things are involved. For example, write "The voltage was split between two capacitors," but "The work was divided among four engineers."

comprise: *Comprise* means *to consist of*: "The frame comprises four steel rods" (i.e., the frame *consists of* four steel rods) and "Four steel rods make up the frame" (***not*** "Four steel rods comprise the frame").

Key idea: Avoid double negatives in formal writing.

double negatives: Avoid the **use** of two or more negatives (*not* or words starting with *un*) in the same sentence. Rewrite by canceling out pairs of negatives: "The project was like our previous work" (***not*** "The project was not unlike our previous work.")

farther/further: *Farther* refers to distance, while *further* refers to time or quantity. Thus, "The ultrahigh-mileage vehicle went farther on a tank of gas," while "Further negotiations are necessary to seal the contract."

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*While *affect* is usually a verb, it is used in psychology as a noun (for example, the Jones affect). The word *effect* almost always is a noun, but it is used *very rarely* as a verb, as in "Temperature effected a change in elasticity." (This means temperature *brought about* a change in elasticity.)

fewer/less: *Fewer* is used in reference to the *number* of things, while *less* refers to the *quantity* (or amount) of an object. For example, "Our model has fewer adjustable parameters" (i.e., fewer number of parameters), and "The high-efficiency engine used less gasoline" (i.e., a lesser amount of gasoline).

irregardless: *Irregardless* is an example of a double negative. The prefix *ir-* and the suffix *-less* both negate *regard*. Please write *regardless* anytime you are tempted to write *irregardless*.

its/it's: Here is a nagging exception to the rule that you add an apostrophe to indicate the possessive form. The word "its" is the possessive form: "Its color was red." The word *it's* is a contraction of *it is*: "It's hot today." In general, *avoid contractions in formal writing*.

Key idea: Avoid contractions in formal writing.

personification: Personification (also called anthropomorphism) is the assignment of human characteristics to nonhuman objects, as in "The day smiled on me." Personification should be avoided in technical writing. Some people dislike the assignment of any active verb to any inanimate objects. In this view, some say you should avoid statements such as "The data show . . . " or "The experiments demonstrate . . . ." Although there is a difference of opinion on this matter, it is best to avoid egregious examples of personification in your technical writing (such as "The data really grabbed me by the throat," which is too informal as well).

precede/proceed: *Precede* means *to come before*, while *proceed* means *to continue or move forward*. Thus, "The air-conditioning study preceded the heating study" (meaning that the air-conditioning study was conducted first) and "The work proceeded without interruption" (meaning that the work continued without interruption).

presently: *Presently* means both *soon* and *currently*. Strunk and White (1979) suggest that *presently* be used only in the sense of *soon*.

4.10 Proofreading

Key idea: Always proofread your work.

The secret to good proofreading is practice. You can check your proofreading skills by asking others to read your work and give you feedback. An example of proofreading is given in Example 3.

EXAMPLE 3: PROOF-READING

Read the following paragraph and list the errors you encounter. Allow 60 seconds for this exercise. Rewrite the paragraph to eliminate the errors. **[*Warning:* The following text may contain errors!]**

Abstract

Project personnel conducted a laboratory study to definitively determine the engineeering feasability of polychlorinated biphenyl (PCB) removal by granular activated carbon. The study used an expanded bed granular activated carbon reactor in the upflow mode. PCB concentrations in the column effluent was measured by standard techniques. Study data is consistent with surface diffusion as the rate-limiting step, although much scatter in the data is observed. Columns were sacrificed at the conclusion of the study and carbon analysis revealed PCB saturation is the first 50% of the bed. Future studies will be conducted on the affect of the recycle rate on column performance.

SOLUTION

A list of errors (with the corresponding section numbers in parentheses) is given in Table 3.

TABLE 3 Errors in Proofreading Example

Sentence	Error(s)
First sentence	"to definitively determine" is a split infinitive (4.5), "engineeering" (engineering) and "feasability" (feasibility) are misspelled (4.7)
Second sentence	" . . . expanded bed granular activated carbon reactor . . . " contains an adjective chain (4.5)
Third sentence	" . . . concentrations . . . was . . . " is a subject/verb mismatch (4.1). The use of the passive voice (4.2) is discouraged, unless it is clear who analyzed the samples from other parts of the report.
Fourth sentence	" . . . data is . . . " is a subject/verb mismatch (4.1). *Note*: The sentence " . . . much scatter in the data is . . . " is fine, since the subject, "scatter," is singular.
Fifth sentence	This sentence is a long sentence (3.2). Also, the sentence should read, " . . . saturation *in* the first . . . " (rather than " . . . saturation *is* the first . . . ").
Sixth sentence	Use of passive voice is inconsistent with the active voice used elsewhere in the paragraph (4.2). Also, "affect" should be "effect" (4.9).

Here is an improved version of the abstract:

Abstract

Project personnel conducted a laboratory study to determine definitively the engineering feasibility of polychlorinated biphenyl (PCB) removal by granular activated carbon (GAC). The study used an expanded bed GAC reactor in the upflow mode. A contract laboratory measured PCB concentrations in the column effluent by standard techniques. Study data are consistent with surface diffusion as the rate-limiting step, although much scatter in the data is observed. Columns were sacrificed at the conclusion of the study. Carbon analysis revealed PCB saturation in the first 50% of the bed. We plan to conduct future studies on the effect of the recycle rate on column performance.

5 TYPES OF ENGINEERING DOCUMENTS

5.1 Introduction

Thus far in this chapter, you have been exposed to the organization of engineering reports. Reports are used to present the results of a study. A report may transmit the results of the entire project (called a *final* or *full report*), transmit the results of a portion of the project (called a *progress report*), or transmit a small piece of a report in a short form (often called a *letter report*).

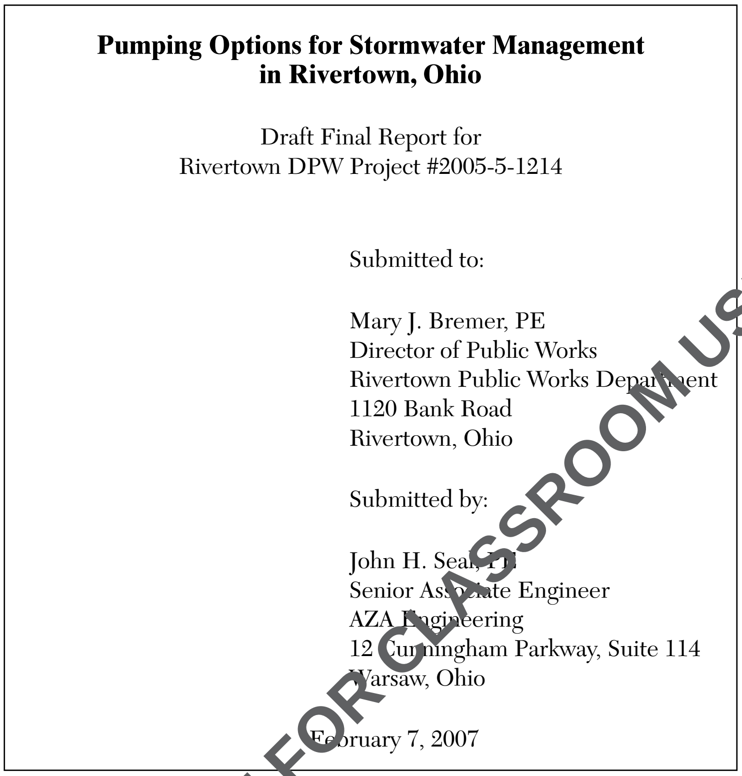
In addition to reports, engineers write several other kinds of documents. Common document types include letters, memorandums, and email.

5.2 Reports

Key idea: Reports should include a cover page and a transmittal letter.

The general outline of an engineering report was discussed in Section 2. Two other elements of a report deserve mention. First, every report should have a cover page. A cover page includes the names of the authors (and their professional titles), the names of the recipients (and their professional titles), the report or project title, a project identifier, and the date. Many formats are possible, as long as this information is included. Locate the required information for a cover page in the example cover page in Figure 1.

Second, most reports have a *transmittal letter* (also called a *cover letter*). The transmittal letter is a short letter that accompanies the report. The format of letters is presented in Section 5.3.



Pumping Options for Stormwater Management
in Rivertown, Ohio

Draft Final Report for
Rivertown DPW Project #2005-5-1214

Submitted to:

Mary J. Bremer, PE
Director of Public Works
Rivertown Public Works Department
1120 Bank Road
Rivertown, Ohio

Submitted by:

John H. Seal, PE
Senior Associate Engineer
AZA Engineering
12 Cunningham Parkway, Suite 114
Warsaw, Ohio

February 7, 2007

Figure 1. An Example of a Cover Page

Key idea: Letters should have a heading (including the date, recipient's name, and title), closing (including your name, title, and signature), and structured paragraphs (the first paragraph should summarize previous correspondence and state the purpose of the letter, the next paragraphs should present supporting information, and the last paragraph should summarize the main point and state the required actions or follow-up communication).

5.3 Letters

Engineers use letters to document the transmission of ideas to the client or other agency. Letters must have structure. The heading of a letter includes the date and recipient's name and title. The first paragraph of a letter should summarize previous correspondence and state the purpose of the letter. In the next paragraph or paragraphs, supporting information should be presented. The last paragraph of the letter should summarize the main points and state the required actions or follow-up communication. In the closing information of a letter, include your name, title, and signature. An example letter is shown in Figure 2. Note the heading information; introductory, supporting, and concluding paragraphs; and closing information.

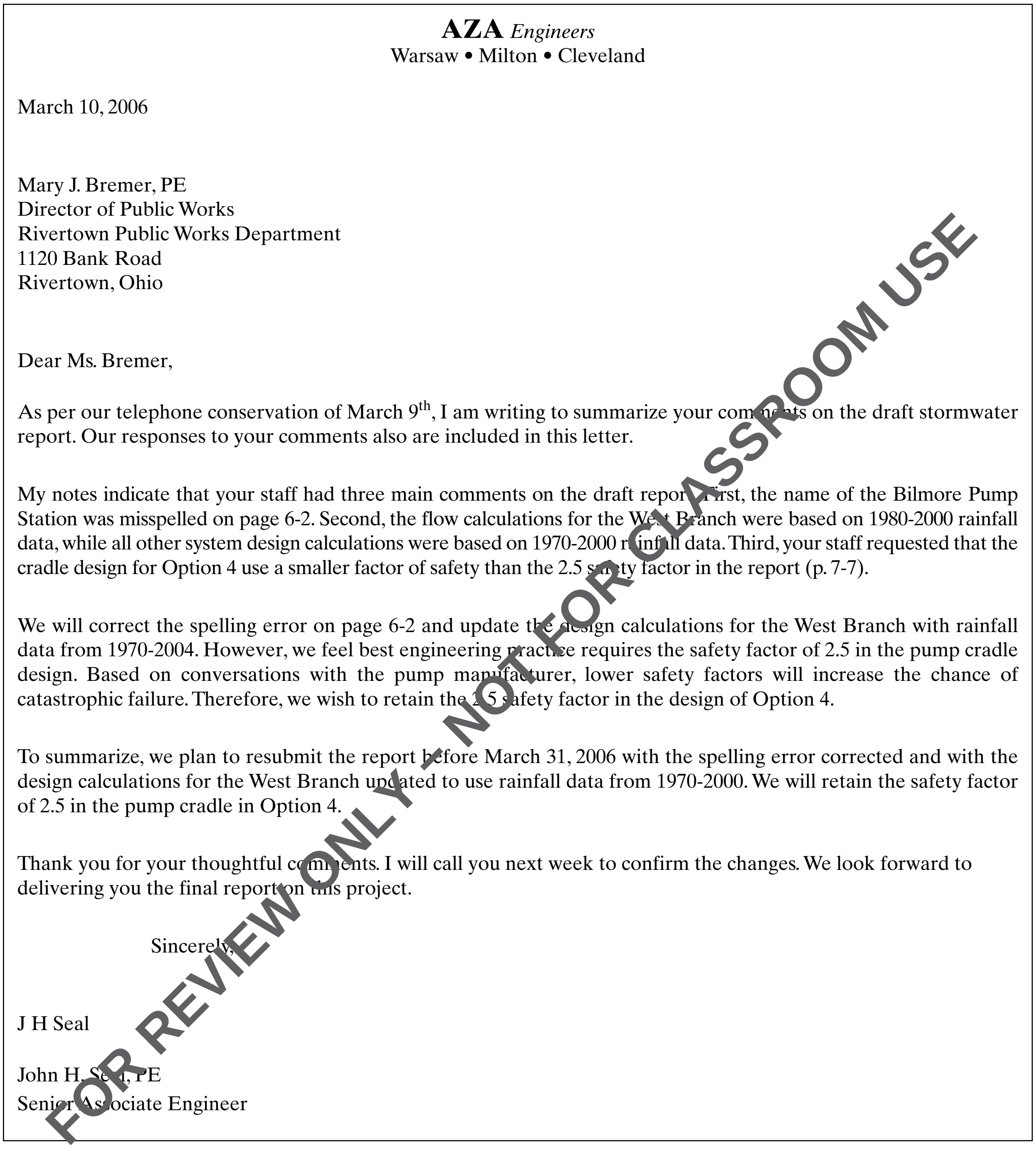
memorandum: A short note used to document engineering work

Key idea: Memos should have a heading (including to whom the memo is written, who wrote the memo, the memo topic, the date, and the word *Memorandum*), and the same structured paragraphs as a letter.

5.4 Memorandums

A ***memorandum*** (plural: memorandums or memoranda) is a short note. Similar to letters, memorandums are used for short documentation of engineering work. In fact, the word *memorandum* is a shortened form of the phrase *memorandum est*—Latin for "it is to be remembered." Memorandums are frequently used for messages inside an organization (called *internal memorandums*).

Memorandums (or memos) are structured similarly to letters (see Section 5.3), but without the heading and closing information of a letter. Heading information in a memo tells you to whom the memo is written, who wrote the memo, the memo topic, the date, and the word *Memorandum*.



AZA *Engineers*
Warsaw • Milton • Cleveland

March 10, 2006

Mary J. Bremer, PE
Director of Public Works
Rivertown Public Works Department
1120 Bank Road
Rivertown, Ohio

Dear Ms. Bremer,

As per our telephone conservation of March 9th, I am writing to summarize your comments on the draft stormwater report. Our responses to your comments also are included in this letter.

My notes indicate that your staff had three main comments on the draft report. First, the name of the Bilmore Pump Station was misspelled on page 6-2. Second, the flow calculations for the West Branch were based on 1980-2000 rainfall data, while all other system design calculations were based on 1970-2000 rainfall data. Third, your staff requested that the cradle design for Option 4 use a smaller factor of safety than the 2.5 safety factor in the report (p. 7-7).

We will correct the spelling error on page 6-2 and update the design calculations for the West Branch with rainfall data from 1970-2004. However, we feel best engineering practice requires the safety factor of 2.5 in the pump cradle design. Based on conversations with the pump manufacturer, lower safety factors will increase the chance of catastrophic failure. Therefore, we wish to retain the 2.5 safety factor in the design of Option 4.

To summarize, we plan to resubmit the report before March 31, 2006 with the spelling error corrected and with the design calculations for the West Branch updated to use rainfall data from 1970-2000. We will retain the safety factor of 2.5 in the pump cradle in Option 4.

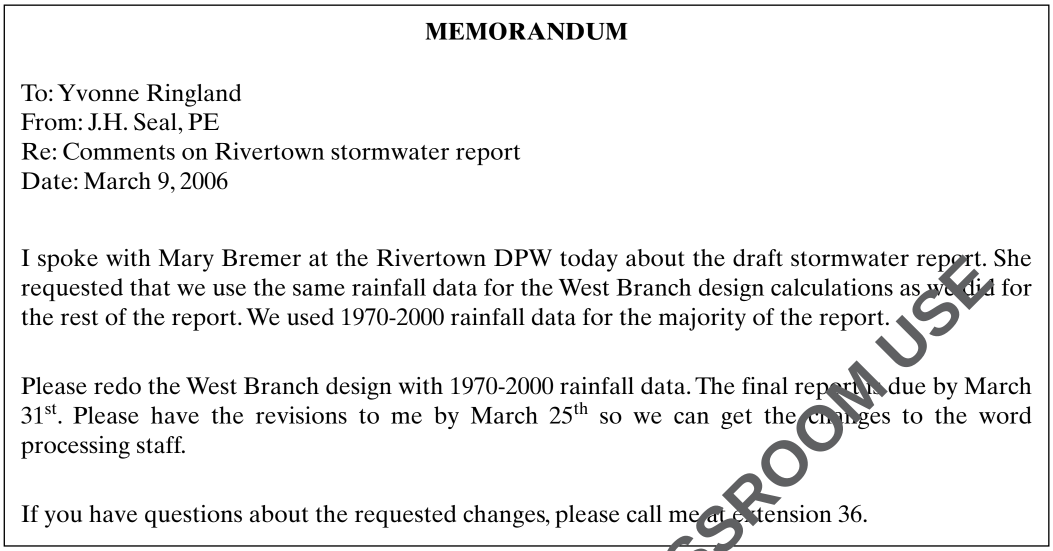
Thank you for your thoughtful comments. I will call you next week to confirm the changes. We look forward to delivering you the final report on this project.

Sincerely,

J H Seal

John H. Seal, PE
Senior Associate Engineer

Figure 2. Example of a Technical Letter



MEMORANDUM

To: Yvonne Ringland
From: J.H. Seal, PE
Re: Comments on Rivertown stormwater report
Date: March 9, 2006

I spoke with Mary Bremer at the Rivertown DPW today about the draft stormwater report. She requested that we use the same rainfall data for the West Branch design calculations as we did for the rest of the report. We used 1970-2000 rainfall data for the majority of the report.

Please redo the West Branch design with 1970-2000 rainfall data. The final report is due by March 31st. Please have the revisions to me by March 25th so we can get the changes to the word processing staff.

If you have questions about the requested changes, please call me at extension 36.

Figure 3. Example of a Memorandum

Memo paragraphs are similar to those of letters: previous correspondence and memo purpose should be summarized in the first paragraph, supporting information in the following paragraphs, and main points summarized in the last paragraph. An example of a memo is given in Figure 3. Note the heading information and purpose of each of the three paragraphs. A copy of this memo likely would be placed in the project file to document the internal communication of the consulting firm.

5.5 Email

Key idea: When writing business email, avoid contractions and emoticons, proofread carefully, double-check the recipient list, and do not include anything in an email that you would not include in other business documents.

Nearly every college student in the 21st century has used email, usually for informal conversation. Email also can be used in formal business correspondence, sometimes in place of a letter or memo.

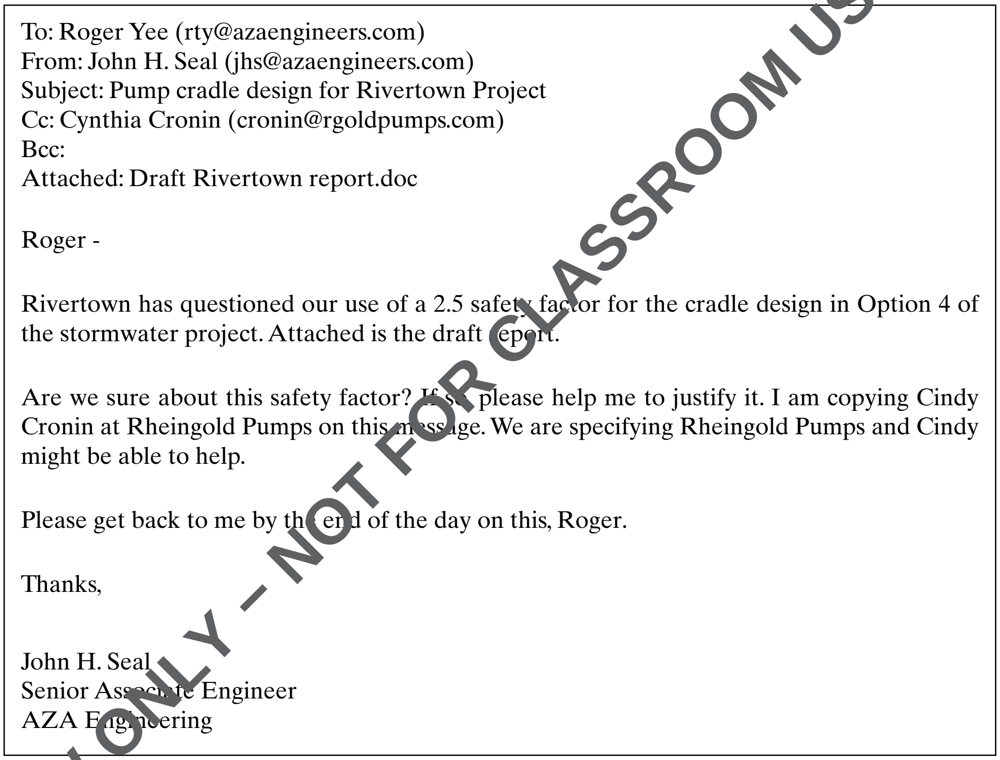
Although email is less formal than other forms of written communication, it is easy to let an overly familiar style creep into your formal email correspondence. You use different words in speaking to clients and colleagues than you use to speak to friends at a party. Similarly, use more formal language in business email. Following are some rules for business email correspondence:

- Avoid email contractions (e.g., *RU* for *are you* and **s** for *smile*).
- Avoid *emoticons*—text characters used to express emotions (such as :-) for a smiley face).
- Proofread carefully before you hit "send." Look for language that may be offensive or inappropriate.
- Double-check the names on the "to" list before you send the email. "Replying to all" with the results of your recent medical check-up (when you intended to forward the results to your roommate) is a serious breach of business protocol.

- Emails are as much a part of the technical and legal record as are other documents. Do not include anything in an email that you would not include in other business documents.

An example of a business email message is shown in Figure 4.

Email is not the only kind of electronic written document in engineering today. For a look at the future of written technical communication, see the *Focus on Writing: Whither Paper Reports?*



To: Roger Yee (rty@azaengineers.com)
From: John H. Seal (jhs@azaengineers.com)
Subject: Pump cradle design for Rivertown Project
Cc: Cynthia Cronin (cronin@rgoldpumps.com)
Bcc:
Attached: Draft Rivertown report.doc

Roger -

Rivertown has questioned our use of a 2.5 safety factor for the cradle design in Option 4 of the stormwater project. Attached is the draft report.

Are we sure about this safety factor? If so, please help me to justify it. I am copying Cindy Cronin at Rheingold Pumps on this message. We are specifying Rheingold Pumps and Cindy might be able to help.

Please get back to me by the end of the day on this, Roger.

Thanks,

John H. Seal
Senior Associate Engineer
AZA Engineering

Figure 4. Example of a Business Email

FOCUS ON WRITING: WHITHER PAPER REPORTS?

BACKGROUND

Probably since the first pyramid was built, engineers have been summarizing their work by writing reports. This chapter was devoted to helping you write better reports and other engineering documents. There are many cases in which the results of engineering work are better communicated by electronic documents. Many clients now are requesting electronic or on-line reports.

ELECTRONIC MANUALS

As an example of electronic reporting, many industries are replacing entire bookshelves of operation and maintenance (O&M) manuals with *on-line manuals*. The on-line O&M manuals typically are written in HTML, XML, or other programming languages used in Web page development. In addition, manuals and other electronic engineering documents commonly are written in Adobe's proprietary *portable document format* as PDF files.

Electronic manuals have a number of advantages over traditional documentation. First, they reduce the need for operations and maintenance training. Perez et al. (2001) estimated that the effectiveness of O&M training at a drinking-water treatment plant was increased four- to sixfold using on-line materials as compared with paper manuals. More effective training results in fewer errors and cost savings.

Second, electronic manuals are much easier to keep current. Engineers struggle to maintain current sets of plans about engineered systems. Facilities personnel need to know the actual conditions of the structure (as-built conditions), not the system as originally designed (design conditions). Electronic manuals allow engineers to update material very quickly and accurately. The underlying database of equipment and other system attributes can be updated centrally, allowing users to access up-to-date information from any location.

Third, electronic manuals are easier to access. Facility personnel sometimes dread the thought of flipping through literally thousands of pages of manuals in three-ring binders to find the information they need. Electronic manuals are written with *hyperlinks* (as on Web pages). This allows the user to find related information quickly. In fact, electronic manuals look like Web pages. As with the Web itself, e-manuals can be very graphically oriented, with liberal use of drawings, photographs, and videos. In addition, electronic manuals can be linked to manufacturer's Web pages. If, say, you need a new gasket for a pump, you can click on the manufacturer's link and find the part easily.

Fourth, electronic manuals are portable. Many electronic manuals are mounted on company intranets, allowing for secure access by facility personnel from any location. In other cases, the manuals are burned onto CD-ROMs. One CD-ROM can replace up to 1,540 pounds of paper manuals (Perez et al., 2001).

WILL YOU EVER SEE A PAPERLESS OFFICE?

For the foreseeable future, engineers probably will continue to produce reports on paper. The "paperless office" continues to be frustratingly just out of reach. However, the engineer's life is becoming increasingly "webcentric" (i.e., centered on the World Wide Web). As an engineer of the future (and as a person brought up to think of the Internet as an important resource), you should think creatively about how information needs in engineering can be addressed by electronic sources. Always ask whether electronic documents will add value to the information (by allowing linkage to other data sources or by providing real-time data or by using multimedia formats).

Perhaps in your lifetime, paper reports will become as quaint as slide rules and manual typewriters. Regardless of the delivery medium, engineering reports will still be based on the principles outlined in this text: organization, signposting, and clarity.

6 SUMMARY

The key to good written technical documents is *organization*. The typical structure of an engineering report includes several aspects: the abstract (or executive summary), introduction/background/literature review, methods, results, discussion, conclusions/recommendations, and references.

Technical documents also must be organized at the paragraph, sentence, and word levels. Choose words to make your writing concise, simple, and specific. In your technical writing, be aware of the rules of grammar and spelling. Strive to use the active voice and avoid gender-specific language. Always proofread your work before allowing it to leave your hands.

In addition to reports, engineers produce letters, memos, and emails almost daily in their working lives. Letters have a heading, a closing, and structured paragraphs. The first paragraph summarizes previous correspondence and states the purpose of the letter. The next paragraphs present supporting information. The last paragraph summarizes the main points and states the required actions or follow-up communication. Memos have the same paragraph structure, with a different heading and no closing. Business emails are part of the business record and should be created and sent in a professional manner.

SUMMARY OF KEY IDEAS

- Organize technical documents from the largest to smallest scale: outline level, paragraph level, sentence level, and word level.
- Common elements of technical documents include the abstract (or executive summary), introduction/background/literature review, methods, results, discussion, conclusions/recommendations, and references.
- The abstract should contain a summary of each element of the report.
- The introduction should take the reader from the report title to an understanding of why the report was written.
- In the methods section, justify the study approach, present data collection techniques, and discuss data analysis methods.
- In the results section, present the results and note the general trends.
- Interpret data in the discussion section.
- Conclusions and recommendations are often in list form and should be written very carefully.
- Although many reference formats are acceptable, the references must be complete and consistent.
- Use section headings or numbering schemes as signposts in technical documents.
- Each sentence should express a single idea.
- Choose words to make your writing concise, simple, and specific.
- Avoid making up new words or new uses of words in conventional technical writing.
- Make sure that the subject and verb agree in number (i.e., they must be both singular or both plural).
- Use a consistent voice, with preference for the active voice.
- Generally use the present tense, unless describing work done in the past.
- Avoid the use of gender-specific pronouns.
- Use *who* as a pronoun for human subjects, *that* for specific nonhuman subjects, and *which* for nonhuman subjects in clauses set off by commas.
- With adjectives and adverbs, avoid adjective chains and make sure the adverb or adjective modifies only the verb or noun you intend to modify.
- Avoid nonstandard capitalization and abbreviations.
- Never assume a document is free of errors because it passes the spell checker.
- Make sure you give credit (by use of a citation) when presenting someone else's words or ideas.
- Avoid double negatives in formal writing.
- Avoid contractions in formal writing.
- Always proofread your work.

- Reports should include a cover page and a transmittal letter.
- Letters should have a heading (including the date, recipient's name, and title), closing (including your name, title, and signature), and structured paragraphs (the first paragraph should summarize previous correspondence and state the purpose of the letter, the next paragraphs should present supporting information, and the last paragraph should summarize the main points and state the required actions or follow-up communication).
- Memos should have a heading (including to whom the memo is written, who wrote the memo, the memo topic, the date, and the word *Memorandum*) and the same structured paragraphs as a letter.
- When writing business email, avoid contractions and emoticons, proofread carefully, double-check the recipient list, and do not include anything in an email that you would not include in other business documents.

Problems

1. Pick two textbooks other than this one. What kinds of signposting are used in the texts? Describe the scheme used to show hierarchy in the signposting.
2. What are the characteristics of a good sentence?
3. What are the three aspects of good word choice in technical writing? Find good and poor examples of word choice in a newspaper or technical journal.
4. List whether the following nouns should take a singular or plural verb form: engineer, axes, phenomena, axis, datum, criterion, thermodynamics, phenomenon, Microsoft, and criteria. You may need to use a dictionary.
5. Find five examples of the use of passive voice in this text. Rewrite them in the active voice.
6. Repair the following paragraph, if necessary. **[*Warning*: The following material may contain errors!]**

   Plans and specifications who lack careful preparation may be faulty. The engineer must use all his skill to find and correct the problems. The engineer that refines her own design is more likely to find their own errors.
7. For each of the following, identify the problem or problems in the use of adjectives or adverbs, if any, and correct the errors. **[*Warning*: The following material may contain errors!]**

   a. "The mass-produced germanium junction transistor was a major advance."
   b. "The project manager attempted to slowly accelerate the production rate."
   c. "The contract only required plant construction, not the operation of the plant."
   d. "Alternating current power transmission first occurred at Niagara Falls in 1895."

8. Select any paragraph in this text. Paraphrase the idea without a direct quotation, and include a citation and a reference. Repeat with a paragraph from a technical journal of interest to you.
9. Write a letter to your professor asking for permission to take a make-up exam.
10. Write a memo to a classmate to organize a study session for one of your courses.

Oral Technical Communications

1 INTRODUCTION

Few activities intimidate new engineers more than public speaking. Technical oral presentations need not be painful. They can be tamed by focusing on three kinds of activities:

- What to do *before* the talk,
- What to do *during* the talk, and
- What to do *after* the talk.

Many people think that the *delivery* is the key to technical talks. While the delivery is important, the truth is that oral presentations are made or broken by the work put in *before* the talk is delivered. A good technical talk is well organized, with instructive visual aids. It is delivered with the help of useful but nonintrusive memory aids. The talk will be rehearsed, but not overly practiced. These critical activities—organization, visual aids design, memory aids design, and practice—take place well before the oral presentation is made to the audience. The details of talk organization and preparation will be presented in Sections 2 through 4.

What is your gut reaction to the thought of standing up before a handful or dozens or hundreds of people and delivering technical material? If your palms are sweating already, then Section 5 may help. In Section 5, your plan of action immediately before the talk (including how to deal with nervousness) will be reviewed. You will learn what to say and how to say it.

Finally, improvement in your technical speaking skills is made only by what you do after the talk. Section 6 will provide hints on obtaining feedback and implementing good speaking habits.

SECTIONS

OBJECTIVES

After reading this chapter, you will be able to:

- organize a technical oral presentation;
- design visual aids;
- design memory aids;
- deliver an effective technical oral presentation.

From *A User's Guide to Engineering*, James N. Jensen.

2 BEFORE THE TALK: ORGANIZATION

Key idea: Technical presentations can be improved by considering the activities before the talk, during the talk, and after the talk.

Key idea: Identify the presentation goals, target audience, and constraints on the presentation (especially time constraints).

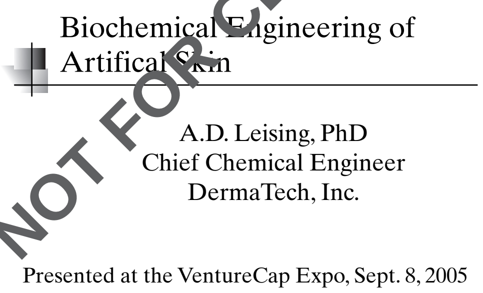
visual aids: media used to accompany oral presentations (e.g., slides and overhead transparencies)

title slide: visual aid containing the presentation title and information about the authors

Recall that before writing a single word of the oral presentation, you must identify the goals of the presentation, the target audience, and the constraints on the presentation. The main constraint on oral presentations is the time allotted for the talk. In your career, almost every oral presentation you give will have time constraints. One key to good oral presentations is to respect your audience's time and use their time wisely.

Only after identifying goals, audience, and constraints can an outline be written. With an outline in place, the individual **visual aids** can be designed. Technical talks usually begin with a **title slide**.* The title slide contains the title of the talk and the names and affiliations of the authors. The title slide is the oral presentation equivalent of the cover page. Any example title slide is shown in Figure 1.

In many technical presentations, the second slide is an outline or overview of the talk. While an outline slide is optional, it serves as a good road map for the remainder of the talk. Audiences may feel more comfortable if they know where the presentation is going. The outline slide is the first opportunity for signposting in an oral technical presentation. An example outline slide is shown in Figure 2.

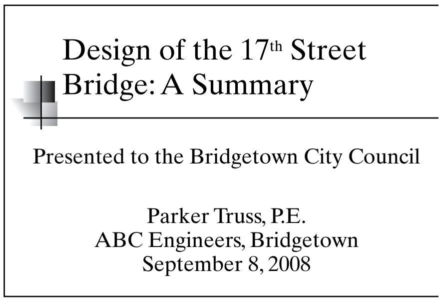


Biochemical Engineering of
Artifical Skin

A.D. Leising, PhD
Chief Chemical Engineer
DermaTech, Inc.

Presented at the VentureCap Expo, Sept. 8, 2005

Figure 1. An Example of a Title Slide



Design of the 17th Street
Bridge: A Summary

Presented to the Bridgetown City Council

Parker Truss, P.E.
ABC Engineers, Bridgetown
September 8, 2008

Figure 2. An Example of an Outline Slide

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*To simplify the language here, visual aids in general will be called "slides." Information of the types of visual aids may be found in Section 3.2.

Key idea: Use an outline to organize the talk and an outline slide to show your organization.

The remaining sections of a technical talk vary with the goals and target audience. A generic structure that includes an introduction/background, methods, results, discussion, conclusions, and recommendations is a good place to start. Technical talks rarely include an abstract, formal literature review, or list of references.

3 BEFORE THE TALK: DESIGNING VISUAL AIDS

Key idea: The number of visual aids should be about $^{3}/_{4}$ times the number of minutes allotted to the presentation.

Once the outline has been established, you can start to design the visual aids. A major difference between written and oral presentations is the reliance on visual aids in oral communication. You must select the number, type, and content of visual aids.

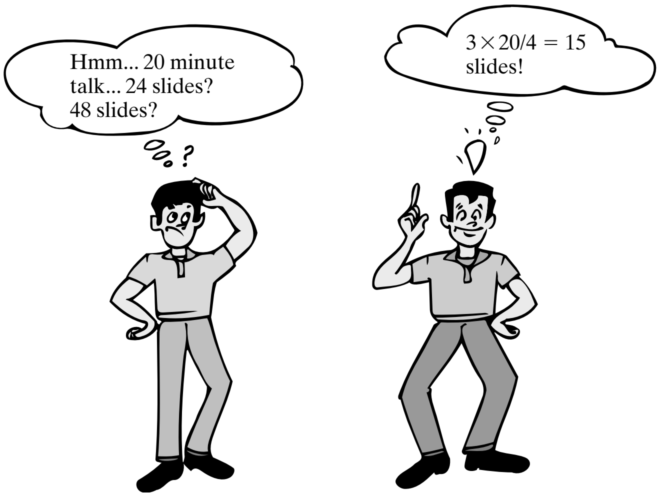
3.1 Number of Visual Aids

The number of visual aids depends most strongly on the length of the presentation. *To estimate the maximum number of visual aids, multiply the number of minutes in the presentation by 0.75.* For example, a 30-minute talk should have no more than 21 to 23 slides.

The natural tendency is to prepare too many visual aids. After all, if the number of slides is $^{3}/_{4}$ of the number of minutes, then the average time per slide is $^{4}/_{3}$ minutes = 80 seconds. Many first-time speakers reason that several of the slides in the presentation (e.g., the title and outline slides) will take much less than 80 seconds to present. They conclude that they can have *many more* slides than the number calculated from $^{3}/_{4}$ (number of minutes). *This logic almost always leads to very rushed and incoherent presentations*. Until you become very experienced in oral technical presentations, use the "$^{3}/_{4}$ times the number of minutes" value as a firm guide.

3.2 Types of Visual Aids

Several types of visual aids are available, including slides, overhead transparencies, poster boards and flip charts, blackboards and whiteboards, and computer displays and projectors. Physical models and material to be passed around the audience also are used as visual aids.



Key idea: In selecting the type of visual aid, consider image quality, eye contact, and production cost and time. Then use only one type of visual aid in a talk.

In selecting a type of visual aid, three factors are important: image clarity, maintenance of eye contact, and production cost and time. The advantages and disadvantages of several types of visual aids are summarized in Table 1. In many professional presentations, image clarity may be paramount. It may be worth the money to produce the highest quality images available.

Eye contact is important for two reasons. First, it allows you to get feedback from the audience. Are they bored? Engaged? Having trouble hearing you? Second, eye contact allows the audience to be drawn into your words. Try listening to a movie or television program with your eyes shut. The magic is reduced when the eye contact is lost. Still not convinced? The next time you speak before a group of people, notice how much time the audience spends looking at your *eyes* rather than the screen.

Visual aids also can be expensive and time-consuming to produce. Always estimate the cost and time required to produce any visual aid before committing to a type of visual aid. If the turnaround time for producing visual aids is long, you may have to adjust your schedule to meet the presentation deadline.

Regardless of the type of visual aid selected, it is important to use only one type of visual aid. Switching back and forth between two types can be distracting to the audience, especially if the room lights are turned on and off repeatedly. For the vast majority of technical talks, stick to one type of visual aid. Each type of visual aid will be discussed in more detail.

Slides

Color photographic slides provide the sharpest images. Slides come with a major disadvantage: they require the room to be darkened. In a dark room, you risk losing eye contact with the audience. Slides also can be expensive and time-consuming to produce.

Overhead Transparencies

Overhead transparencies, also called *overheads*, provide a good trade-off between image clarity and eye contact. The images may be poorer than slides (although color laser printers are capable of producing very high quality overheads on special transparency film).

In presenting overheads, the room lights generally are on, but dimmed. Thus, eye contact is still possible. Unless you have an assistant, overheads require you to stand

TABLE 1 Types of Visual Aids and Their Characteristics

Type	Image Quality	Eye Contact	Cost and Time	Other
Slides	Very high	Moderate (room dark)	Moderate	Image very sharp
Overhead transparencies	High	Good	Small	Good compromise
Poster boards and flip charts	Very high	Excellent	Moderate to large	Good for smaller audiences
Whiteboards and blackboards	Low	Excellent	Very small	For informal work
Computers	Can be very high	Moderate (room dark)	Small	Watch compatibility problems

near the projector. Avoid blocking the audience's view of the projection screen with your body.

Poster Boards and Flip Charts

Poster boards and flip charts are large-format visual aids, displayed on an easel. They are used frequently by consulting engineers because they allow the lights to be on; thus, they maximize eye contact with the audience and increase audience participation. Poster boards and flip charts are not appropriate for large audiences.

Blackboards and Whiteboards

Blackboards and whiteboards are appropriate for informal technical presentations. Their use allows the audience to write notes at the same pace as the speaker/writer. They are a good choice when note taking is important or when audience participation is critical.

Computers

Computer-based presentations quickly are becoming the most common delivery mode for technical presentations. Computer-based presentations have a number of advantages over other media:

- They can be changed at the last moment.
- They can include Internet-based materials, videos, and animations.
- They avoid the expense and lead time required to make photographic slides.

Computer-based presentations have several disadvantages as well. Compatibility problems often arise between notebook computers and projection devices. It is important to make sure that your notebook computer interfaces properly with the intended projector. The ability to change computer-based presentations at the last minute may tempt you to throw together the talk at the last minute. As always, do not let the technology control the message.

Computer-based presentations offer their own challenges regarding the content of the slides. Information on content specific to computer-based presentations is presented in Section 3.5.

3.3 Content of Visual Aids: Word Slides

There are two types of visual aid content: word slides and data slides. Word slides typically contain only words, symbols, and/or equations. Data slides communicate data and may include tables or figures.

Key idea: Word slides should contain as few words as possible.

Word slides should contain as few words as possible to communicate the required information. *It is undesirable to fill a word slide with text*: the audience will read the words rather than look at you.[*] *You* want to take control of the material and present it to the audience yourself.

Sometimes, symbols or equations can be used in place of words. The choice of equations or words depends on the audience. For a technical audience, a word slide about Newton's Second Law of Motion might contain the equation $F = ma$. For a less technical audience, the gist of the Second Law may be more clearly made with words:

---

[*] You can prove this point to yourself with a simple experiment. Gather a group of 20 or so people. Prepare two overheads: one with a wordy message and one with an abbreviated form (e.g., "The rain in Spain falls mainly in the plains" and "Spain: Rains in plains"). Show the first overhead and present the message word for word. Show the second overhead and use the same word-for-word speech as the first overhead. You will notice that the audience's eyes are on the screen when you show the first overhead. Their eyes are more likely to be on you when you show the second overhead.

"Force is proportional to both acceleration and mass." For a nontechnical audience, perhaps a cartoon would best illustrate the point.

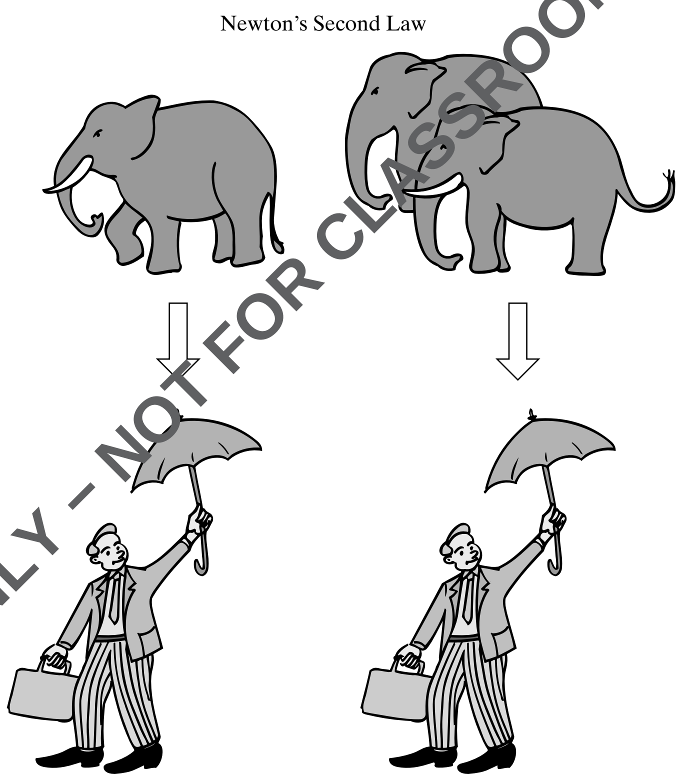
For a technical audience:
Newton's Second Law

$$F = ma.$$

For a less technical audience:
Newton's Second Law

Force is proportional to both acceleration and mass.

For a nontechnical audience:

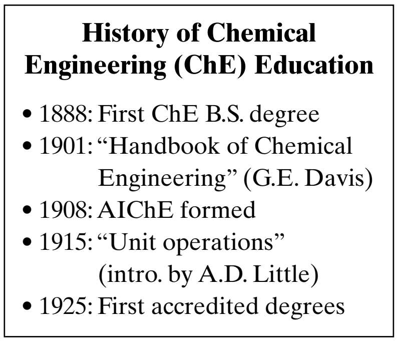


Newton's Second Law

The force doubles when the mass doubles.

Word slides should take into account the shape of the visual aid. For example, overhead transparencies and computer-based presentation slides have a length-to-width ratio of 11:8.5 ≈ 1.3:1. Photographic slides usually have a ratio of about 0.7:1. It is pleasing to the eye to have the word shape match the visual aid shape.

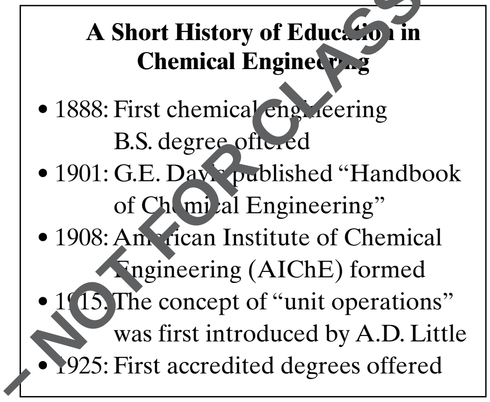
Matching the word shape to the visual aid shape also means that the font size can be as large as possible. It is important in word slides to use a large font size. Typically, slides and overheads should have font sizes from about 28 to 44 point. Use consistent font sizes (i.e., major headings all in one size and minor headings all in another size). Presentation software (such as Microsoft PowerPoint or Corel Presentations) can help in maintaining a consistent presentation format. Two word slide examples may be found in Figures 3 and 4.



History of Chemical Engineering (ChE) Education

- 1888: First ChE B.S. degree
- 1901: “Handbook of Chemical Engineering” (G.E. Davis)
- 1908: AIChE formed
- 1915: “Unit operations” (intro. by A.D. Little)
- 1925: First accredited degrees

Figure 3. Word Slide Example 1 (dates from http://www.cems.umn.edu/~aiche_ug/history/h_toc.html)



A Short History of Education in Chemical Engineering

- 1888: First chemical engineering B.S. degree offered
- 1901: G.E. Davis published “Handbook of Chemical Engineering”
- 1908: American Institute of Chemical Engineering (AIChE) formed
- 1915: The concept of “unit operations” was first introduced by A.D. Little
- 1925: First accredited degrees offered

Figure 4. Word Slide Example 2

PONDER THIS

Critique the examples in Figures 3 and 4. Which would be more appropriate for an oral presentation? How could both examples be improved?

Note the use of abbreviations in Figure 3. Abbreviations allow for a larger font size to be used. Small words (*the* and *of*) are eliminated to avoid having the audience read the text rather than listen to the words. In both examples, the slide needs to be *presented*. Figure 3 would make a better slide in an oral presentation. Figure 4 might be better in a written document, where no additional words are used to explain the text.

3.4 Content of Visual Aids: Data Slides

Key idea: Create tables specific to the point you wish to make.

Data slides can be tables or figures. In oral presentations, it is critical that *tables contain only the data required*. Speakers sometimes photocopy large tables onto overhead transparencies and present the tabular material as follows: “I know you can’t read all the numbers in this table, but note that the gear ratio of 20-to-1 was optimal.” If you wish to speak about a gear ratio of 20:1, design a data or word slide specific to that point.

Properties of Air

Temp. (°C)	Density (kg/m³)	Viscosity (N-s/m²)	Speed of Sound (m/s)
−40	1.514	1.57	306.2
−20	1.395	1.63	319.1
0	1.292	1.71	331.4
20	1.204	1.82	343.3
40	1.127	1.87	349.1
60	1.060	1.97	365.7

"I know you can't read all the tiny numbers, but the speed of sound in air is less than 350 m/s in the temperature range of 0 to 20°C."

"As you can see, the speed of sound in air is less than 350 m/s in the temperature range of 0 to 20°C."

Properties of Air

Temperature (°C)	Speed of Sound (m/s)
0	331.4
20	343.3

Make tables specific to the points you wish to emphasize.

3.5 Special Notes about Computer-Based Presentations

Today's software allows you to prepare amazing computer-based presentations, with vibrant colors, inspiring animations, and hundreds of fonts. While all those embellishments are possible, you must ask yourself if they are right for your presentation and your audience.

PONDER THIS

How can you decide if animations and other embellishments are appropriate?

Use the same criteria that you applied to all other aspects of your presentation: Do the embellishments help you to deliver your message to the target audience?

Key idea: With computer-based presentations, watch the colors, number of fonts, and animations.

You should keep a few thoughts in mind as you design computer-based presentations. First, *go easy on the color combinations*. Start with the prepackaged color combinations in the presentation software. Stick with two to four colors, using them consistently for signposting. If you have poor color vision or are unsure of your artistic skills, then you may wish to have a friend review your work prior to presentation.

Second, *use a small number of font families*. You can use font size and font weight (bold, italic, etc.) to create a style, but using many font families is distracting. For example, some textbooks are written with only two font families (Times New Roman and Arial), but over a dozen combinations of font size and weight. If you use nonstandard fonts, then you can run into font availability problems if you use a different computer for the presentation than you used to create the talk.

Third, *be very careful about animations* (e.g., flying text and swirling slide transitions). Some people find animations very annoying. Use them sparingly unless you know your audience well.

4 BEFORE THE TALK: PREPARING TO PRESENT

4.1 Practicing Oral Presentations

Several tricks can make your practice time more valuable. First, practice your talk for the first time *before* the visual aids are finalized. In this way, you can identify and edit

Key idea: Practice before the visual aids are finalized.

any slides that do not make your points as cleanly as you want. Last-minute changes in visual aids can be expensive and stressful (although computer-based presentations are making last-minute changes easier).

Second, record the duration of *each section* of your talk during the first few practice rounds. This approach allows you to judge the *balance* of the talk. The meat of the talk (e.g., the results and discussion if you are presenting project results) should occupy at least half the time. Timing the talk also helps you to know where cuts or additions should take place if the first run-throughs show that the talk is too long or too short.

Key idea: When practicing, time each section as you practice alone and in front of others.

Third, practice the talk both by yourself and in front of others. When practicing by yourself, always *speak aloud* so you can rehearse any troublesome phrases or transitions. In addition, try to practice in front of others to get feedback about the talk before the main presentation (see also Section 6).

How often should you practice the talk before the big day? This is a matter of personal preference. Some people require many practice runs before they feel comfortable with the material, while others become stale after just a few practice sessions. *Experiment with different degrees of practicing to determine what level of preparation suits your personality*.

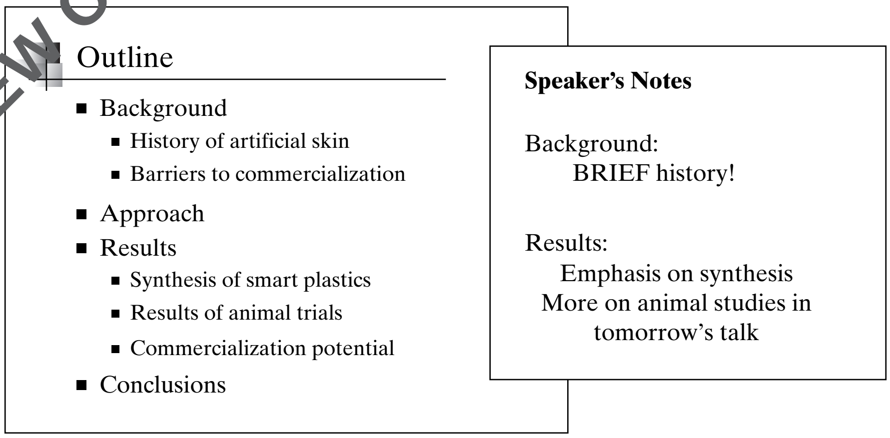
memory aids: notes used to help remember the main points in the talk

4.2 Memory Aids

Memory aids are the notes or devices that help ensure a smooth talk. Memory aids should be designed to help you remember the main points in the talk. Always practice the talk with the same memory aids you intend to use in the final presentation. Common memory aids include

- An outline of the talk
- Note cards containing a list of the key points for each slide
- Speaker's notes in presentation software

An outline lets you see quickly where you are in the presentation. Note cards are useful for making sure that you cover the important points before you go to the next slide. Most computer-based presentation software allows you to put your speaker notes near a miniature version of the slide so you can remind yourself to make the main points you wish.



Outline

- Background
  - History of artificial skin
  - Barriers to commercialization
- Approach
- Results
  - Synthesis of smart plastics
  - Results of animal trials
  - Commercialization potential
- Conclusions

Speaker's Notes

Background:
BRIEF history!

Results:
Emphasis on synthesis
More on animal studies in
tomorrow's talk

Speaker's notes in a computer-based presentation

It pays to take a few seconds to glance at your notes or outline before you change slides. Although a few seconds may feel like an eternity when you are in front of an audience, the slight pause will help you gain confidence that you are not forgetting anything important. Audiences generally appreciate the small respites as well.

Key idea: Avoid memorizing or reading oral presentations.

A final note about memory aids. Do not read the talk or memorize it completely. We all write differently than we talk. A read speech usually sounds "written." A memorized talk almost always sounds mechanical and forced. Read or memorized talks have another pitfall. If you lose your place or become flustered when reading or reciting by memory, general meltdown often occurs. If you use streamlined notes, it is much easier to get back on track.

5 DURING THE TALK

5.1 Pre-Talk Activities

Key idea: Learn about the facilities and coordinate introductions well before the talk.

Before walking to the podium or to the front of the conference room to give your talk, it is important to know what to expect. Examine the podium or speaking area well before the talk begins. Before you begin speaking, you want to know the answers to several questions:

- Is there a pointer?
- Is the projection equipment in working order?
- Who is responsible for changing computer or slide-projector slides? Are personnel available to help with your overhead transparencies?
- What type of microphone is in use?
- Is there a podium light to allow you to read your notes when the room lights go off? (Memory aids are useless if the room is in complete darkness, a fact you do not want to learn during your first technical presentation!)

It is also helpful to find and introduce yourself to the person who will introduce you. He or she may require some background information from you and may be able to help answer questions about the availability of pointers and the like. You should ask whether he or she will signal you when the allotted time has nearly expired.

5.2 Group Presentations

Key idea: Practice transitions between speakers in group presentations.

Group presentations raise their own set of challenges. It is critical to practice the transitions between the speakers. In general, it is better not to have too many speakers in a short period of time. Make sure the responsibilities of each speaker are understood, including whether one speaker will introduce the next speaker.

5.3 Nervousness

The main concern of most neophyte speakers is the control of nervousness. Being nervous means you care about the presentation. This is a positive attribute, as long as you can control the outward signs of nervousness.

Key idea: Do not worry about *being* nervous; learn to control or avoid the *signs* of nervousness.

The key to dealing with "the jitters" is to determine how nervousness affects you. If being nervous makes you speak more quickly, then focus on slowing your pace. If nervousness makes your hands shake, then avoid holding anything (such as notes or a pointer) during the talk. *It is natural to be a little apprehensive, but desirable to minimize the manifestations of nervousness.*

Remember also that for many talks you will give, the audience *wants* you to succeed. You are giving the talk for a reason. It is likely that the members of the audience desire the information you will share with them. Engineers face truly hostile audiences only rarely in their career.

5.4 What to Say

Key idea: Paraphrase information in word slides and point to each item in a list.

Technical presentations consist of two elements: presentation of word or data slides and making transitions between slides. When presenting word slides, it is often useful to paraphrase the material rather than reading it to the audience (see also Section 3.3). Again, you are trying to control the message. With lists, gesture to each item as you present it to remind the audience where you are in the slide.

Keep a mental checklist of the items to be covered during the presentation of figures. You should

Key idea: When presenting figures, tell what the figure is showing, identify the axes, communicate the meaning of each plot, and enumerate the main points to be made.

1. Tell the audience what the figure represents.
2. Identify the axes (with units).
3. Communicate the meaning of each plot (i.e., state the legend information).
4. Enumerate the main points to be made.

Figure 5 contains a sample figure and text showing how the figure would be presented orally. Look at the text in Figure 5 carefully and note the elements presented: a description of what the figure is showing (“removal of dye over time using the new technology”), identification of the axes with units (“time in minutes” and “dye concentration in milligrams per liter”), the meaning of each plot (“solid squares are the experimental data and the line is the first-order model fit”), and enumeration of the main points (“two points to notice in this figure. First, the technology . . . ”).

Tell ’em Rule: the idea that you present information three times in a talk: you tell ’em what you will tell them, then tell ’em the information, and finally tell ’em what you just told them

Recall that it is necessary to remind the audience of your organization. This is crucial in oral presentations. If audience members feel lost, they will tune out completely. There is an old doctrine in public speaking called the **Tell ’em Rule**. According to the Tell ’em Rule, you present information three times in a talk: you tell ’em what

Sample Presentation Text:
Shown here is the removal of dye over time using the new technology. The x-axis is time in minutes and the y-axis is the dye concentration in milligrams per liter. The solid squares are the experimental data and the line is the first-order model fit. There are two points to notice in this figure. First, the technology could reduce the dye concentration to below two milligrams per liter in 20 minutes. Second, the exponential model fits the data reasonably well.

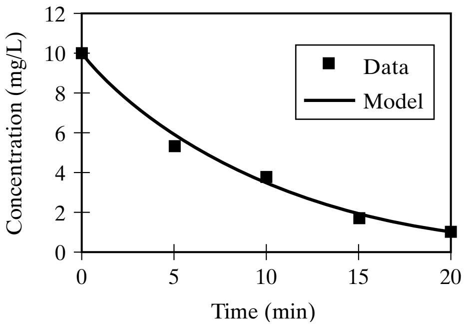


Figure 5. Example of the Presentation of Data in a Figure

you will tell them, then tell 'em the information, and finally tell 'em what you just told them. Following this rule allows for smooth transitions (also called *segues*) between parts of the talk. For example, you may say,

> I wish to give you a little background information on rotary engines. Rotary engines were used first in the automotive industry in . . . . [text omitted for clarity]. Now that I've told you about the history of rotary engines, let's turn to the modern versions of this unique engine type.

Notice the three presentations of the information ("I wish to give you . . . ," "Rotary engines were used first . . . ," and "Now that I've told you about . . . "). Also note the transition to the modern versions of the rotary engine (" . . . let's turn to the . . . ").

Key idea: Use signposting liberally in technical oral presentations.

The process of telling the audience where you are during transitions between major portions of a talk is called *signposting*. The word *signposting* comes from the analogy with road signs: well-spaced markers tell the audience where you are in the talk. Most technical speakers do not signpost enough. Audiences are much more comfortable when they know they are in synch with the speaker. To assist in signposting, it is helpful to present an outline of the presentation near the beginning of the talk. By referring to the outline, you can keep the audience with you through the talk. Intermediate outlines can be placed in the middle of the talk for complicated sections. For example, you may wish to have an outline of the results to guide the audience through the results section.

5.5 How to Say It

The audience responds to two features of a speaker: the speaker's voice and body. The voice should vary in pitch and intensity: a monotone voice leads to a sleeping audience. Speak through each sentence to avoid swallowing words at the end of the sentence. Be aware of the *speed* and *volume* of your voice. It is useful to have a colleague in the audience signal you (discreetly, of course) if you are speaking too quickly or too softly. The volume of your speech depends on the room and amplification.

Key idea: Speak loudly and slowly. Use meaningful hand gestures and move your body without pacing.

Your body movements should be purposeful and strong. The main problem for most speakers concerns what to do with the hands. Use them to your advantage! Hand gestures are a great way to emphasize important points. For the most important messages, make your gestures higher. Avoid holding pens, pencils, or other mental crutches, and **never** leave your hands in your pockets.

Your legs can work for you as well. Avoid standing stock-still. Walk toward the audience and engage its members at critical points in the talk. While mechanical pacing should be avoided, small steps can make a speaker seem more human to the audience.

In spite of your best preparation, things sometimes go wrong in oral presentations. A few true stories are shared in the *Focus on Talks: Horror Stories*.

6 AFTER THE TALK

Key idea: Seek feedback and incorporate changes into your speaking style.

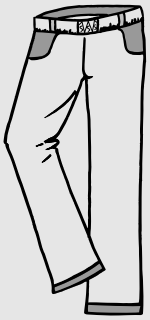
After a talk, seek out feedback from colleagues in the audience. Listen to their constructive criticism and think about modifications to your speaking style that will make communication more effective. Do not be afraid to identify weaknesses in your speaking style and practice ways to overcome them.

Finally, be an attentive listener. Listen critically to other speakers (such as colleagues, professional speakers, actors, and your professors) and note what you like and dislike about their speaking styles. Ask yourself why you like or dislike their speaking style. Why do good speakers engage you personally? Are they friendly, open, and confident? Incorporate the good aspects and avoid the bad in your next presentation.

FOCUS ON TALKS: HORROR STORIES

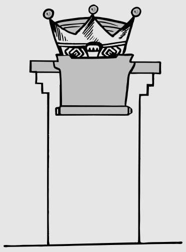
INTRODUCTION

Even after reading this chapter, you may still approach your first professional oral presentation with some trepidation. In this section, a few true stories of oral presentations gone awry are shared. Do not panic when you read these stories. They are offered in the spirit of comic relief and to show you that bad things sometimes happen to good presenters. (*Note*: Stories labeled "Lytle" come from the "Stress of Selling" articles compiled by Chris Lytle on the Monster.com Web site. Stories labeled "Hoff" come from Ron Hoff's (1992) very readable book on oral presentations. All other stories come from my experiences or the experiences of my colleagues.)



FROM THE "DRESS FOR SUCCESS" DEPARTMENT

Numerous speakers have walked back to their seat after an oral presentation, only to discover in horror that their pants or skirt zipper was in the down position. Perhaps "check your zipper" is as important as "check your slides." During a graduate course, I noticed my students giggling every time I turned to face them after writing on the blackboard. When I asked them what was going on, they gleefully informed me that I had a sticker of a lamb on my derrière (courtesy of my then-two-year-old daughter). I keep the sticker on my class notebook to this day to remind me to check my attire.



FROM THE "LOCATION, LOCATION, LOCATION" DEPARTMENT

A colleague of mine relates the tale of a presentation he gave for a job interview. He used a long wooden pointer to emphasize his points. But being a good speaker, he kept good eye contact with the audience. Part way through the talk, he realized that he was pointing *behind* the screen with the pointer.

Podiums also can be a source of frustration. Lytle collected the story of a presenter who stood on a stool behind the podium during a speech to 1,500 people. Shortly after the presentation started, the heel of her pump broke. She fell off the stool and crashed onto the concrete floor. Her sympathetic audience gave her the courage to complete the presentation.

Hoff reports that the Queen of England stepped up to a podium during a visit to the United States, only to find that the podium was higher than her head.

FROM THE "NEVER LET THEM SEE YOU SWEAT" DEPARTMENT

Obviously nervous presenters make the audience a little uncomfortable, so never draw attention to your nervousness. I witnessed a student presentation at a state conference where the speaker was using a laser pointer. The pointer danced all over the screen as the speaker's hand shook. Rather than letting it pass, he said, "Well, look at that—I must be really nervous!"

Hoff reports a company treasurer starting a speech with "I'm so nervous this morning. I hope you can't see how badly my knees are shaking." Guess where the audience's eyes were glued for the remainder of the speech. Of course, you should avoid bringing attention to overconfidence as well. Al Gore probably regrets the sighs picked up by microphones during the first presidential debate of 2000.

FROM THE "EQUIPMENT MALFUNCTION" DEPARTMENT

A colleague of mine gave a technical talk in another country, where a more powerful slide projector bulb was in use. She stared in shock as her first slide literally melted before her eyes. Needless to say, she completed the talk without slides.

Lytle reports a presenter panicking when the overhead projector did not turn on. Reaching down to plug in the power cord resulted in a loud ripping noise as the seam of his pants gave out.

FROM THE "WATCH YOUR LANGUAGE" DEPARTMENT

Word choice is important in oral presentations. Lytle relates a story from a salesman giving a presentation before a defense contractor with a product representative (rep). The product rep had a way of choosing the worst possible words to express himself. Quoting from the Web site: "Discussing the ease with which you can use the product, the other rep stated, 'You don't have to be a rocket scientist to use this.' Twenty rocket scientists [in the audience] sat back in their chairs and crossed their arms. After 20 minutes of weasel words to get their interest back . . . [the rep said], 'We just have to get your propeller heads to talk to our propeller heads to work it out.' With that, their propeller heads stood up and walked out." Phrases like *propeller head* or *gear head*—both derogatory terms for technical staff—are inappropriate in formal speech.

Written words on slides can bite you, too. A consulting engineer reports that she made up slides with the client's names based on a telephone call she made to the client. Unfortunately, several of the names were misspelled, leading to embarrassment and, not surprisingly, an unsuccessful bid for the project.

The moral of these stories? Be prepared, be relaxed, and go with the flow. While you never may face the discomfort of the speakers in these stories, remember that audiences often are pulling for you. If something unusual happens, finish with grace and hope for the best.

7 SUMMARY

Most of the work in an oral presentation occurs before the talk is presented. Before the talk, take the time to organize the material, construct the visual aids (which should number no more than $^{3}/_{4}$ times the number of minutes), and practice. Learn about the facilities in the room before you walk to the podium.

During the talk, do not worry about being nervous, but learn to control or avoid the signs of nervousness. Take your time in presenting data slides (especially figures). During transitions from one part of the talk to another, be sure to "tell 'em" three times: preview the material, present the material, and summarize the material. Modulate the speed and volume of your voice and use your hands effectively.

After the talk, seek feedback to become a better speaker. Remember, the best way to become an effective technical speaker is to take every opportunity to give technical talks.

SUMMARY OF KEY IDEAS

- Technical presentations can be improved by considering the activities before the talk, during the talk, and after the talk.
- Identify the presentation goals, target audience, and constraints on the presentation (especially time constraints).
- Use an outline to organize the talk and an outline slide to show your organization.
- The number of visual aids should be about $^{3}/_{4}$ times the number of minutes allotted to the presentation.
- In selecting the type of visual aid, consider image quality, eye contact, and production cost and time. Then use only one type of visual aid in a talk.
- Word slides should contain as few words as possible.
- Create tables specific to the point you wish to make.

- With computer-based presentations, watch the colors, number of fonts, and animations.
- Practice before the visual aids are finalized.
- When practicing, time each section as you practice alone and in front of others.
- Avoid memorizing or reading oral presentations.
- Learn about the facilities and coordinate introductions well before the talk.
- Practice transitions between speakers in group presentations.
- Do not worry about *being* nervous; learn to control or avoid the *signs* of nervousness.
- Paraphrase information in word slides and point to each item in a list.
- When presenting figures, tell what the figure is showing, identify the axes, communicate the meaning of each plot, and enumerate the main points to be made.
- Use signposting liberally in technical oral presentations.
- Speak loudly and slowly. Use meaningful hand gestures and move your body without pacing.
- Seek feedback and incorporate changes into your speaking style.

Problems

1. Pick an engineering topic of interest to you and identify a target audience. How will the target audience influence the visual aids you select and the material you present in your talk?
2. Write an outline for a 15-minute talk on the topic and target audience selected in Problem 1.
3. How would your outline change if you were asked to prepare a five-minute talk? A two-minute talk?
4. How many visual aids will you need for the talk?
5. Prepare visual aids for the talk using the principles presented in this chapter.
6. Practice the 15-minute talk. Prepare a table showing the percentage of time in the talk devoted to each of the major sections of the presentations. Refine the talk to better use the time allotted and summarize your refinements.
7. Before presenting the talk, what questions do you anticipate from the audience?
8. Present the talk to a group of people pretending to be your target audience. Did you predict (in Problem 7) the questions that were asked? What feedback did you receive from the audience?
9. Rewrite your talk using double the number of visual aids that you prepared in Problem 7. Present the revised talk to a group of people pretending to be your target audience. What feedback did you get about the number of visual aids?
10. Attend lectures delivered by three different public speakers. For each speaker, list and explain two aspects of his or her speaking style that appeal to you the most and two aspects that appeal to you the least.

Engineering Ethics

1 INTRODUCTION

Engineering is a profession. This means in part that engineers must practice their profession in accordance with high ethical standards. In this chapter, you will explore *why* engineers must act ethically and examine the basic codes of engineering ethics. Examples will be used to illustrate the ethical conflicts that occur on the job.

Ethics can be studied on many levels. Please understand that the discussions in this chapter are on a very practical level. The philosophy of ethics (sometimes called *formal ethics*) is a beautiful and interesting field of study. This is not a chapter on formal ethics. Rather, the purpose of this chapter is to provide you with guidance on how to live your life as an engineer.*

2 PROFESSIONAL ISSUES

Ethics refers to a system of moral principles. All professions have standards of ethics to which their members are bound. In fact, a code of ethics allowing practitioners to "police themselves" is really a prerequisite for a profession.

Ethical issues in the medical, legal, and political arenas appear almost daily in the newspaper. Engineers also must follow ethical standards.

SECTIONS

OBJECTIVES

After reading this chapter, you will be able to:

- explain why engineers should be ethical;
- list the canons in the NSPE Code of Ethics;
- identify the correct ethical choices in engineering applications.

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*A student of moral philosophy might say that this chapter is about *normative ethics* (i.e., the principles that guide how we should live our lives), rather than *metaethics* (i.e., the study of what is good).

From *A User's Guide to Engineering*, James N. Jensen.

PONDER THIS

Why should engineering follow ethical standards?

ethics: a system of moral principles

Recall that engineering ethics is important because (1) engineering affects public safety and health, and (2) public trust in engineers must be preserved, since engineering work is not easy to understand.

3 CODES OF ETHICS

3.1 Introduction

Many engineering societies have their own codes of ethical behavior. Engineering societies having codes of ethics (and other ethics documents) are listed in Table 1. The differences between the codes are fairly minor. Most of the ethical standards are modeled after the code of ethics of the National Society of Professional Engineers (NSPE). To understand the concepts underlying the various ethics doctrines, the NSPE Code of Ethics will be examined in more detail.

3.2 NSPE Code of Ethics

NSPE Fundamental Canons of Ethics: the six basic principles outlining the professional responsibilities of engineers

Board of Ethical Review: an NSPE committee that offers commentary on ethics cases

NSPE has established six principles called the ***Fundamental Canons of Ethics***. The principles refer to the responsibilities of engineers when conducting their work and when approving documents. When a PE approves a document, he or she is *personally certifying* that the work meets professional standards. An NSPE committee called the ***Board of Ethical Review*** (BER) offers commentary on ethics cases to show engineers how the fundamental canons have been interpreted in the past. Each of the fundamental canons will be presented with examples on their interpretation. (*Note*: The entire NSPE Code of Ethics is given at the end of the chapter. More examples of the interpretation of the fundamental canons can be found in the Rules of Practice and Professional Obligations sections of the NSPE Code of Ethics.)

Key idea: Engineers shall hold paramount the safety, health, and welfare of the public.

Canon 1: Engineers shall hold paramount the safety, health, and welfare of the public. This is the most important of the fundamental canons. It states that nothing—not profit, not inconvenience, not personal gain—comes before the safety, health, and welfare of the public. Remember, safety, health, and welfare are paramount. If you face a contradiction in your work life between canons, Canon 1 prevails.

Canon 1 has three important interpretations. First, the canon has been interpreted to mean that individual engineers must notify their employer, client, or the proper authorities when life or property is endangered. Notification must occur *even if the client requests that data or any other engineering work be held back*. For example, if you discover a potentially dangerous situation in the course of your professional work, you **must** report it even if the paying client *demands* that you squelch the information.

TABLE 1 Engineering Societies with Codes of Ethics

Organization	Last Revision	Other Ethics Documents
American Consulting Engineers Council (ACEC)	1980	none
American Institute of Chemical Engineers (AIChE)	1989	none
American Society of Civil Engineers (ASCE)	1993	ASCE's Guidelines on Practice
American Society of Mechanical Engineers (ASME)	1991	ASME Criteria for Interpretation of the Canons
Institute of Electrical and Electronics Engineers (IEEE)	1990	Employment Guidelines

Safety outweighs all other considerations.

A second implication of the first canon is that engineers must approve only documents that conform to applicable standards. Approving plans that you know are not in compliance with standards is an ethical violation and grounds for loss of your engineering license.

A third implication of the first canon is that engineers have a responsibility to report any violations of the code of ethics. Reporting known violations is a form of *whistle-blowing*. Professionals who come public with mistakes made by themselves, their firm, or their colleagues risk being fired or ostracized. However, because of the overriding importance of the safety, health, and welfare of the public, engineers have a moral duty to report ethical violations committed by themselves or others.

Key idea: Engineers shall perform services only in the areas of their competence.

Canon 2: Engineers shall perform services only in the areas of their competence. At present, engineers usually are licensed in a particular discipline. This canon makes it clear that engineers must stay in their areas of expertise. Thus, a chemical engineer cannot approve structural engineering plans.

One ramification of this canon is that you must approve only documents prepared under your supervision. For example, a mechanical engineer cannot approve heating, ventilation, and air conditioning (HVAC) plans drawn up by people being supervised by another engineer. As a practical matter, the second canon means that each technical portion (e.g., electrical, mechanical, and structural portions) of a set of plans usually must be approved individually.

Key idea: Engineers shall issue public statements only in an objective and truthful manner.

Canon 3: Engineers shall issue public statements only in an objective and truthful manner. As stated in Section 2, the engineering profession thrives because of the public trust. This canon states that you must be honest in your dealings with the public. For example, you must acknowledge if you are being paid to issue a public statement about an engineering issue. Suppose you are being paid by a developer to lay out a new neighborhood. If you speak before a city council meeting in favor of the development, then you must identify yourself as an engineer paid by the developer.

Key idea: Engineers shall act for each employer or client as faithful agents or trustees.

Canon 4: Engineers shall act for each employer or client as faithful agents or trustees. The practice of engineering depends on the trust between the engineer and the public. Engineering also is dependent on the trust between the engineer and the client. This canon says in part that the client has the right to expect that the engineer will use his or her best engineering judgment in solving the client's problems.

This canon also is interpreted to mean that engineers must disclose to the client all known or *potential* conflicts of interest. Identification of potential conflicts of interest can be difficult. Clearly, the engineer cannot represent two clients who may come into conflict. For example, you could not represent both a potentially polluting industry and the town owning the wastewater treatment facility or both a developer and a city where the developer does work.

Key idea: Engineers shall avoid deceptive acts.

Canon 5: Engineers shall avoid deceptive acts. This canon has implications in the procurement of work. For example, it is a violation of the code of ethics to falsify your qualifications. In addition, it is considered unethical to offer or give a contribution to influence a public authority's decision about who should be awarded a contract.

The difference between ethical and unethical behavior can be very small. Clearly, it is improper to offer a bribe to the head of a housing authority to get a contract. What about taking the town engineer out to lunch right before a contract is awarded? What about giving the daughter of the mayor extra playing time on the soccer team you coach?

Key idea: Engineers shall conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

Canon 6: Engineers shall conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession. This canon greatly affects the lives of engineers. It means that engineers must advise their clients if the engineers believe a project will *not* be successful. In addition, engineers are prohibited by this canon from accepting free material from suppliers or contractors in return for specifying their products or services.

Language similar to that in the sixth canon is used by the Accreditation Board for Engineering and Technology (ABET) in the fundamental principles section of their code of ethics. (One responsibility of ABET is to certify undergraduate engineering programs.) The ABET fundamental principles state that engineers can "uphold and advance the integrity, honor, and dignity of the engineering profession by"

I. Using their knowledge and skill for the enhancement of human welfare;
II. Being honest and impartial, and serving with fidelity the public, their employers, and clients;
III. Striving to increase the competence and prestige of the engineering profession; and
IV. Supporting the professional and technical societies of their disciplines (Wright, 1994).

Although the NSPE canons remain silent on the issue, both the ABET and ASCE codes of ethics include ethical obligations for professional development. In other words, engineers are ethically obligated to continue their technical training and education throughout their career. Thus, even though some states do not require continuing education for relicensing as a professional engineer, continued technical training is part of your ethical obligation as an engineer.

4 EXAMPLES OF ENGINEERING ETHICS

Engineering ethics can become very complex. Sometimes, one ethical canon contradicts another. Two examples will be presented to illustrate the applications of the fundamental canons. These examples are taken from case studies developed by NSPE's Board of Ethical Review. Take a moment to consider your responses before reading the comments that follow the discussion questions. For examples of ethics that crop up in business practice, see the *Focus on Ethics: Workplace Ethics*.

4.1 Not Reporting Violations

Case: A civil engineer is hired to assess the structural integrity of a 60-year-old apartment building. The structure of the building is determined to be sound. However, during the inspection, mechanical and electrical problems are noted. The problems are severe enough that they may lead to safety concerns. The engineer tells the client of the problems, but does not include them in the report. The client reminds the engineer of his obligations regarding client confidentiality and then moves to sell the building quickly without repairs. The engineer decides not to report the violations to the authorities.

Discussion: This example represents a conflict between the responsibility to protect public safety (Canon 1) and client confidentiality (Canon 4). Does Canon 2 (not working outside your area of expertise) play in this case?

PONDER THIS

Which factor is more important? Could the engineer have avoided the conflict by including the problems in his original report?

Board of Ethical Review comments: The Board concluded that the engineer had an ethical obligation to report the problems to the authorities because of the paramount importance of public safety (Canon 1). The engineer was correct not to include the problems in his report, since the problems were outside of the engineer's area of expertise (Canon 2).

4.2 Whistle-Blowing

Case: The city engineer/director of public works for a medium-sized city is the only licensed professional engineer in a position of responsibility within the city government. The city has several large food processing plants that discharge large amounts of waste into the sewage system during canning season. The engineer is responsible for the wastewater treatment plant. She reports to her supervisor about the inadequate capacity of the treatment plant to handle potential overflow during the rainy season and offers several possible solutions. The engineer also privately notifies other city officials about the plant problem, but her supervisor removes the responsibility for the wastewater treatment plant from her. She also is placed on probation and warned not to discuss the matter further or she will be fired.

Discussion: This example explores what engineers must do to meet their ethical obligations.

PONDER THIS

Has the engineer discharged her ethical responsibilities by notifying city officials of the potential problem?

Board of Ethical Review comments: The Board concluded that removal of responsibility for the treatment plant did not terminate the engineer's ethical obligations, even when threatened with loss of employment. Again, public health and safety are of highest importance (Canon 1). The Board thought that the engineer should have reported the potential problem to higher authorities in the state or federal government.

5 SUMMARY

Engineers are professionals and must meet high ethical standards. Engineering ethics is required for two reasons. First, engineering directly influences public safety, health, and welfare. Second, engineering work is not easy to understand, so the trust between the public and engineers must not be diminished by unethical behavior.

Several codes of engineering ethics exist. Most are similar to the six NSPE Fundamental Canons of Ethics. The six canons require that engineers shall (1) hold paramount

FOCUS ON ETHICS: WORKPLACE ETHICS

Engineering ethics often is taught with the high-stakes ethics cases discussed in Problems 4 through 6. While interesting and instructive, the large cases do not provide you as a new engineer with tools you can use to address everyday ethics questions.

In this section, you will be presented with a series of ethics questions and possible solutions. You may wish to discuss the questions in a group, so that you can exchange ideas. One of the lessons is that ethics questions often do not have one correct answer. Responses to ethical dilemmas in the workplace can be ranked from better to worse. (Of course, some responses are just plain wrong.)

The questions below are from an ethics game called *Gray Matters*. The game was devised by George Sammet, Jr., to teach business ethics to the employees of Martin Marietta (now Lockheed Martin). Sammet was Vice President of International Ethics and Business Conduct for Lockheed Martin and now works for Grainer and Associates in Ottawa. The questions presented here were selected for their relevance to the engineering workplace and interest to entry-level engineers.

For each question below, a Web site is given to allow you to select from potential responses. The questions are quoted from the onlineethics.org Web site.

Enjoy the game and your discussion of the answers.

GrayMatters **Case #8**
Appropriating Office Supplies for Personal Use

"Two of your subordinates routinely provide their children with school supplies from the office. How do you handle this situation?"

Web site: http://onlineethics.org/corp/graymatters/case8.html

GrayMatters **Case #64**
Instructed to Distort the Truth?

"You are on a proposal-writing team. In the orientation briefing, the head of the team gives the following guidance: 'We really have to win this one. I want you to be really optimistic in what you write.' How do you interpret her advice?"

Web site: http://onlineethics.org/corp/graymatters/case64.html

GrayMatters **Case #87**
Supplier Offers You a Discount

"You are in Production Control. Planning on adding a porch onto your house, you visit a lumberyard to get ideas and a price. During the discussion, the sales manager says, 'Oh, you work for XYZ Company. They buy a lot from us, so I'm going to give you a special discount.' What do you do?"

Web site: http://onlineethics.org/corp/graymatters/case87.html

GrayMatters **Case #24**
HIV Positive Employee

"A female employee tells you, her manager, that a fellow employee is HIV positive. What do you do?"

Web site: http://onlineethics.org/corp/graymatters/case24.html

GrayMatters **Case #72**
He Calls All the Women "Sweetie"

"When a male supervisor talks to any female employee, he always addresses her as 'Sweetie.' You have overheard him use this term several times. As the supervisor's manager, should you do anything?"

Web site: http://onlineethics.org/corp/graymatters/case72.html

How did you do in your group? The maximum and minimum possible scores for the five scenarios above are +50 and −55, respectively.

the safety, health, and welfare of the public; (2) perform services only in the areas of their competence; (3) issue public statements only in an objective and truthful manner; (4) act for each employer or client as faithful agents; (5) avoid deceptive acts; and (6) conduct themselves honorably, responsibly, ethically, and lawfully to enhance the honor, reputation, and usefulness of the profession.

SUMMARY OF KEY IDEAS

- Engineers shall hold paramount the safety, health, and welfare of the public.
- Engineers shall perform services only in the areas of their competence.
- Engineers shall issue public statements only in an objective and truthful manner.
- Engineers shall act for each employer or client as faithful agents or trustees.
- Engineers shall avoid deceptive acts.
- Engineers shall conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

Problems

1. What are the six canons in the NSPE Code of Ethics?
2. Is there a hierarchy among the canons in the NSPE Code of Ethics?
3. Review the Professional Obligations section of the NSPE Code of Ethics at the end of the chapter. Discuss the ethical implications of engineering consulting firms making campaign contributions.
4. Discuss the ethical behavior of engineers in the Space Shuttle *Challenger* disaster. For background information, see the World Wide Web Ethics Center for Engineering and Science, hosted by Case Western Reserve University at http://www.onlineethics.org. This site contains a fine discussion of engineering ethics, including detailed examples of whistle-blowing in engineering.
5. Discuss the ethical behavior of engineers in the walkway collapse at the Kansas City Hyatt Regency Hotel. For background information, see Pfrang and Marshall (1982).
6. Discuss the ethical behavior of engineers with regard to the structural problems in New York City's Citicorp Towers. For background information, see the World Wide Web Ethics Center for Engineering and Science, hosted by Case Western Reserve University at http://www.onlineethics.org.
7. Pick a field of engineering and discuss how an ethical violation would adversely affect public health, safety, or welfare.

Problems 8 through 10 are taken from actual ethics cases that came before NSPE's Board of Ethical Review. For each scenario, discuss the applicable parts of the NSPE Code of Ethics and decide whether the behavior was ethical.

8. Due to potential dangers during construction, an engineer recommends to a client before a project begins that a full-time person should be hired for on-site monitoring of the project. The client rejects the request for on-site monitoring, stating that

the monitor would increase project costs to an unreasonable level. The engineer starts work on the project anyway. Was it ethical for the engineer to begin the project knowing that the client would not agree to hire an on-site monitor?

9. A company was advised by a state agency to get permission to discharge waste into a river. The company hires a consulting engineer to help them respond to the state's request. The engineer finds that the waste will degrade the quality of the river below established standards and that treating the waste will be expensive. The engineer tells the company of these findings orally, before the final report is written. The company then pays the engineer, terminates the engineering service agreement, and tells the engineer not to write a report. The engineer hears later that the company reported to the state agency that the waste discharge will not degrade the quality of the river. Does the engineer have an ethical obligation to report the findings to the state agency?

10. A state agency hires an engineer to conduct a feasibility study on a proposed highway spur. The spur will go through an area near where the engineer owns property. The engineer tells the state agency of the potential conflict of interest, but the agency does not object to the engineer working on the project. The engineer completes the study and the highway spur is built. Did the engineer act ethically by performing the study, even though the engineer's property may be affected?

NSPE CODE OF ETHICS FOR ENGINEERS

Preamble

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.

I. Fundamental Canons

Engineers, in the fulfillment of their professional duties, shall:

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

II. Rules of Practice

1. Engineers shall hold paramount the safety, health and welfare of the public.
    a. If engineers' judgment is overruled under circumstances that endanger life or property, they shall notify their employer or client and such other authority as may be appropriate.
    b. Engineers shall approve only those engineering documents that are in conformity with applicable standards.

   c. Engineers shall not reveal facts, data, or information without the prior consent of the client or employer except as authorized or required by law or this Code.
   d. Engineers shall not permit the use of their name or associate in business ventures with any person or firm that they believe are engaged in fraudulent or dishonest enterprise.
   e. Engineers shall not aid or abet the unlawful practice of engineering by a person or firm.
   f. Engineers having knowledge of any alleged violation of this Code shall report thereon to appropriate professional bodies and, when relevant, also to public authorities, and cooperate with the proper authorities in furnishing such information or assistance as may be required.

2. Engineers shall perform services only in the areas of their competence.
   a. Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved.
   b. Engineers shall not affix their signatures to any plans or documents dealing with subject matter in which they lack competence, nor to any plan or document not prepared under their direction and control.
   c. Engineers may accept assignments and assume responsibility for coordination of an entire project and sign and seal the engineering documents for the entire project, provided that each technical segment is signed and sealed only by the qualified engineers who prepared the segment.
3. Engineers shall issue public statements only in an objective and truthful manner.
   a. Engineers shall be objective and truthful in professional reports, statements, or testimony. They shall include all relevant and pertinent information in such reports, statements, or testimony, which should bear the date indicating when it was current.
   b. Engineers may express publicly technical opinions that are founded upon knowledge of the facts and competence in the subject matter.
   c. Engineers shall issue no statements, criticisms, or arguments on technical matters that are inspired or paid for by interested parties, unless they have prefaced their comments by explicitly identifying the interested parties on whose behalf they are speaking, and by revealing the existence of any interest the engineers may have in the matters.
4. Engineers shall act for each employer or client as faithful agents or trustees.
   a. Engineers shall disclose all known or potential conflicts of interest that could influence or appear to influence their judgment or the quality of their services.
   b. Engineers shall not accept compensation, financial or otherwise, from more than one party for services on the same project, or for services pertaining to the same project, unless the circumstances are fully disclosed and agreed to by all interested parties.

c. Engineers shall not solicit or accept financial or other valuable consideration, directly or indirectly, from outside agents in connection with the work for which they are responsible.

d. Engineers in public service as members, advisors, or employees of a governmental or quasi-governmental body or department shall not participate in decisions with respect to services solicited or provided by them or their organizations in private or public engineering practice.

e. Engineers shall not solicit or accept a contract from a governmental body on which a principal or officer of their organization serves as a member.

5. Engineers shall avoid deceptive acts.

a. Engineers shall not falsify their qualifications or permit misrepresentation of their or their associates' qualifications. They shall not misrepresent or exaggerate their responsibility in or for the subject matter of prior assignments. Brochures or other presentations incident to the solicitation of employment shall not misrepresent pertinent facts concerning employers, employees, associates, joint venturers, or past accomplishments.

b. Engineers shall not offer, give, solicit or receive, either directly or indirectly, any contribution to influence the award of a contract by public authority, or which may be reasonably construed by the public as having the effect of intent to influencing the awarding of a contract. They shall not offer any gift or other valuable consideration in order to secure work. They shall not pay a commission, percentage, or brokerage fee in order to secure work, except to a bona fide employee or bona fide established commercial or marketing agencies retained by them.

III. Professional Obligations

1. Engineers shall be guided in all their relations by the highest standards of honesty and integrity.

a. Engineers shall acknowledge their errors and shall not distort or alter the facts.

b. Engineers shall advise their clients or employers when they believe a project will not be successful.

c. Engineers shall not accept outside employment to the detriment of their regular work or interest. Before accepting any outside engineering employment they will notify their employers.

d. Engineers shall not attempt to attract an engineer from another employer by false or misleading pretenses.

e. Engineers shall not promote their own interest at the expense of the dignity and integrity of the profession.

2. Engineers shall at all times strive to serve the public interest.

a. Engineers shall seek opportunities to participate in civic affairs; career guidance for youths; and work for the advancement of the safety, health, and well-being of their community.

b. Engineers shall not complete, sign, or seal plans and/or specifications that are not in conformity with applicable engineering standards. If the client or employer insists on such unprofessional conduct, they shall notify the proper authorities and withdraw from further service on the project.

    c. Engineers shall endeavor to extend public knowledge and appreciation of engineering and its achievements.

3. Engineers shall avoid all conduct or practice that deceives the public.
    a. Engineers shall avoid the use of statements containing a material misrepresentation of fact or omitting a material fact.
    b. Consistent with the foregoing, engineers may advertise for recruitment of personnel.
    c. Consistent with the foregoing, engineers may prepare articles for the lay or technical press, but such articles shall not imply credit to the author for work performed by others.
4. Engineers shall not disclose, without consent, confidential information concerning the business affairs or technical processes of any present or former client or employer, or public body on which they serve.
    a. Engineers shall not, without the consent of all interested parties, promote or arrange for new employment or practice in connection with a specific project for which the engineer has gained particular and specialized knowledge.
    b. Engineers shall not, without the consent of all interested parties, participate in or represent an adversary interest in connection with a specific project or proceeding in which the engineer has gained particular specialized knowledge on behalf of a former client or employer.
5. Engineers shall not be influenced in their professional duties by conflicting interests.
    a. Engineers shall not accept financial or other considerations, including free engineering designs, from material or equipment suppliers for specifying their product.
    b. Engineers shall not accept commissions or allowances, directly or indirectly, from contractors or other parties dealing with clients or employers of the engineer in connection with work for which the engineer is responsible.
6. Engineers shall not attempt to obtain employment or advancement or professional engagements by untruthfully criticizing other engineers, or by other improper or questionable methods.
    a. Engineers shall not request, propose, or accept a commission on a contingent basis under circumstances in which their judgment may be compromised.
    b. Engineers in salaried positions shall accept part-time engineering work only to the extent consistent with policies of the employer and in accordance with ethical considerations.
    c. Engineers shall not, without consent, use equipment, supplies, laboratory, or office facilities of an employer to carry on outside private practice.

7. Engineers shall not attempt to injure, maliciously or falsely, directly or indirectly, the professional reputation, prospects, practice, or employment of other engineers. Engineers who believe others are guilty of unethical or illegal practice shall present such information to the proper authority for action.
   a. Engineers in private practice shall not review the work of another engineer for the same client, except with the knowledge of such engineer, or unless the connection of such engineer with the work has been terminated.
   b. Engineers in governmental, industrial, or educational employ are entitled to review and evaluate the work of other engineers when so required by their employment duties.
   c. Engineers in sales or industrial employ are entitled to make engineering comparisons of represented products with products of other suppliers.
8. Engineers shall accept personal responsibility for their professional activities, provided, however, that engineers may seek indemnification for services arising out of their practice for other than gross negligence, where the engineer's interests cannot otherwise be protected.
   a. Engineers shall conform with state registration laws in the practice of engineering.
   b. Engineers shall not use association with a nonengineer, a corporation, or partnership as a "cloak" for unethical acts.
9. Engineers shall give credit for engineering work to those to whom credit is due, and will recognize the proprietary interests of others.
   a. Engineers shall, whenever possible, name the person or persons who may be individually responsible for designs, inventions, writings, or other accomplishments.
   b. Engineers using designs supplied by a client recognize that the designs remain the property of the client and may not be duplicated by the engineer for others without express permission.
   c. Engineers, before undertaking work for others in connection with which the engineer may make improvements, plans, designs, inventions, or other records that may justify copyrights or patents, should enter into a positive agreement regarding ownership.
   d. Engineers' designs, data, records, and notes referring exclusively to an employer's work are the employer's property. The employer should indemnify the engineer for use of the information for any purpose other than the original purpose.
   e. Engineers shall continue their professional development throughout their careers and should keep current in their specialty fields by engaging in professional practice, participating in continuing education courses, reading in the technical literature, and attending professional meetings and seminars.

—As revised January 2003