THIRD EDITION

Engineering Fundamentals

DESIGN, PRINCIPLES, AND CAREERS

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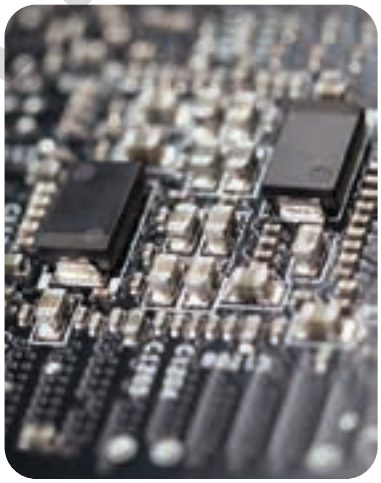


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Preface

What is engineering? *Engineering Fundamentals* provides a complete introduction to the field. It is written to help you learn about engineering and how it affects our everyday lives. You will learn how engineering is different from science and technology. You will also learn how science, math, and technology are an integral part of engineering design.

Engineering Fundamentals begins by giving you a clear picture of the basics of engineering. First, you will learn about engineering and the types of work engineers in various disciplines do. The next chapter discusses engineering as a profession. This includes such topics as the functions of engineers, regulating bodies, ethics, and teamwork. The chapter also discusses various impacts of engineering as well as the future of engineering.

You will then read an extensive, five-chapter introduction to the engineering design process. Real-world examples are given to help you understand why each step of the process is necessary when designing new products, devices, or systems.

This section is followed by 10 chapters that focus on engineering disciplines. Each of these chapters describes the specific engineering career, its educational requirements, and examples of real-world engineering projects. *Engineering Fundamentals* also discusses the principles associated with each discipline. The basic science and math required to understand the engineering and technology principles are explained in these chapters.

Engineering Fundamentals is illustrated with photographs and drawings to help explain chapter concepts. Each chapter begins with one Think Like an Engineer essential question and a list of objectives. Important terms related to engineering are shown in ***bold italics*** where they are defined. Several features throughout the chapter enhance chapter content while explaining related math, science, history, design, tools, or green concepts. At the end of each chapter, a variety of questions (Know and Understand, Apply and Analyze, and Critical Thinking) help check your understanding of chapter material. Communicating about Engineering activities helps you develop and improve your language skills. Chapter activities provide opportunities to apply what you have learned in each chapter.

Engineering Fundamentals will educate you about career opportunities in engineering and provide practical applications of math and science principles. *Engineering Fundamentals* will inspire you to consider engineering-related careers and to be more successful in your math and science courses.

About the Authors

Ryan A. Brown is a professor in the School of Teaching and Learning at Illinois State University. He currently teaches courses for preservice teachers on topics such as instructional methods and assessment, and graduate courses that focus on teacher education and curriculum theory. He holds a joint appointment in the Department of Technology and teaches a course on teaching energy, power, and transportation. Previously, he taught a variety of courses at the secondary level, including design processes, transportation systems, and fundamentals of engineering. Dr. Brown coauthored *Exploring Design, Technology, & Engineering* with Dr. R. Thomas Wright and *Energy, Power, and Transportation* with Dr. Len S. Litowitz. Dr. Brown's educational background includes a bachelor's degree and master's degree from Ball State University in technology education and a PhD in Curriculum Studies from Indiana University.

Joshua W. Brown is a professor in the Department of Technology and Engineering Education at Illinois State University. He previously taught middle school and high school in Indiana. He currently prepares future technology and engineering education teachers, teaches engineering design graphics, and is actively involved in the Technology and Engineering Education Collegiate Association (TEECA) and the Technology Student Association (TSA). His research focus is in STEM education and integrating engineering into secondary classrooms. Dr. Brown has a BS in Technology Education from Ball State University, an EdM in Educational Psychology from University of Illinois, and a PhD in Curriculum Studies from Purdue University.

Michael Berkeihiser is a Technology and Engineering teacher and chair of the Technology and Engineering Department at Unionville High School in Kennett Square, Pennsylvania. He teaches courses in engineering, engineering design, architectural design, electronics, and robotics. Mr. Berkeihiser coauthored *Manufacturing and Automation Technology* with Dr. R. Thomas Wright. His educational background includes a bachelor's degree from Millersville University and a master's degree from Ball State University.

Reviewers

The authors and publisher wish to thank the following industry and teaching professionals for their valuable input into the development of *Engineering Fundamentals*.

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New to This Edition

The following additions and updates were made to the third edition of *Engineering Fundamentals*:

- More than 70 chapter-related activities integrated into each chapter, ensuring that students engage in hands-on activities that illuminate content application. Topics range from chapter-content reinforcement to real-world applications, including design projects related to different engineering disciplines.
- New chapter features include chapter-opening question Think Like an Engineer to prompt student discussions; Did You Know? facts about engineering-related interest; and Engineering Quotes to motivate and inspire students.
- For digital subscribers, new interactive animations with assessment questions enrich learning.
- New end-of-chapter questions follow new Integrated Learning Solution format: Know and Understand, Apply and Analyze, and Critical Thinking questions, as well as Communicating about Engineering, ensuring that multiple levels of learning can be assessed.
- Updated engineering discipline chapters to keep students abreast of current technology, such as an explanation of quantum dots in Chapter 9.
- Updated examples of cutting-edge technologies, such as a discussion of wind turbines in Chapter 8, and updated information on vaccine development in Chapter 16.
- Updated photos to show current materials and equipment.
- Updated Standards for Technological and Engineering Literacy (STEL) correlation chart to new edition. Correlation charts help instructors determine what areas of the text meet these important standards.

Precision Exams by YouScience Certification

Goodheart-Willcox is pleased to partner with YouScience to correlate *Engineering Fundamentals* with their Engineering Technology certification standards. Students who pass the exam and performance portion of the exam can earn a Career Skills certification. Precision Exams by YouScience and Career Skills Exams were created in partnership with industry and subject matter experts to align real-world job skills with marketplace demands. Students can showcase their skills and knowledge with industry-recognized certifications—and build outstanding resumes to stand out from the crowd!

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And for teachers, Precision Exams by YouScience provides:

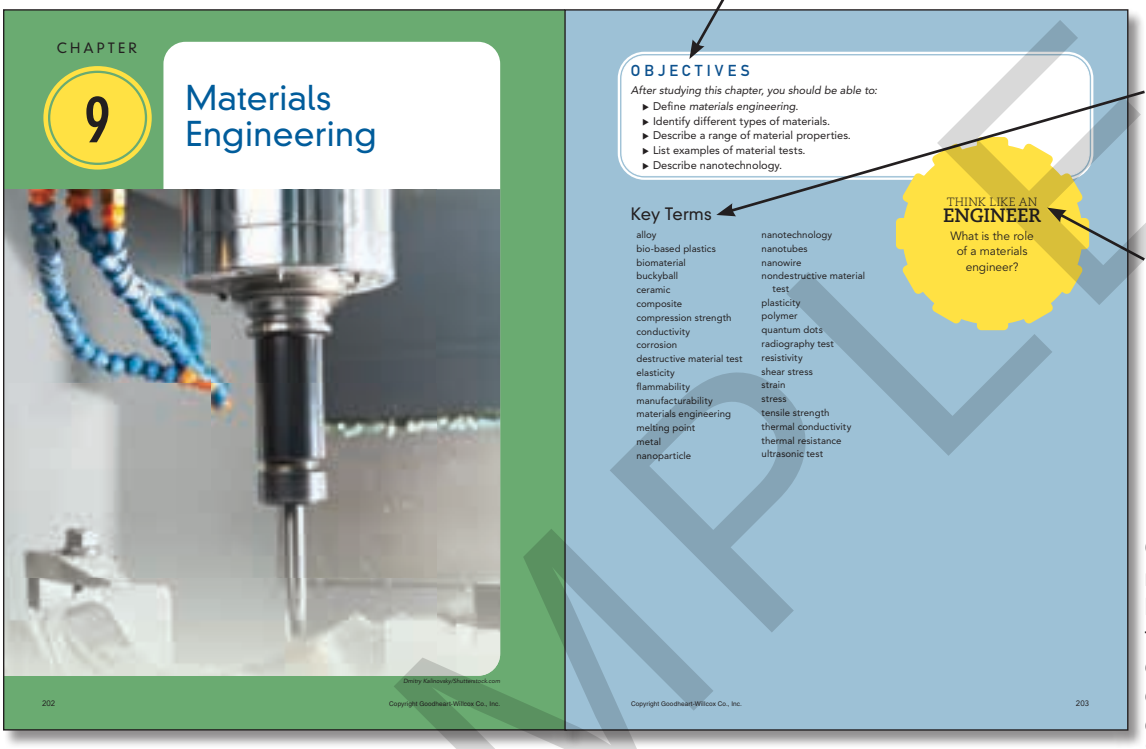
- Access to a library of Career Skills Exams, including pre- and post-assessments for all 16 National Career Clusters
- Suite of on-demand reporting to measure program and student academic growth
- Easy-to-use, 100% online administration

To see how *Engineering Fundamentals* correlates to Precision Exams by YouScience standards, visit the Correlations tab at www.g-w.com/engineering-fundamentals-2023. For more information about Precision Exams by YouScience, visit www.youscience.com/certifications/career-clusters/.

Guided Tour

The instructional design includes student-focused learning tools to help students succeed. This visual guide highlights the features designed for the textbook.

Objectives clearly identify the knowledge and skills to be obtained when the chapter is completed.


CHAPTER 9

Materials Engineering

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OBJECTIVES

After studying this chapter, you should be able to:

- Define *materials engineering*.
- Identify different types of materials.
- Describe a range of material properties.
- List examples of material tests.
- Describe nanotechnology.

Key Terms

alloy
bio-based plastics
biomaterial
buckyball
ceramic
composite
compression strength
conductivity
corrosion
destructive material test
elasticity
flammability
manufacturability
materials engineering
melting point
metal
nanoparticle
nanotechnology
nanotubes
nanowire
nondestructive material test
plasticity
polymer
quantum dots
radiography test
resistivity
shear stress
strain
stress
tensile strength
thermal conductivity
thermal resistance
ultrasonic test

THINK LIKE AN ENGINEER

What is the role of a materials engineer?

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Key Terms list the key terms to be learned in the chapter.

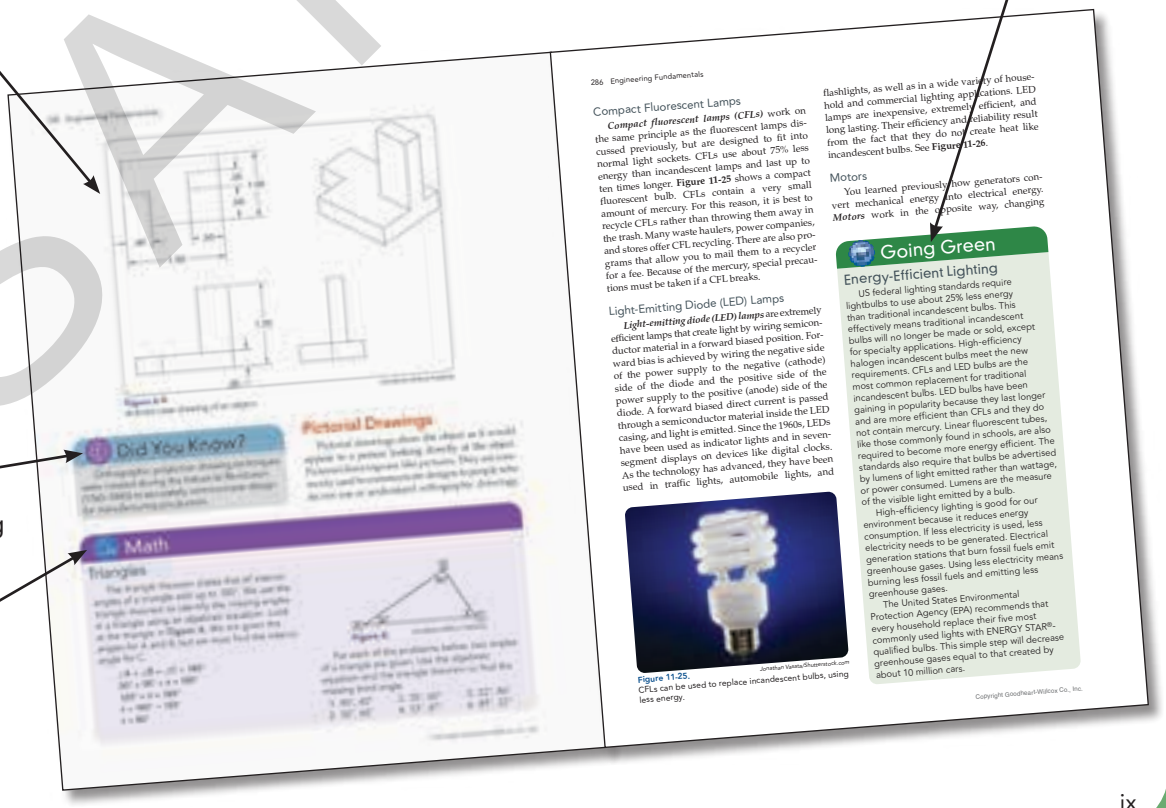
Think Like an Engineer questions spur discussion with your classmates and require you to use your critical thinking skills.

Going Green notes highlight key items related to sustainability, energy efficiency, and environmental issues.

Illustrations have been designed to clearly and simply communicate the specific topic. Photographic images have been updated to show the latest equipment.

Did You Know? provides facts about engineering and engineers.

Math features provide a review of math concepts associated with chapter content.


Did You Know?

Pictorial Drawings

Math

Triangles

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Compact Fluorescent Lamps

Compact fluorescent lamps (CFLs) work on the same principle as the fluorescent lamps discussed previously, but are designed to fit into normal light sockets. CFLs use about 75% less energy than incandescent lamps and last up to ten times longer. **Figure 11-25** shows a compact fluorescent bulb. CFLs contain a very small amount of mercury. For this reason, it is best to recycle CFLs rather than throwing them away in the trash. Many waste haulers, power companies, and stores offer CFL recycling. There are also programs that allow you to mail them to a recycler for a fee. Because of the mercury, special precautions must be taken if a CFL breaks.

Light-Emitting Diode (LED) Lamps

Light-emitting diode (LED) lamps are extremely efficient lamps that create light by wiring semiconductor material in a forward biased position. Forward bias is achieved by wiring the negative side of the power supply to the negative (cathode) side of the diode and the positive side of the power supply to the positive (anode) side of the diode. A forward biased direct current is passed through a semiconductor material inside the LED casing, and light is emitted. Since the 1960s, LEDs have been used as indicator lights and in seven-segment displays on devices like digital clocks. As the technology has advanced, they have been used in traffic lights, automobile lights, and flashlights, as well as in a wide variety of household and commercial lighting applications. LED lamps are inexpensive, extremely efficient, and long lasting. Their efficiency and reliability result from the fact that they do not create heat like incandescent bulbs. See **Figure 11-26**.

Motors

You learned previously how generators convert mechanical energy into electrical energy. *Motors* work in the opposite way, changing

Going Green

Energy-Efficient Lighting

US federal lighting standards require lightbulbs to use about 25% less energy than traditional incandescent bulbs. This effectively means traditional incandescent bulbs will no longer be made or sold, except for specialty applications. High-efficiency halogen incandescent bulbs meet the new requirements. CFLs and LED bulbs are the most common replacement for traditional incandescent bulbs. LED bulbs have been gaining in popularity because they last longer and are more efficient than CFLs and they do not contain mercury. Linear fluorescent tubes, like those commonly found in schools, are also required to become more energy efficient. The standards also require that bulbs be advertised by lumens of light emitted rather than wattage, or power consumed. Lumens are the measure of the visible light emitted by a bulb.

High-efficiency lighting is good for our environment because it reduces energy consumption. If less electricity is used, less electricity needs to be generated. Electrical generation stations that burn fossil fuels emit greenhouse gases. Using less electricity means burning less fossil fuels and emitting less greenhouse gases.

The United States Environmental Protection Agency (EPA) recommends that every household replace their five most commonly used lights with ENERGY STAR®-qualified bulbs. This simple step will decrease greenhouse gases equal to that created by about 10 million cars.

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Figure 11-25. CFLs can be used to replace incandescent bulbs, using less energy.

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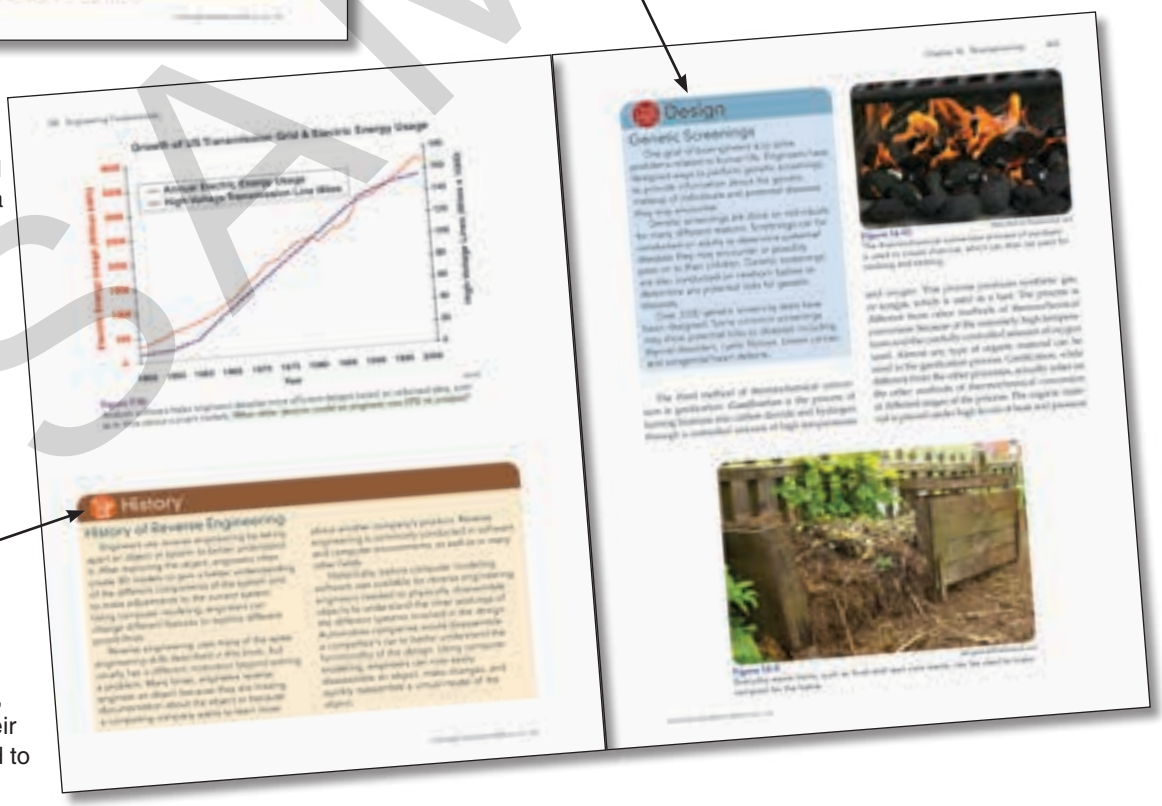
Science features review science concepts related to chapter material.

Engineering Quotes help motivate and inspire you.

Design features showcase elements of the engineering design process and explain its role in finding a final solution.



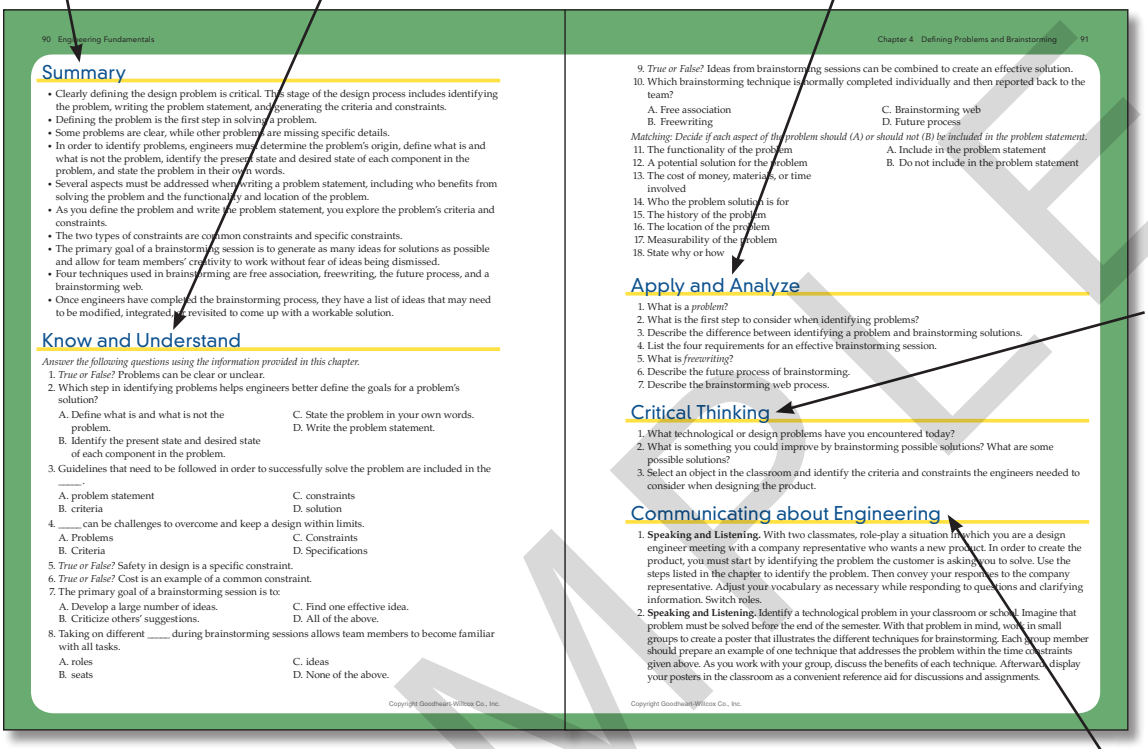
Tools features detail the types of tools that are used in a particular area of engineering, as well as how to use them safely and effectively.

History features explore engineers and their designs throughout history, explaining how their knowledge has led to today's designs.

Summary feature provides an additional review tool for you and reinforces key learning objectives.

Know and Understand questions enable you to demonstrate knowledge, identification, and comprehension of chapter material.

Apply and Analyze questions extend learning and develop your abilities to use learned material in new situations and to break down material into its component parts.



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Summary

- Clearly defining the design problem is critical. This stage of the design process includes identifying the problem, writing the problem statement, and generating the criteria and constraints.
- Defining the problem is the first step in solving a problem.
- Some problems are clear, while other problems are missing specific details.
- In order to identify problems, engineers must determine the problem's origin, define what is and what is not the problem, identify the present state and desired state of each component in the problem, and state the problem in their own words.
- Several aspects must be addressed when writing a problem statement, including who benefits from solving the problem and the functionality and location of the problem.
- As you define the problem and write the problem statement, you explore the problem's criteria and constraints.
- The two types of constraints are common constraints and specific constraints.
- The primary goal of a brainstorming session is to generate as many ideas for solutions as possible and allow for team members' creativity to work without fear of ideas being dismissed.
- Four techniques used in brainstorming are free association, freewriting, the future process, and a brainstorming web.
- Once engineers have completed the brainstorming process, they have a list of ideas that may need to be modified, integrated, or revisited to come up with a workable solution.

Know and Understand

Answer the following questions using the information provided in this chapter.

1. *True or False?* Problems can be clear or unclear.
2. Which step in identifying problems helps engineers better define the goals for a problem's solution?
   A. Define what is and what is not the problem.
   B. Identify the present state and desired state of each component in the problem.
   C. State the problem in your own words.
   D. Write the problem statement.
3. Guidelines that need to be followed in order to successfully solve the problem are included in the _____.
   A. problem statement
   B. criteria
   C. constraints
   D. solution
4. _____ can be challenges to overcome and keep a design within limits.
   A. Problems
   B. Criteria
   C. Constraints
   D. Specifications
5. *True or False?* Safety in design is a specific constraint.
6. *True or False?* Cost is an example of a common constraint.
7. The primary goal of a brainstorming session is to:
   A. Develop a large number of ideas.
   B. Criticize others' suggestions.
   C. Find one effective idea.
   D. All of the above.
8. Taking on different _____ during brainstorming sessions allows team members to become familiar with all tasks.
   A. roles
   B. seats
   C. ideas
   D. None of the above.

9. *True or False?* Ideas from brainstorming sessions can be combined to create an effective solution.
10. Which brainstorming technique is normally completed individually and then reported back to the team?
    A. Free association
    B. Freewriting
    C. Brainstorming web
    D. Future process

Matching: Decide if each aspect of the problem should (A) or should not (B) be included in the problem statement.

11. The functionality of the problem
12. A potential solution for the problem
13. The cost of money, materials, or time involved
14. Who the problem solution is for
15. The history of the problem
16. The location of the problem
17. Measurability of the problem
18. State why or how

   A. Include in the problem statement
   B. Do not include in the problem statement

Apply and Analyze

1. What is a *problem*?
2. What is the first step to consider when identifying problems?
3. Describe the difference between identifying a problem and brainstorming solutions.
4. List the four requirements for an effective brainstorming session.
5. What is *freewriting*?
6. Describe the future process of brainstorming.
7. Describe the brainstorming web process.

Critical Thinking

1. What technological or design problems have you encountered today?
2. What is something you could improve by brainstorming possible solutions? What are some possible solutions?
3. Select an object in the classroom and identify the criteria and constraints the engineers needed to consider when designing the product.

Communicating about Engineering

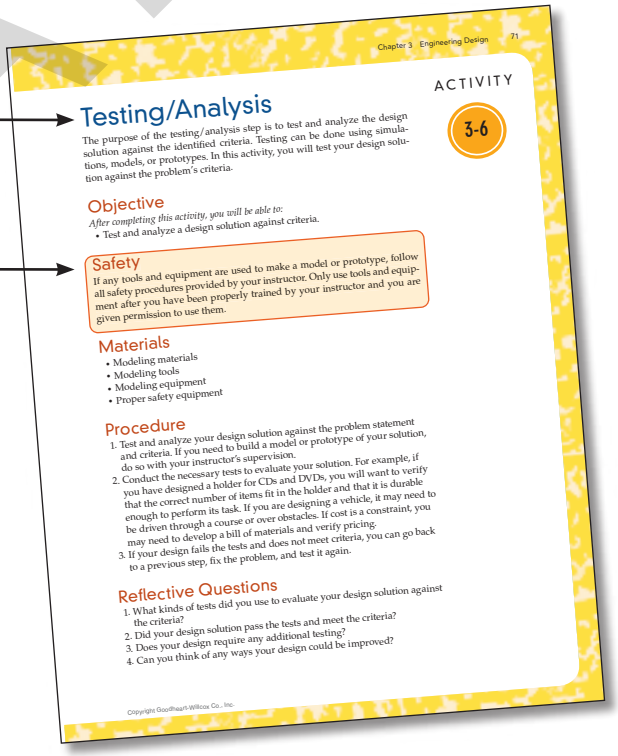
1. **Speaking and Listening.** With two classmates, role-play a situation in which you are a design engineer meeting with a company representative who wants a new product. In order to create the product, you must start by identifying the problem the customer is asking you to solve. Use the steps listed in the chapter to identify the problem. Then convey your responses to the company representative. Adjust your vocabulary as necessary while responding to questions and clarifying information. Switch roles.
2. **Speaking and Listening.** Identify a technological problem in your classroom or school. Imagine that problem must be solved before the end of the semester. With that problem in mind, work in small groups to create a poster that illustrates the different techniques for brainstorming. Each group member should prepare an example of one technique that addresses the problem within the time constraints given above. As you work with your group, discuss the benefits of each technique. Afterward, display your posters in the classroom as a convenient reference aid for discussions and assignments.

Critical Thinking questions develop higher-order thinking, problem-solving, personal, and workplace skills.

Communicating about Engineering activities designed to improve and develop language skills such as reading, speaking, and listening.

Activities extend your learning and help you apply knowledge.

Safety Notes alert you to potentially dangerous materials and practices.



ACTIVITY 3-6

Testing/Analysis

The purpose of the testing/analysis step is to test and analyze the design solution against the identified criteria. Testing can be done using simulations, models, or prototypes. In this activity, you will test your design solution against the problem's criteria.

Objective

After completing this activity, you will be able to:

- Test and analyze a design solution against criteria.

Safety

If any tools and equipment are used to make a model or prototype, follow all safety procedures provided by your instructor. Only use tools and equipment after you have been properly trained by your instructor and you are given permission to use them.

Materials

- Modeling materials
- Modeling tools
- Modeling equipment
- Proper safety equipment

Procedure

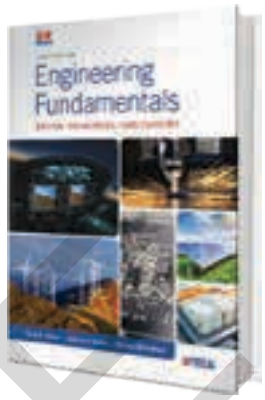
1. Test and analyze your design solution against the problem statement and criteria. If you need to build a model or prototype of your solution, do so with your instructor's supervision.
2. Conduct the necessary tests to evaluate your solution. For example, if you have designed a holder for CDs and DVDs, you will want to verify that the correct number of items fit in the holder and that it is durable enough to perform its task. If you are designing a vehicle, it may need to be driven through a course or over obstacles. If cost is a constraint, you may need to develop a bill of materials and verify pricing.
3. If your design fails the tests and does not meet criteria, you can go back to a previous step, fix the problem, and test it again.

Reflective Questions

1. What kinds of tests did you use to evaluate your design solution against the criteria?
2. Did your design solution pass the tests and meet the criteria?
3. Does your design require any additional testing?
4. Can you think of any ways your design could be improved?

TOOLS FOR STUDENT AND INSTRUCTOR SUCCESS

Student Tools



Student Text

Engineering Fundamentals provides a complete introduction to the field, starting with the design process and then reviewing, in-depth, 10 common engineering disciplines. For each discipline, career options, educational requirements, basic math and science principles, and real-world applications are presented. The content fully supports STEM initiatives and an activity-based curriculum.

Online Learning Suite

The Online Learning Suite provides the foundation of instruction and learning for digital and blended classrooms. An easy-to-manage shared classroom subscription makes it a hassle-free solution for both students and instructors. An online student text, along with rich supplemental content, brings digital learning to the classroom. All instructional materials are found on a convenient online bookshelf and accessible at home, at school, or on the go.

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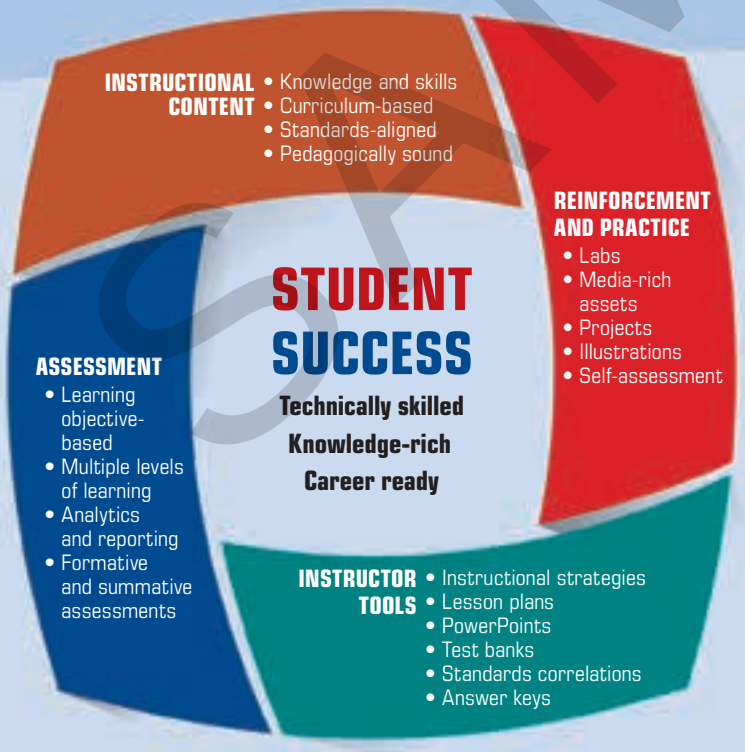

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Brief Contents

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Feature Contents

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