INTRODUCTION



Foundations of Engineering & Technology will help you to understand the following:

- How people use technology to make our world work.
- How engineering is needed to create technology.
- Why engineered systems work the way they do.
- The ways engineering and technology affect both people and our planet.

Foundations of Engineering & Technology ties engineering into eight industry contexts for technological activity:

- Manufacturing
- Construction
- Energy and power
- Information and communication
- Transportation and logistics
- Medicine and healthcare
- Agriculture and biological technologies
- Computation, automation, artificial intelligence, and robotics

In this book, you will learn that technology is a reaction to problems and opportunities—a human adaptive system. You will learn about technological systems and how engineering practices, habits, and knowledge are used to create them. You will also learn about the problem-solving and the engineering design process, including how to test, evaluate, and communicate design solutions.

Sections in the text explore the connection between technology and engineering, the steps in the engineering design process, technological systems, the engineered world, and the partnership between technology, engineering, and society.

Foundations of Engineering & Technology contains many photographs, drawings, diagrams, and original artwork that help explain the concepts in the text. This material has been carefully selected to make technology and engineering understandable. Each chapter begins with learning objectives so you know the expected learning goals. Technical Terms appear in bold italics in each chapter to increase your awareness of them. Know and Understand, Apply and Analyze, and Critical Thinking questions, as well as STEM Applications improve your understanding of chapter materials. Engineering Design activities and TSA Modular Activities help you apply chapter content to real-world situations.

Impacts, both positive and negative, accompany the use of technology. The only way people in the modern world can choose and apply technology responsibly is to understand how technology develops, how the various technological systems work, and how engineering is applied to these systems.

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ABOUT THE AUTHORS

Dr. Greg J. Strimel is an Associate Professor of Technology Leadership and Innovation at Purdue University in West Lafayette, Indiana. In this role, he educates pre-service teachers on the processes of developing engineering and technology curriculum and maintaining learning facilities/laboratories. Additionally, he is the program lead for the Design & Innovation program, where he supports students in their pursuits of innovation through cross-disciplinary collaborations. Dr. Strimel's educational degrees include a bachelor of science and a master of education in technology education from California University of Pennsylvania, and a doctorate of philosophy in occupational and technical studies, with an emphasis on engineering and technology education from Old Dominion University. His prior teaching experiences include serving as a high school engineering and technology teacher in Maryland, teaching assistant professor of engineering at West Virginia University, and adjunct instructor for engineering and technology teacher education at the University of Maryland Eastern Shore and California University of Pennsylvania. Dr. Strimel has also served as a high school career and technology education department chair, the director of K–12 initiatives for West Virginia University, and a professional development leader for multiple engineering and technology curriculum providers. His work has been recognized through the International Technology and Engineering Educators Association's Distinguished Technology and Engineering Educator Designation and Purdue University's highest honor for undergraduate teaching.

Dr. Michael E. Grubbs is the Coordinator for Career and Technical Education at Baltimore County Public Schools in Maryland. Previously, he was the Supervisor of Technology and Engineering Education for Baltimore County Public Schools. He currently serves on the National Alliance for Partnerships in Equity (NAPE) Education Foundation Board and Baltimore County Government Workforce Development Board; and he provides leadership to ACTE Region 1. Dr. Grubbs' educational degrees include a bachelor of science and a master of education in technology education from California University of Pennsylvania; an educational specialist in workforce education from the University of Georgia; and a doctorate of philosophy in curriculum and instruction with an emphasis on integrative STEM education from Virginia Tech. Dr. Grubbs has served as a middle school technology and engineering education teacher for Clayton County Public Schools, lead middle school teacher for Clayton County Public Schools, graduate research assistant for Virginia Tech, and adjunct instructor for New River Community College. His work has been recognized through the Donald Maley Spirit of Excellence: Outstanding Graduate Student citation; the CTETE International Travel grant and 21st Century Leader fellowship; Virginia Tech's Outstanding Student in Integrative STEM Education award; and the ITEEA Emerging Leader designation. Dr. Grubbs has served the profession in multiple roles, including secretary, marketing committee chair, and webmaster for CTETE. He has written numerous articles on technology and engineering education, and presented regionally, nationally, and internationally.

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Dr. R. Thomas Wright is one of the leading figures in technology-education curriculum development in the United States. Dr. Wright has served the profession through many professional offices. These offices include president of the International Technology and Engineering Educators Association (ITEEA) and president of the Council on Technology Teacher Education (CTTE; now known as the Council on Technology and Engineering Teacher Education [CTETE]). His work has been recognized through the ITEEA Academy of Fellows award and Award of Distinction; the CTETE Technology Teacher Educator of the Year; the Epsilon Pi Tau Laureate citation and Distinguished Service citation; the Sagamore of the Wabash award from the governor of Indiana; the Bellringer award from the Indiana superintendent of public instruction; the Ball State University Faculty of the Year award and George and Frances Ball Distinguished Professorship; and the EEA-Ship citation. Dr. Wright's educational background includes a bachelor degree from Stout State University, a master of science degree from Ball State University, and a doctoral degree from the University of Maryland. His teaching experience includes three years as a junior high instructor in California and 37 years as a university instructor at Ball State University. In addition, he has also been a visiting professor at Colorado State University; Oregon State University; and Edith Cowan University in Perth, Australia.

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REVIEWERS

The author and publisher wish to thank the following industry and teaching professionals for their valuable input into the development of ***Foundations of Engineering & Technology***.

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Westinghouse Electric Corp.
Weyerhauser Co.
Wisconsin Milk Marketing Board

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NEW TO THIS EDITION

In every new edition, current information and perspectives, as well as best learning design practices are always at the forefront of revision decision-making. The following list details the more significant changes made to the eighth edition of ***Fundamentals of Engineering & Technology***.

- Content has been updated to align with 2020 Standards for Technological and Engineering Literacy (STEL), designed by ITEEA (International Technology and Engineering Educators Association), and the Engineering Technology standards designed by YouScience®.
- Learning Objectives throughout the text have been refined to align with instructional design best practices and to ensure effective coverage of all necessary concepts.
- Added to each chapter is an Essential Question that aligns with the Framework for P–12 Engineering Learning, designed by the Advancing Excellence in P–12 Engineering Education (AE3) and the American Society for Engineering Education (ASEE) research collaborative.
- Modular numbering was added to offer easier reference to learning objectives and specific sections.
- Learning objective references were added to every ExamView question for instructor exam planning.
- Updated end-of-chapter question types reflect a robust instructional learning solution to assess multiple levels of learning: Know and Understand, Apply and Analyze, Critical Thinking, and STEM Applications. A significant number of new questions were added.
- Content in Chapters 1, 22, and 28 added achievements and contributions made by women in engineering.
- Chapter 3 contains a significant reorganization to emphasize engineering habits of mind, engineering knowledge, and engineering practices.
- Chapter 5 contains reorganization of material as well as additional examples and detail in developing solutions, engineering drawings, and computer simulations.
- Chapter 6 contains a significant reorganization along with new sections on manufacturing and material classification.
- Chapter 15 contains a new section on sustainability in home manufacturing as well as an example to help students recognize potential societal impacts when designing products.
- Chapter 23 includes the expanding field of logistics within transportation and new content on electric vehicles.
- Chapter 28 includes an example of how the COVID-19 pandemic called for engineering processes and product improvements to provide sanitizers, facemasks, and vaccines under critical conditions.

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PARTNERSHIPS

YouScience® Industry Certifications

Goodheart-Willcox is pleased to partner with YouScience®, correlating select Goodheart-Willcox titles to YouScience® Industry Certifications to the benefit of states, instructors, and students working to achieve them. YouScience® is the leading technology provider dedicated to solving the skills and exposure gap crisis for students and employers.

YouScience® Industry Certifications, part of the YouScience Brightpath academic and career guidance platform, offer students entry- to mid-level certifications that act as tangible proof of their skills and knowledge. For more information about YouScience, including a complete listing of their Industry Certifications, please visit https://www.youscience.com/certifications/.

To see how ***Foundations of Engineering & Technology*** correlates to the Engineering Technology credential offered by YouScience, visit the Correlations tab at www.g-w.com/foundations-engineering-technology-2025.

ITEEA Partnership

Goodheart-Willcox is pleased to partner with the International Technology and Engineering Educators Association (ITEEA) by correlating ***Foundations of Engineering & Technology*** to their Standards for Technological and Engineering Literacy (STEL). The STELs provide an up-to-date roadmap for classroom teachers, district supervisors, administrators, states, and curriculum developers to promote technology and engineering education program development and curriculum design from Pre-K through twelfth grade.

To see how ***Foundations of Engineering & Technology*** correlates to STEL, visit the Correlations tab at www.g-w.com/foundations-engineering-technology-2025.

AE3 and ASEE Partnership

Drs. Strimel and Grubbs were key participants in the development of the Framework for P–12 Engineering Learning, designed by the Advancing Excellence in P–12 Engineering Education (AE3) and the American Society for Engineering Education (ASEE) research collaborative. ***Foundations of Engineering & Technology*** follows the framework developed by these organizations to (1) cultivate engineering literacy, (2) assist in academic and technical achievement through integration of concepts and practices across all school subjects, (3) enhance students' understanding of engineering-related career paths, and (4) set a solid foundation for students who wish to pursue postsecondary education for an engineering-related career.

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Guided Tour

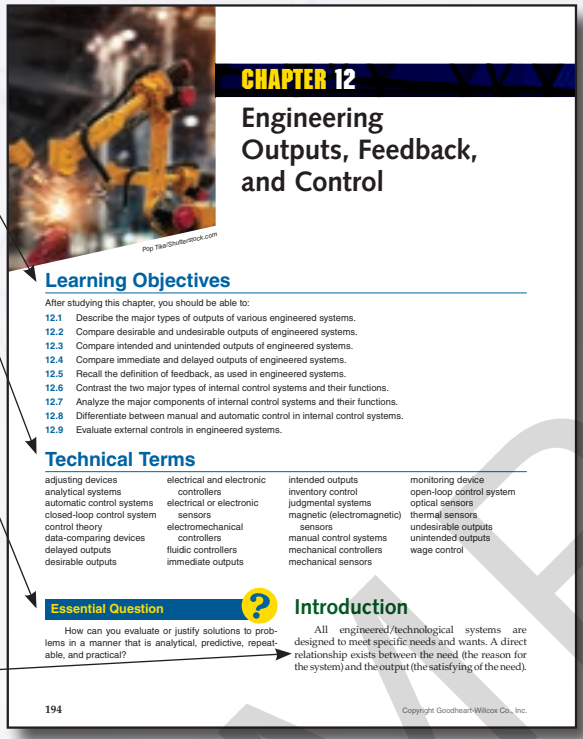
The instructional design includes student-focused learning tools to help students succeed. This visual guide highlights the features designed for the textbook.

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

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

Essential Question asks a broadly framed question to keep in mind throughout the chapter. Insights gained in reading the material should give you the ability to answer it.

Introduction provides an overview and preview of the chapter content.



CHAPTER 12

Engineering Outputs, Feedback, and Control

Pop Tika/ShutterStock.com

Learning Objectives

After studying this chapter, you should be able to:

- 12.1 Describe the major types of outputs of various engineered systems.
- 12.2 Compare desirable and undesirable outputs of engineered systems.
- 12.3 Compare intended and unintended outputs of engineered systems.
- 12.4 Compare immediate and delayed outputs of engineered systems.
- 12.5 Recall the definition of feedback, as used in engineered systems.
- 12.6 Contrast the two major types of internal control systems and their functions.
- 12.7 Analyze the major components of internal control systems and their functions.
- 12.8 Differentiate between manual and automatic control in internal control systems.
- 12.9 Evaluate external controls in engineered systems.

Technical Terms

adjusting devices
analytical systems
automatic control systems
closed-loop control system
control theory
data-comparing devices
delayed outputs
desirable outputs
electrical and electronic controllers
electrical or electronic sensors
electromechanical controllers
fluidic controllers
immediate outputs
intended outputs
inventory control
judgmental systems
magnetic (electromagnetic) sensors
manual control systems
mechanical controllers
mechanical sensors
monitoring device
open-loop control system
optical sensors
thermal sensors
undesirable outputs
unintended outputs
wage control

Essential Question

How can you evaluate or justify solutions to problems in a manner that is analytical, predictive, repeatable, and practical?

Introduction

All engineered/technological systems are designed to meet specific needs and wants. A direct relationship exists between the need (the reason for the system) and the output (the satisfying of the need).

194

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Academic Connection provides information on topics relevant to chapter materials that connect the content to communication, history, literacy, and essay writing.



Academic Connection: Literacy

Reading in Technical and Scientific Subjects

Those who work in a technical or scientific profession must be able to think deeply about their specific discipline. They develop competency in their particular area of focus through literacy—the ability to read and write effectively.

When reading technical or scientific texts, you may find the following strategies helpful:

- Determine the central ideas or most important points of the text.
- Explain or depict a complex process.
- Write an accurate summary of the text.
- In this chapter, you are reading about the complex process of engineering design. To aid in your understanding of this process, complete the following tasks:
- Create a list of the most important points about the engineering design process. Start by looking at the headings and subheadings in the chapter text and write down the main point of each section.
- Make a sketch, graphic, or visual of how you would enact the engineering design process to solve a particular problem.
- Develop a concept map to summarize all that you have learned about engineering design after reading this chapter. **A *concept map*** is a tool that you can use to graphically organize the information that you have obtained, **Figure 4-A**. To create a concept map, write on the center of a piece of paper. Connect this term to the most important points of the chapter, and then connect those main points to their supporting concepts.

Completing these tasks will help you to precisely follow a multiple-step procedure. These strategies are useful when you are developing solutions to complex problems through the engineering design process.

A strategy to help you use the engineering design process is an engineering notebook or journal. In this notebook or journal, write your proposed set of procedures to solve the problem. Base the procedures on the information in this chapter. (Remember that the engineering design process is not a linear process—your procedure can continuously change.) As you complete the engineering design process, be sure to record all of the results in your engineering notebook or journal.

Figure 4-A. A concept map.

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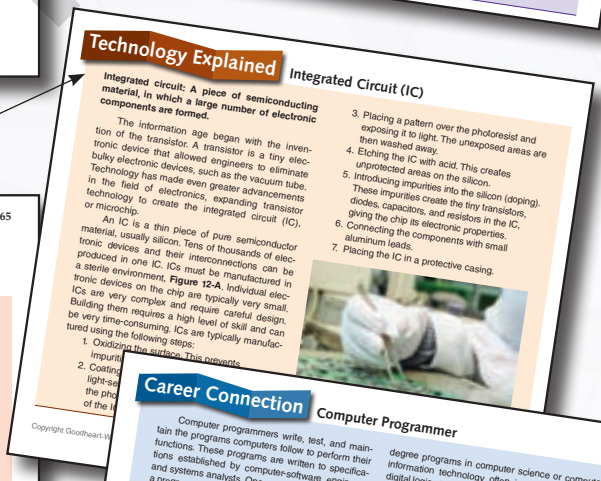
Technology Explained features explain how technological devices and systems work.



Technology Explained

Integrated Circuit (IC)

Integrated circuit: A piece of semiconducting material, in which a large number of electronic components are formed.

The information age began with the invention of the transistor. A transistor is a tiny electronic device that allowed engineers to eliminate bulky electronic devices, such as the vacuum tube. Technology has made even greater advancements in the field of electronics, expanding transistor technology to create the integrated circuit (IC), or microchip.

An IC is a thin piece of pure semiconductor material, usually silicon. Tens of thousands of electronic devices and their interconnections can be produced in one IC. ICs must be manufactured in a sterile environment, **Figure 12-A**. Individual electronic devices on the chip are typically very small. Building them requires a high level of skill and can be very time-consuming. ICs are typically manufactured using the following steps:

1. Oxidizing the surface. This prevents impurities
2. Coating
3. Placing a pattern over the photoresist and exposing it to light. The unexposed areas are then washed away.
4. Etching the IC with acid. This creates unprotected areas on the silicon.
5. Introducing impurities into the silicon (doping). These impurities create the tiny transistors, diodes, capacitors, and resistors in the IC, giving the chip its electronic properties.
6. Connecting the components with small aluminum leads.
7. Placing the IC in a protective casing.

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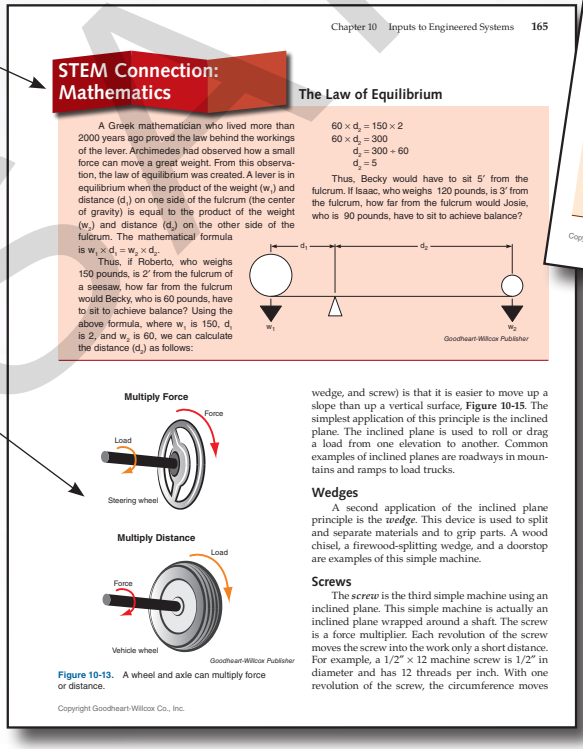
STEM Connection connects content from the chapter to concepts in science, technology, engineering, or math.

Illustrations are designed to clearly and simply communicate the specific topic. Many illustrations were replaced and updated for this edition.



STEM Connection: Mathematics

The Law of Equilibrium

A Greek mathematician who lived more than 2000 years ago proved the law behind the workings of the lever. Archimedes had observed how a small force can move a great weight. From this observation, the law of equilibrium was created. A lever is in equilibrium when the product of the weight (w_1) and distance (d_1) on one side of the fulcrum (the center of gravity) is equal to the product of the weight (w_2) and distance (d_2) on the other side of the fulcrum. The mathematical formula is $w_1 \times d_1 = w_2 \times d_2$.

Thus, if Roberto, who weighs 150 pounds, is 2′ from the fulcrum of a seesaw, how far from the fulcrum would Becky, who is 60 pounds, have to sit to achieve balance? Using the above formula, where w_1 is 150, d_1 is 2, and w_2 is 60, we can calculate the distance (d_2) as follows:

$60 \times d_2 = 150 \times 2$
$60 \times d_2 = 300$
$d_2 = 300 \div 60$
$d_2 = 5$

Thus, Becky would have to sit 5′ from the fulcrum. If Isaac, who weighs 120 pounds, is 3′ from the fulcrum, how far from the fulcrum would Josie, who is 90 pounds, have to sit to achieve balance?

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Multiply Force

Multiply Distance

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Figure 10-13. A wheel and axle can multiply force or distance.

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wedge, and screw) is that it is easier to move up a slope than up a vertical surface, **Figure 10-15**. The simplest application of this principle is the inclined plane. The inclined plane is used to roll or drag a load from one elevation to another. Common examples of inclined planes are roadways in mountains and ramps to load trucks.

Wedges

A second application of the inclined plane principle is the *wedge*. This device is used to split and separate materials and to grip parts. A wood chisel, a firewood-splitting wedge, and a doorstop are examples of this simple machine.

Screws

The *screw* is the third simple machine using an inclined plane. This simple machine is actually an inclined plane wrapped around a shaft. The screw is a force multiplier. Each revolution of the screw moves the screw into the work only a short distance. For example, a 1/2″ × 12 machine screw is 1/2″ in diameter and has 12 threads per inch. With one revolution of the screw, the circumference moves

Career Connection features are an important part of preparing for a career or college. This feature will help you understand responsibilities associated with specific job titles and the coursework and degree requirements for the job.



Career Connection

Computer Programmer

Computer programmers write, test, and maintain the programs computers follow to perform their functions. These programs are written to specifications established by computer-software engineers and systems analysts. Once a program is designed, a programmer then converts the design into a logical series of instructions the computer can follow. These instructions are coded in a conventional programming language. Programmers update, repair, modify, and expand existing programs. They test a program and make changes until it produces the correct results.

Programmers often are grouped into two broad types—applications programmers and systems programmers. Applications programmers write programs to handle a specific job. Systems programmers write programs to maintain and control computer systems' software.

Students who have strong analytical, mathematical, computational thinking, and problem-solving skills do well in these roles. Bachelor's degree programs in computer science or computer information technology often include the study of digital logic, data structure, algorithms, programming languages, software design, and operating systems.

The number of computer science related jobs is predicted to continue to grow faster than any other STEM-related job over the next couple of decades. Potential projects for computer programmers include:

- Use a variety of programming languages to write software programs.
- Interact with software developers to design new software programs.
- Transform program design ideas into a language that can be processed by a computer.
- Test and debug software programs.

Professional organizations for computer programmers include the Association for Women in Computing; the Computing Research Association; and the Institution of Electrical and Electronics Engineers Computer Society.

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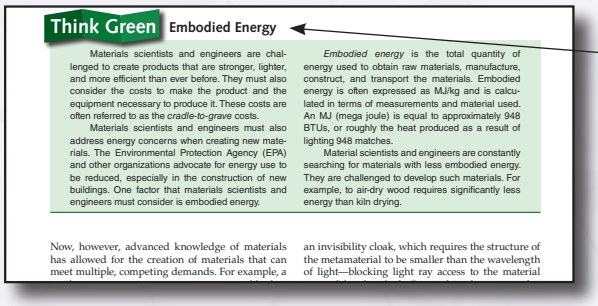
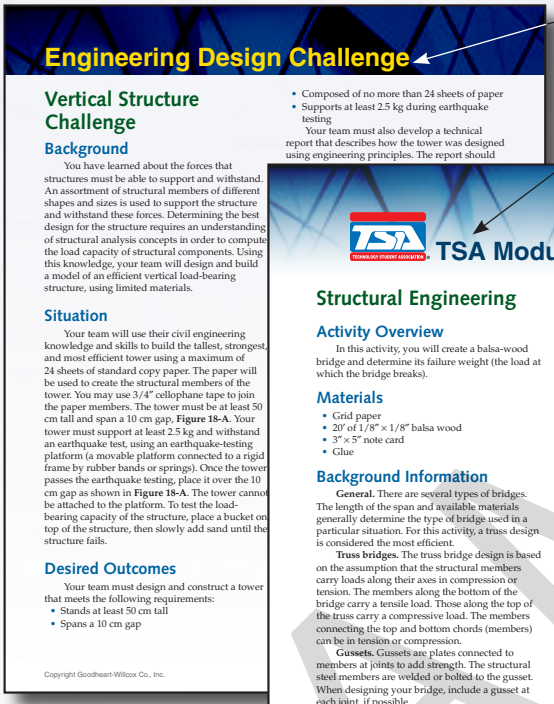


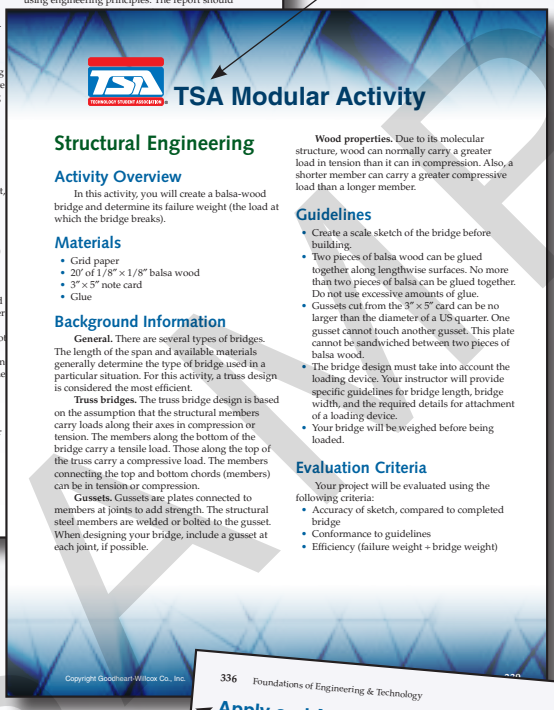
Think Green highlights key items related to sustainability, energy efficiency, and environmental issues.

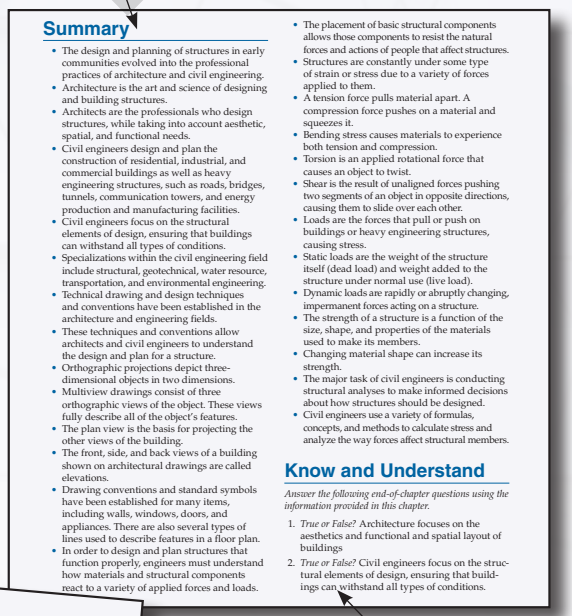
Engineering Design Challenges provide laboratory activities requiring creativity and critical thinking skills related to chapter topics. These activities extend your learning and help you apply knowledge.

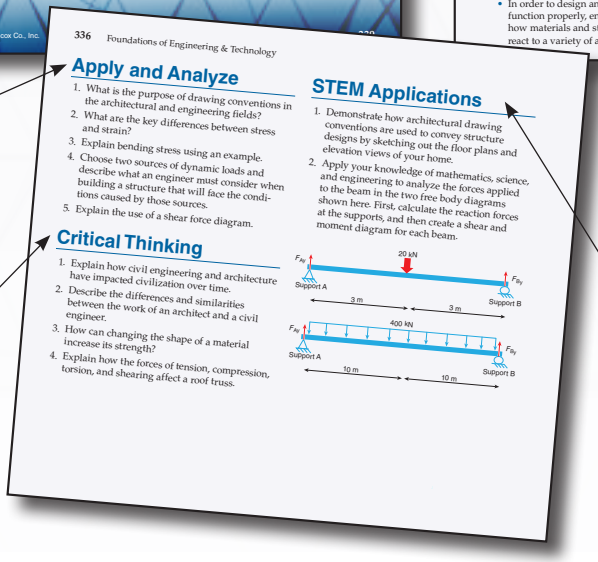
TSA Modular Activity features provide additional activities intended to develop skills used in TSA (Technology Student Association) competitive events.

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









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.

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

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

STEM Applications encourage application of concepts to real-life situations and help develop skills related to chapter content.

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TOOLS FOR STUDENT AND INSTRUCTOR SUCCESS

Student Tools

Student Text



Foundations of Engineering & Technology provides an exciting, full-color, and highly illustrated learning resource. The text presents in-depth engineering concepts and practical applications in a manner that engages students to expand their engineering and technical knowledge and to spur career interests.

Lab Workbook

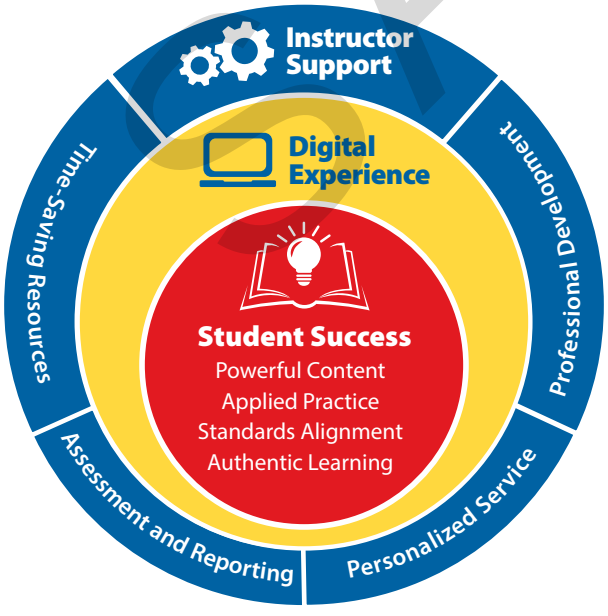
- Chapter Review Questions provide more opportunities to assess student understanding of each chapter's learning objectives.
- Engineering Design Challenge worksheets correspond with content covered in the text and offer space to collaborate with peers.
- Engineering and Technology Activities provide additional hands-on projects to strengthen understanding of core concepts as well as skills needed in different industries.

G-W Digital Companion

- E-flash cards, matching, and vocabulary exercises and games allow interaction with content to create opportunities to increase achievement.

Online Learning Suite

- Provides easy-to-use access and navigation
- Includes accessible resources for all learners
- Encourages exploration and discovery (or practice and repetition)



Instructor Tools

LMS Integration

Integrate Goodheart-Willcox content within your Learning Management System for a seamless user experience for both you and your students. EduHub LMS–ready content in Common Cartridge® format facilitates single sign-on integration and gives you control of student enrollment and data. With a Common Cartridge integration, you can access the LMS features and tools you are accustomed to using and G-W course resources in one convenient location—your LMS.

G-W Common Cartridge provides a complete learning package for you and your students. The included digital resources help your students remain engaged and learn effectively:

- **Digital Textbook**
- Online **Lab Workbook content**
- **Drill and Practice** vocabulary activities

When you incorporate G-W content into your courses via Common Cartridge, you have the flexibility to customize and structure the content to meet the educational needs of your students. You may also choose to add your own content to the course.

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Online Instructor Resources

- The **Instructor Resources** provide instructors with time-saving preparation tools such as answer keys, editable lesson plans, and other teaching aids.
- **Instructor's Presentations for PowerPoint®** are fully customizable, richly illustrated slides that help you teach and visually reinforce the key concepts from each chapter.
- Administer and manage assessments to meet your classroom needs using **Assessment Software with Question Banks**, which include hundreds of matching, completion, multiple choice, and short answer questions to assess student knowledge of the content in each chapter.

See www.g-w.com/foundations-engineering-technology-2025 for a list of all available resources.

Professional Development

- Expert content specialists
- Research-based pedagogy and instructional practices
- Options for virtual and in-person Professional Development

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BRIEF CONTENTS

Section 1—Engineering and Technology: Knowledge, Practices, and Habits for Solving Problems

1 Technology: Dynamic, Human-Created Systems and Products 2
2 Connecting Technology and Engineering Through Mathematics and Science 15
3 Engineering in Action 26

Section 2—Engineering Design and Development

4 Engineering Design Problem Solving 42
5 Developing Design Solution Ideas 60
6 Making Design Solutions 85
7 Evaluating Design Solutions 113
8 Communicating Design Solutions 122

Section 3—Engineered Systems

9 Technology as an Engineered System 141
10 Inputs to Engineered Systems 157
11 Engineering Processes 177
12 Engineering Outputs, Feedback, and Control 194

Section 4—The Engineered World

13 Designing the World Through Engineering 213
14 Manufacturing Part 1: Processing Resources 226
15 Manufacturing Part 2: Producing Products 257
16 Meeting Needs Through Materials Science and Engineering 274
17 Construction: Designing and Building Structures 291
18 Meeting Needs Through Architecture and Civil Engineering 315
19 Energy and Power: Harnessing and Using Our Resources 340
20 Meeting Needs Through Mechanical Engineering 369
21 Information and Communication: Connecting Information, Ideas, and People 389
22 Meeting Needs Through Electrical, Computer, and Software Engineering . . . 415
23 Transportation and Logistics: Moving People and Cargo 447
24 Meeting Needs Through Aerospace Engineering 478
25 Medicine and Healthcare: Maintaining Wellness 493
26 Meeting Needs Through Biomedical Engineering 511
27 Agriculture and Biological Technologies: Producing, Using, and Caring for Living Organisms 531
28 Meeting Needs Through Chemical Engineering 567

Section 5—Engineering, Technology, and Society

29 Engineering and Technology: A Societal View 588
30 Engineering and Technology: A Personal View 601
31 Managing and Organizing a Technological Enterprise 617
32 Operating a Technological Enterprise 630
33 Understanding and Assessing the Impact of Engineering and Technology . . . 647

SAMPLE



CONTENTS

Section 1
Engineering and Technology: Knowledge, Practices, and Habits for Solving Problems

Chapter 1
Technology: Dynamic, Human-Created Systems and Products 2
Introduction 2
1.1 Technology Defined 3
1.2 Technology as a Dynamic Process. 3
1.3 Positive and Negative Aspects of Technology 3
1.4 The Evolution of Technology 5
1.5 Technology and People 9
1.6 Industrial Contexts for the Application of Technology 10

Chapter 2
Connecting Technology and Engineering Through Mathematics and Science 15
Introduction 15
2.1 Engineering Defined 16
2.2 Technology's Relationship to Engineering 17
2.3 Engineering and Technology Outcomes: Inventions and Innovations 21

Chapter 3
Engineering in Action 26
Introduction 26
3.1 The Engineering Profession. 27
3.2 Qualities of an Engineer 29
3.3 Engineering Habits of Mind 30
3.4 Engineering Practices 33
3.5 Engineering Knowledge 36

Section 2
Engineering Design and Development

Chapter 4
Engineering Design Problem Solving 42
Introduction 42
4.1 Problem Solving and Design 43
4.2 System and Product Design 44
4.3 Problem Solving and Design in Engineering 47
4.4 Strategies in Engineering Design 49
4.5 Enacting and Iterating Steps in Engineering Design 56

SAMPLE

Chapter 5
Developing Design Solution Ideas 60
Introduction 61
5.1 Identify and Define the Problem 61
5.2 Gather Information 63
5.3 Develop Solutions 64

Chapter 6
Making Design Solutions 85
Introduction 85
6.1 Physically Modeling Design Solutions 86
6.2 Physical Models 87
6.3 Producing Physical Models 88
6.4 Material Processing 89
6.5 Experimenting with Materials and Tools for Optimization 108

Chapter 7
Evaluating Design Solutions 113
Introduction 113
7.1 Evaluating Design Solutions 113
7.2 Determine Test Criteria 114
7.3 Establish a Procedure for Testing/Experimentation 116

Chapter 8
Communicating Design Solutions 122
Introduction 122
8.1 Written Communication 123
8.2 Oral Communication 132

Section 3
Engineered Systems

Chapter 9
Technology as an Engineered System 141
Introduction 141
9.1 Technology as an Engineered System 142
9.2 Systems Thinking 143
9.3 Universal Systems Model 145

Chapter 10
Inputs to Engineered Systems 157
Introduction 157
10.1 People 158
10.2 Tools and Machines 160
10.3 Materials 166
10.4 Information 170
10.5 Energy 170
10.6 Finances 171
10.7 Time 173

SAMPLE

Chapter 11
Engineering Processes 177
Introduction 177
11.1 Problem-Solving and the Engineering Design Process 178
11.2 Production Processes 178
11.3 Management Processes 190

Chapter 12
Engineering Outputs, Feedback, and Control 194
Introduction 194
12.1 Outputs 195
12.2 Feedback and Control 198

Section 4
The Engineered World

Chapter 13
Designing the World Through Engineering 213
Introduction 213
13.1 The Engineered World 213
13.2 Designing Through Engineering 214
13.3 Engineering Design in Technologies and Industries 215
13.4 Navigating the Engineered World 223

Chapter 14
Manufacturing Part 1: Processing Resources 226
Introduction 226
14.1 Manufacturing and Construction 227
14.2 The Evolution of Manufacturing 227
14.3 Modern Manufacturing 229
14.4 Computer-Integrated Manufacturing 230
14.5 Primary and Secondary Manufacturing 234
14.6 Types of Material Resources 236
14.7 Material Processing 246

Chapter 15
Manufacturing Part 2: Producing Products 257
Introduction 257
15.1 Types of Manufacturing Processes 258
15.2 Product Production 263
15.3 Product Design and Development 264
15.4 Designing the Production Process 268
15.5 Manufacturing Enterprises 269

Chapter 16
Meeting Needs Through Materials Science and Engineering . 274
Introduction 274
16.1 Materials Science and Engineering 275
16.2 Evolution of Materials Science 275

SAMPLE

16.3 Classifying Materials 277
16.4 Advancements in Materials 284

Chapter 17
Construction: Designing and Building Structures 291
Introduction 291
17.1 Types of Buildings 292
17.2 Constructing Buildings 294
17.3 Heavy Engineering Structures 306

Chapter 18
Meeting Needs Through Architecture and Civil Engineering . 315
Introduction 315
18.1 The Development of Architecture and Civil Engineering 316
18.2 Architecture and Civil Engineering 316
18.3 Architectural Design and Drawing Fundamentals 319
18.4 Civil Engineering Foundations 321
18.5 Structural Members, Shapes, Materials, and Strength 325
18.6 Structural Analysis 329

Chapter 19
Energy and Power: Harnessing and Using Our Resources . 340
Introduction 340
19.1 Energy, Work, and Power 341
19.2 Types of Energy 341
19.3 Forms of Energy 342
19.4 Sources of Energy 344
19.5 Energy Conversion 347
19.6 Inexhaustible-Energy Converters 348
19.7 Renewable-Energy Converters 354
19.8 Thermal-Energy Converters 356
19.9 Electrical-Energy Converters 360

Chapter 20
Meeting Needs Through Mechanical Engineering 369
Introduction 369
20.1 Evolution of Mechanical Engineering 370
20.2 Scientific and Mathematical Principles 372
20.3 Measuring Work, Power, and Torque 381
20.4 Mechanical Engineering and Materials Science 383
20.5 Mechanical Engineering and Mechatronics 383
20.6 Mechanical Engineering Careers 384

Chapter 21
Information and Communication: Connecting Information, Ideas, and People 389
Introduction 389
21.1 Information and Communication Technology 390
21.2 Communication 392
21.3 Information and Communication Systems 396

SAMPLE

21.4 Printed Graphic Communication 398
21.5 Photographic Communication 398
21.6 Telecommunication 398
21.7 Technical Graphic Communication 404
21.8 Computer and Internet Communication 404

Chapter 22
Meeting Needs Through Electrical, Computer, and Software Engineering 415
Introduction 416
22.1 Defining Disciplines 416
22.2 Evolution of Electrical, Computer, and Software Engineering . . . 418
22.3 The Science of Electricity 420
22.4 Computer Systems 433

Chapter 23
Transportation and Logistics: Moving People and Cargo . . . 447
Introduction 448
23.1 Transportation and Logistics Defined 448
23.2 Transportation as a System 449
23.3 Types of Transportation Systems 449
23.4 Transportation-System Components 451
23.5 Vehicular Systems 453
23.6 Land-Transportation Vehicles 456
23.7 Water-Transportation Vehicles 461
23.8 Air-Transportation Vehicles 466
23.9 Space-Transportation Vehicles 472

Chapter 24
Meeting Needs Through Aerospace Engineering 478
Introduction 478
24.1 Aerospace Engineering Evolution 479
24.2 Aerospace Engineering 483
24.3 Fundamentals of Aircraft Design 483
24.4 Principles of Flight 486
24.5 Materials Selection 489
24.6 Aerospace Engineering in Other Engineering Fields 489

Chapter 25
Medicine and Healthcare: Maintaining Wellness 493
Introduction 493
25.1 Technology and Wellness 494
25.2 Technology and Illness 497

Chapter 26
Meeting Needs Through Biomedical Engineering 511
Introduction 511
26.1 Evolution of Biomedical Engineering 512
26.2 Biomedical Engineers 513

SAMPLE

26.3 Products of Biomedical Engineering 514
26.4 Human Physiology. 517
26.5 Biomechanics 523
26.6 Biomaterials. 525
26.7 Biomedical Imaging 526
26.8 Government Regulations and Standards 527
26.9 Bioethics 527

Chapter 27
Agriculture and Biological Technologies: Producing, Using, and Caring for Living Organisms 531
Introduction 532
27.1 Types of Agriculture 532
27.2 Animal Husbandry 542
27.3 Aquaculture 544
27.4 Agriculture and Biotechnology 544
27.5 Food-Processing Technologies. 546
27.6 Primary Food Processing 547

Chapter 28
Meeting Needs Through Chemical Engineering 567
Introduction 568
28.1 Chemical Engineering 568
28.2 Chemical Engineering Fundamentals 570
28.3 Chemistry 570
28.4 Structure and Properties of Matter. 571
28.5 Chemical Reactions and Bonds 577
28.6 Chemical Equations 580
28.7 States of Matter 581
28.8 Organic Chemistry and Biochemistry 582
28.9 Chemical Engineering: Applications 583

Section 5
Engineering, Technology, and Society

Chapter 29
Engineering and Technology: A Societal View 588
Introduction 588
29.1 Technology and Natural Forces 588
29.2 Technology and the Future 589
29.3 Technology's Challenges and Promises 590

Chapter 30
Engineering and Technology: A Personal View 601
Introduction 601
30.1 Technology and Lifestyle 602
30.2 Technology and Employment. 604

SAMPLE

30.3 Technology and Individual Control 608
30.4 Technology and Major Concerns 609
30.5 Technology and New Horizons 611

Chapter 31
Managing and Organizing a Technological Enterprise . . . 617
Introduction 617
31.1 Technology and the Entrepreneur 617
31.2 Technology, Engineering, and Management 618
31.3 Risks and Rewards 621
31.4 Forming a Company 622

Chapter 32
Operating a Technological Enterprise 630
Introduction 630
32.1 Societal Institutions 631
32.2 Economic Enterprises 631
32.3 Areas of Industrial Activity 632
32.4 The Industry-Consumer Product Cycle 643

Chapter 33
Understanding and Assessing the Impact of Engineering and Technology 647
Introduction 647
33.1 Using Technology 647
33.2 Assessing Technology 652

Glossary *657*
Index *683*

SAMPLE

FEATURE CONTENTS



STEM Connection

Science and Mathematics: Calculating Mechanical Advantage 17
Mathematics: Designing the Pyramids 38
Mathematics: Solid Geometry. 72
Mathematics: Measuring Area 98
Science: Conducting an Experiment. 117
Science: Newton's Three Laws of Motion 143
Mathematics: Calculating Acceleration Using Newton's Second Law 152
Mathematics: The Law of Equilibrium 165
Science and Mathematics: Ultrasonic Sensors. 191
Science: Chlorofluorocarbons (CFCs) . . . 198
Science and Engineering: Synthetic Fuels. 250
Science: Forming and Conditioning Materials 262
Mathematics: Consumer Data 266
Science: Creating New Elements 280
Science: Bridge Design and Natural Forces 310
Mathematics: Calculating the Weight of a Structure 331
Science: Laws of Gases 355
Mathematics: Calculating Gear Speeds 379
Science: Newton's First Law of Motion . . . 461
Mathematics: Calculating Buoyant Force 464
Science: Aerodynamics. 487
Science: Genetic Engineering 546
Science: Irradiation 576
Mathematics: Calculating Interest Rates. 621
Mathematics: Calculating Bids 643

Career Connection

Engineering Technician. 16
Engineering Professionals 29
Drafting and Design Engineering 76
Machine Technician 89
Market Research Analyst 118
Technical Writer 133
Systems Engineer. 145
Engineering Manager 160
Process Engineer 179
Control Engineer. 201
Mechatronics Engineer. 223
Petroleum and Natural Gas Engineer. . . . 245
Manufacturing Engineer 258
Materials Scientists and Engineers. 282
Construction Manager 295
Power Plant Operator 344
Mechanical Engineer 371
Computer Programmer 419
Automotive Technician 454
Aerospace Engineer 485
Agricultural and Food Scientist 537
Chemical Engineers 570
Environmental Engineer 593
Technology and Engineering Teachers . . . 605
Top Executives 624
Technical Illustrators 634

SAMPLE

Technology Explained

Computer Numerical Control 93
Power Station 172
Hybrid and Electric Vehicles 184
Integrated Circuit (IC) 203
Fiber Optics 407
Virtual Reality 436
Uncrewed Aerial Vehicle (UAV) 483
Dialysis Machine 506
Heart-Lung Machine 524
Making and Freezing Commercial French Fries 555
Organic Light-Emitting Diodes (OLEDs) . . . 591
Warm-Up Jackets 613
Wind Tunnel 637
Earth-Sheltered Building 653

Academic Connection

History: The Origin of Radar 22
History: Engineering the Pyramids Versus the Burj Khalifa 34
Literacy: Reading in Technical and Scientific Subjects 51
History: The Tennessee Valley Authority (TVA) 186
Literacy: Reading Comprehension Strategies 207
Argumentative Essay: Locating and Obtaining Natural Gas 246
Argumentative Essay: Advantages, Disadvantages, and Ethical Concerns of Nanotechnology 287
History: The Origin of Horsepower 348
Communication: The Power of Radio 392
History: The Beginning of Photojournalism 399
Argumentative Essay: Ethics in Medicine 504
History: X-Ray Imaging 526

Think Green

Carbon Footprint 21
Environmental Engineering 30
Sustainable Design 47
Recycling 106
Organic Cotton 168
Waste Heat Recovery 197
Green Building 219
Green Materials 235
Product Life Cycle and Reduction 264
Embodied Energy 285
Alternative Construction Methods 299
Forest Stewardship Council 346
Efficient Energy Use 347
Inks 398
Electronic Waste 418
Hybrid Vehicles 456
Reusable Spacecraft 480
Local Organic Food 541
Green Household Cleaners 572
Shopping Bags 596
Energy-Efficient Lighting 611
Sustainability Plan 636

SAMPLE

Engineering Design Challenge

Temporary Shelter 59
Design Problem 83
Making a Board Game 111
Bookend Design 138
Newtonian System Design 155
Simple Machine Science Kit 176
Automated Control System Challenge 210
Lumber Processing System 254
Manufacturing Enterprise 273
Advanced Material Creation 290
Load Bearing Heavy Engineering Structure 313
Vertical Structure Challenge 337
Responsibly Harnessing Resources for Energy: Passive Solar House Challenge 367
Wind-Powered Electricity Generator 387
Public Service Announcement for Engineering 413
Prosthesis Challenge 530
Dehydrating Food 563
Exothermic Reactions 586
Resource Depletion 600
Technological Impacts Commercial 616
Forming an Innovation-Driven Enterprise 629
Operating a Company 646

TSA Modular Activity

Computer-Aided Design (CAD), Engineering with Animation 84
Manufacturing Prototype 256
Structural Engineering 339
Promotional Design 414
Webmaster Content Design 445
Medical Technology 509
Agriculture and Biotechnology Design . . . 565

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