This International Student Edition is for use outside of the U.S.

Eighth Edition

Engineering

Fundamentals and Problem Solving

Arvid R. Eide • Steven K. Mickelson • Cheryl L. Eide
Roland D. Jenison • Larry L. Northup

ISTUDY

Engineering Fundamentals & Problem Solving

Arvid R. Eide
Iowa State University

Steven K. Mickelson
Iowa State University

Cheryl L. Eide
Iowa State University

Roland D. Jenison
Iowa State University

Larry L. Northup
Iowa State University

Eighth Edition

Mc Graw Hill

ISTUDY

Mc Graw Hill

ENGINEERING FUNDAMENTALS AND PROBLEM SOLVING

Published by McGraw Hill LLC, 1325 Avenue of the Americas, New York, NY 10019. Copyright ©2023 by McGraw Hill LLC. All rights reserved. Printed in the United States of America. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written consent of McGraw Hill LLC, including, but not limited to, in any network or other electronic storage or transmission, or broadcast for distance learning.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LKV 27 26 25 24 23 22

ISBN 978-1-265-14055-7
MHID 1-265-14055-3

Cover Image: *Liu zishan/Shutterstock*

All credits appearing on page or at the end of the book are considered to be an extension of the copyright page.

The Internet addresses listed in the text were accurate at the time of publication. The inclusion of a website does not indicate an endorsement by the authors or McGraw Hill LLC, and McGraw Hill LLC does not guarantee the accuracy of the information presented at these sites.

mheducation.com/highered

ISTUDY

Contents

1 The Engineering Profession 1

1.1 An Engineering Career 1
1.2 The Technology Team 3
1.3 The Engineering Profession 6
1.4 The Engineering Functions 7
1.5 The Engineering Disciplines 20
1.6 Conclusion 35

2 Education for Engineering 37

2.1 Education for Engineering 37
2.2 The Engineer as a Professional 45
2.3 Conclusion 49

3 Introduction to Engineering Design 51

3.1 An Introduction to Engineering Design 51
3.2 The Design Process 52
3.3 Design and the Customer 56
3.4 The Nature of Engineering Design 57
3.5 Experiencing the Design Process in Education 59
3.6 Design Opportunities and Challenges of the Future 59

4 Engineering Solutions 69

4.1 Introduction 69
4.2 Problem Analysis 69
4.3 The Engineering Method 70
4.4 Problem Presentation 72
4.5 Standards of Problem Presentation 73

5 Representation of Technical Information 89

5.1 Introduction 89
5.2 Collecting and Recording Data 94
5.3 General Graphing Procedures 95
5.4 Empirical Functions 105
5.5 Curve Fitting 106
5.6 Method of Selected Points and Least Squares 106

ISTUDY 5011333

5.7 Empirical Equations: Linear 107
5.8 Empirical Equations: Power Curves 108
5.9 Empirical Equations: Exponential Curves 114

6 Engineering Measurements and Estimations 125

6.1 Introduction 125
6.2 Measurements: Accuracy and Precision 125
6.3 Measurements: Significant Digits 127
6.4 Errors 131
6.5 Estimations 132

7 Dimensions, Units, and Conversions 143

7.1 Introduction 143
7.2 Progress in the United States toward Metrification 144
7.3 Physical Quantities 144
7.4 Dimensions 145
7.5 Units 146
7.6 SI Units and Symbols 147
7.7 Rules for Using SI Units 151
7.8 U.S. Customary and Engineering Systems 156
7.9 Conversion of Units 158
7.10 Celsius, Fahrenheit, and Absolute Scales 163

8 Introduction to Engineering Economics 171

8.1 Introduction 171
8.2 Simple and Compound Interest 172
8.3 Cash-Flow Diagram 178
8.4 Present Worth and Future Worth 179
8.5 Annual Worth and Gradients 183
8.6 Summary Table 203

9 Economics: Decision Making 211

9.1 Economic Decision Making 211
9.2 Depreciation and Taxes 216

10 Statistics 219

10.1 Introduction 219
10.2 Frequency Distribution 220
10.3 Measures of Central Tendency 222
10.4 Measures of Variation 224
10.5 Linear Regression 228
10.6 Coefficient of Correlation 236

ISTUDY

11 Inferential Statistics and Decision Making 251

11.1 Inferential Statistics 251
11.2 Experimental Design 252
11.3 Sampling 253
11.4 Use of Various Distributions 254
11.5 Level of Significance and Confidence Intervals 261

12 Mechanics: Statics 263

12.1 Introduction 263
12.2 Scalars and Vectors 265
12.3 Forces 267
12.4 Types of Force Systems 267
12.5 Transmissibility 268
12.6 Resolution of Forces 269
12.7 Moments 273
12.8 Free-Body Diagrams 275
12.9 Equilibrium 278

13 Mechanics: Strength of Materials 295

13.1 Introduction 295
13.2 Stress 295
13.3 Strain 297
13.4 Modulus of Elasticity 299
13.5 Design Stress 300
13.6 Stress Concentration 306

14 Material Balance 311

14.1 Introduction 311
14.2 Conservation of Mass 311
14.3 Processes 315
14.4 A Systematic Approach 317

15 Energy Sources and Alternatives 329

15.1 Introduction 329
15.2 Fossil Fuels 330
15.3 Finite Supply of Fossil Fuels 331
15.4 Major Areas of Energy Consumption in the United States 337
15.5 Alternate Energy Sources 342

16 Fundamental Energy Principles 351

16.1 Introduction to Thermodynamics 351
16.2 Stored Energy 351

ISTUDY

16.3 Energy in Transit 354
16.4 First Law of Thermodynamics: The Conservation of Energy 357
16.5 Second Law of Thermodynamics 361
16.6 Efficiency 362
16.7 Power 365
16.8 Refrigeration Cycles 367

17 Electrical Theory 371

17.1 Introduction 371
17.2 Structure of Electricity 372
17.3 Static Electricity 373
17.4 Electric Current 373
17.5 Electric Potential 374
17.6 Simple Electric Circuits 374
17.7 Resistance 375
17.8 DC Circuit Concepts 376
17.9 DC Electric Power 382
17.10 Terminal Voltage 384
17.11 Kirchhoff's Laws 385
17.12 Mesh Currents 391

18 Flowcharts 403

18.1 Introduction 403
18.2 Flowcharting 403

Appendices 421

A. Part 1 Unit Conversions 421
Part 2 Unit Prefixes 427
Part 3 Physical Constants 428
Part 4 Approximate Specific Gravities and Densities 429
B. Greek Alphabet 431
C. Chemical Elements 432
D. NSPE Code of Ethics for Engineers 435
E. Areas under the Standard Normal Curve from 0 to z 440
F. Part 1 Selected Algebra Topics 441
Part 2 Selected Trigonometry Topics 449

Answers to Selected Problems 467
Index 477

ISTUDY

Preface

To the Student

As you begin the study of engineering no doubt you are filled with enthusiasm, curiosity, and a desire to succeed. Your first year will be spent primarily in establishing a solid foundation in mathematics, basic sciences, and communications. Also, you will be introduced to selected engineering topics that will demonstrate how engineers approach problem solving, arrive at correct solutions, and interface with other engineering professionals and the general public to implement the solutions. You will see how mathematics, science, and communications provide the means to solve problems and convey the solutions in a manner that can be clearly understood and quickly verified by the appropriate persons. Next, you will discover the need for more in-depth study in many engineering subjects in order to solve increasingly complex problems. We believe the material presented in this book will provide you with a fundamental understanding of how engineers function in today's technological world. After your study of topics in this text, we believe you will be eager to enter the advanced engineering subjects in your chosen discipline, confident that you will successfully achieve your educational goals. You will also find profiles of practicing engineers who were in your shoes a few years ago. They will show the result of your hard work will result in amazing careers.

To the Instructor

Engineering courses for first-year students cover a wide range of topics from an overview of the engineering profession to discipline-specific subjects. A broad set of course goals, including coverage of prerequisite material, motivation, and retention, have spawned a variety of first-year activity. Courses in introductory engineering and problem solving routinely utilize spreadsheets and mathematical solvers in addition to teaching the rudiments of a computer language. The Internet has become a major instructional tool, providing a wealth of data to supplement your class notes and textbooks. This eighth edition continues the authors' intent to introduce the profession of engineering and to provide students with many of the tools and techniques needed to succeed.

The eighth edition of this text draws on the experiences the authors have encountered with the first seven editions and incorporates many excellent suggestions from faculty and students using the text. Over the past 40+ years the fundamentals of problem solving have remained nearly the same, but the numerical tools and presentation techniques have improved tremendously. Therefore our general objectives remain the same for this eighth edition, and we have concentrated on new and emerging problems like microplastics pollution and desalination of water for drinking and community use and improvements in the textual material.

The objectives are (1) to motivate engineering students during their first year when exposure to the subject matter of engineering is limited, (2) to provide students with experience in solving problems in both SI and customary units while presenting

ISTUDY

solutions in a logical manner, (3) to introduce students to subject areas common to most engineering disciplines that require the application of fundamental engineering concepts, and (4) to develop students' skills in solving open-ended problems.

The material in this book is presented in a manner that allows each of you to emphasize certain aspects more than others without loss of continuity. In the eighth edition, new engineering graduate profiles have been added to help student understand better what an engineer does and what recommendations they would have for a new engineering student. Modern engineering examples, data, and photos have been integrated throughout the chapters, and more problems have been added to Connect. The problems that follow most chapters vary in difficulty so that students can experience success rather quickly and still be challenged as problems become more complex.

There is sufficient material in the 18 chapters for a three-credit semester course. By omitting some chapters and/or by varying coverage from term to term, you can present a sound introductory problem-solving course in two to four quarter credits or two semester credits.

The book may be visualized as having three major sections. The first, encompassing the first three chapters, is an introduction to the engineering profession. Chapter 1 provides information on engineering disciplines and functions. If a formal orientation course is given separately, Chapter 1 can be simply a reading assignment and the basis for students to investigate disciplines of interest. Chapter 2 outlines the course of study and preparation for an engineering work environment. Interdisciplinary projects, teaming, and ethics are discussed. Chapter 3 is an introduction to the design process. If time permits, this material can be supplemented with case studies and your personal experiences to provide an interesting and motivating look at engineering.

The second major section, Processing Engineering Data, includes materials we believe that all engineering students require in preparation for success in the engineering profession. Chapters 4 and 5 provide procedures for approaching an engineering problem, determining the necessary data and method of solution, and presenting the results. The authors have found that emphasis in this area will reap benefits when the material and problems become more difficult later.

Chapters 6 and 7 include engineering estimations and dimensions and units (including both customary and SI units). Throughout the book discussions and example problems tend to emphasize SI metric. However, other dimension systems are used extensively today, so a number of our examples and problems contain nonmetric units to ensure that students are exposed to conversions and other units that are commonly used.

Chapters 8 and 9, Engineering Economy, demonstrate the importance of understanding the time value of money in making engineering decisions. Chapter 8 emphasizes basic calculations using everyday information such as credit card debt, savings accounts, and current interest rates. Additionally, the Summary Table 8.8 is a valuable resource that students use well beyond this course. Chapter 9 follows with applications to engineering decision making for equipment selection, depreciation, investments, and taxes. Chapters 10 and 11, Statistics, provide an introduction to a subject that is assuming a greater role in engineering decision making. Chapter 10 introduces basic descriptive statistics, linear regression, and coefficient of correlation. Chapter 11 includes normal distributions as well as *Student's t, F,* and *Chi-Square.* It also adds new material on the use of inferential statistics and a general introduction to randomized sampling

ISTUDY

and experimental design. The ability to take large amounts of test or field data, perform statistical analyses, and draw correct conclusions is crucial in establishing performance parameters. Engineering Economy and Statistics are subdivided, permitting you to choose the first chapter for an introduction to the fundamentals and, if time permits, applications to specific engineering activities can be covered.

The third major section provides engineering content that you can use to reinforce fundamentals from the previous section. Chapters 12 through 17 allow you as an instructor a great deal of flexibility. Chapters 12 and 13 on engineering mechanics provide an introduction to statics and strength of materials. Force vectors, two-dimensional force systems, and the conditions of equilibrium are emphasized in Chapter 12. Chapter 13 emphasizes stresses and strains and requires Chapter 12 as a prerequisite. Chapter 15 has undergone significant updating. Chapter 15 discusses energy forms and sources. The authors believe that engineering students need to become aware of the world's current dependence on fossil fuels very early in their studies so they may apply this knowledge to the use and development of alternative sources of energy.

Chapter 16 follows with an introduction to thermodynamics and applications of the First and Second Laws of Thermodynamics. The study of Chapter 16 should be preceded by coverage of Chapter 15.

Chapter 14, Material Balance, and Chapter 17, Electrical Theory, complete the third major section and contain upgraded example problems.

Certain problems suggest the use of a computer or spreadsheet for solution. These are open-ended or "what-if" problems. Depending on the students' prior work with programming or spreadsheets, additional instruction may be required before attempting these problems. Chapter 18 covers the use of flowcharts, which can be of tremendous help when programming with all kinds of computer languages.

The appendices are provided as a ready reference on selected areas that will enable students to review topics from algebra and trigonometry. The National Society of Professional Engineers' Code of Ethics for Engineers is included and is highly recommended for reading and class discussion. Other appendices include tables, unit conversions, formulas, and selected answers to chapter problems.

Because the text was written for first-year engineering students, mathematical expertise beyond algebra, trigonometry, and analytical geometry is not required for any material in the book. The authors have found, however, that additional experience in pre-calculus mathematics is very helpful as a prerequisite for this text.

ISTUDY

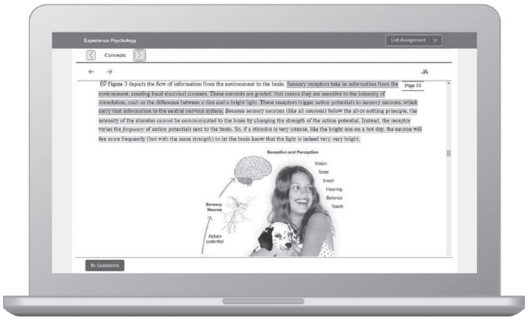
McGraw Hill connect®

Instructors: Student Success Starts with You

Tools to enhance your unique voice

Want to build your own course? No problem. Prefer to use an OLC-aligned, prebuilt course? Easy. Want to make changes throughout the semester? Sure. And you'll save time with Connect's auto-grading too.

65% Less Time Grading



Laptop: McGraw Hill; Woman/dog: George Doyle/Getty Images

Study made personal

Incorporate adaptive study resources like SmartBook® 2.0 into your course and help your students be better prepared in less time. Learn more about the powerful personalized learning experience available in SmartBook 2.0 at **www.mheducation.com/highered/connect/smartbook**

Affordable solutions, added value

Make technology work for you with LMS integration for single sign-on access, mobile access to the digital textbook, and reports to quickly show you how each of your students is doing. And with our Inclusive Access program you can provide all these tools at a discount to your students. Ask your McGraw Hill representative for more information.

Padlock: Jobalou/Getty Images

Solutions for your challenges

A product isn't a solution. Real solutions are affordable, reliable, and come with training and ongoing support when you need it and how you want it. Visit **www.supportateverystep.com** for videos and resources both you and your students can use throughout the semester.

ISTUDY

SUPPORT AT every step

Students: Get Learning that Fits You

Effective tools for efficient studying

Connect is designed to help you be more productive with simple, flexible, intuitive tools that maximize your study time and meet your individual learning needs. Get learning that works for you with Connect.

Study anytime, anywhere

Download the free ReadAnywhere app and access your online eBook, SmartBook 2.0, or Adaptive Learning Assignments when it's convenient, even if you're offline. And since the app automatically syncs with your Connect account, all of your work is available every time you open it. Find out more at **www.mheducation.com/readanywhere**

> ***"I really liked this app—it made it easy to study when you don't have your text-book in front of you."***
>
> - Jordan Cunningham, Eastern Washington University

Calendar: owattaphotos/Getty Images

Everything you need in one place

Your Connect course has everything you need—whether reading on your digital eBook or completing assignments for class, Connect makes it easy to get your work done.

Learning for everyone

McGraw Hill works directly with Accessibility Services Departments and faculty to meet the learning needs of all students. Please contact your Accessibility Services Office and ask them to email accessibility@mheducation.com, or visit **www.mheducation.com/about/accessibility** for more information.

Top: Jenner Images/Getty Images, Left: Hero Images/Getty Images, Right: Hero Images/Getty Images

ISTUDY

Acknowledgments

The authors are indebted to many who assisted in the development of this edition of the textbook. First, we would like to thank the faculty of the former Division of Engineering Fundamentals and Multidisciplinary Design at Iowa State University, who have taught the engineering computations courses over the past 40+ years. They, with the support of engineering faculty from other departments, have made the courses a success by their efforts. Several thousands of students have taken the courses, and we want to thank them for their comments and ideas, which have influenced this edition. The many suggestions of faculty and students alike have provided us with much information that was necessary to improve the previous editions. Special thanks go to the reviewers for this edition whose suggestions were extremely valuable. These suggestions greatly shaped the manuscript in preparation of the eighth edition.

Finally, we thank our families for their continuing support of our efforts.

Arvid R. Eide
Steven K. Mickelson
Cheryl L. Eide
Roland D. Jenison
Larry L. Northup

ISTUDY

About the Authors

Arvid R. Eide received his baccalaureate degree in mechanical engineering from Iowa State University. Upon graduation he spent two years in the U.S. Army as a commissioned officer and then returned to Iowa State as an instructor while completing a master's degree in mechanical engineering. Professor Eide has worked for Western Electric, John Deere, and the Trane Company. He received his Ph.D. in 1974 and was appointed professor and Chair of Freshman Engineering, a position he held from 1974 to 1989, at which time Dr. Eide was appointed Associate Dean of Academic Affairs. In 1996, he returned to teaching as a professor of mechanical engineering. In January 2000 he retired from Iowa State University as professor emeritus of mechanical engineering.

Steven K. Mickelson is the Chuck R. and Jane F. Olsen Professor of Engineering at Iowa State University. His tenure home is in the Department of Agricultural and Biosystems Engineering (ABE). Dr. Mickelson was the Chair for the ABE department from 2011 to 2021. He is currently the Special Advisor to the Senior Vice President and Provost, co-leading the roleout of Iowa State University's new student information and receivable system. His teaching specialties include computer-aided graphics, engineering problem solving, engineering design, and soil and water conservation engineering. His research areas include evaluation of best management practices for reducing surface and groundwater contamination, manure management evaluation for environmental protection of water resources, and the scholarship of teaching and learning. Dr. Mickelson has been very active in the American Society for Engineering Education and the American Society of Agricultural and Biosystems Engineers for the past 40 years. He received his agricultural engineering degrees from Iowa State University in 1982, 1984, and 1991. He is a fellow within the American Society for Agricultural and Biological Engineers.

Cheryl L. Eide has worked with undergraduate student recruitment, retention, advising, and the development of programs to support women and minorities pursuing engineering. Her teaching portfolio includes engineering fundamentals and problem solving, engineering economy, material handling, factory layout, and computer simulation. Dr. Eide helped to re-activate and charter the Heart of Iowa Section of the Society of Women Engineers (SWE) and served as the faculty advisor to the Iowa State SWE student section. She is a member of the Cardinal Key Honor Society, which recognizes outstanding leadership, character, service, and scholarship at Iowa State University where Dr. Eide earned her bachelor's, master's, and doctorate degrees.

Roland D. (Rollie) Jenison taught for 35 years in aerospace engineering and lower-division general engineering. He taught courses in engineering problem solving, engineering design graphics, aircraft performance, and aircraft stability and control, in addition to serving as academic adviser to many engineering students. He was a member of the American Society for Engineering Education (ASEE) and the American Institute of Aeronautics and Astronautics (AIAA), and published numerous papers on engineering education. He served as chair of the Engineering Design Graphics Division of ASEE in 1986–1987. He was active in the development of improved teaching methodologies through the application of team learning, hands-on projects, and open-ended problem solving. He retired in June 2000 as

ISTUDY

professor emeritus in the Department of Aerospace Engineering and Engineering Mechanics at Iowa State University.

Larry L. Northup is a professor emeritus of civil, construction, and environmental engineering at Iowa State University. He has 40 years of teaching experience, with 25 years devoted to lower-division engineering courses in problem solving, graphics, and design. He has two years of industrial experience and is a registered engineer in Iowa. He has been active in ASEE (Engineering Design Graphics Division), having served as chair of the Freshman Year Committee and Director of Technical and Professional Committees (1981–1984). He also served as chair of the Freshman Programs Constituent Committee of ASEE in 1983–1984.

ISTUDY

The Engineering Profession

Chapter Objectives

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

- Understand the role of engineering in the world
- Understand how to prepare for a meaningful engineering career
- Understand the role of an engineer in the engineering workplace
- Describe the responsibilities and roles of the most common engineering disciplines
- Gain academic career advice from past engineering graduates from various engineering disciplines

1.1 An Engineering Career

The rapidly expanding and developing sphere of science and technology may seem overwhelming to the individual exploring a career in a technological field. A technical specialist today may be called engineer, scientist, technologist, or technician, depending on education, industrial affiliation, and specific work. For example, about 700 colleges and universities in 29 countries offer close to 3 600 engineering programs accredited by ABET, the main accrediting body for engineering and technology programs. Included in these programs are such traditional specialties as aerospace, agricultural, architectural, chemical, civil, computer, construction, electrical, industrial, manufacturing, materials, mechanical, and software engineering—as well as expanding bioengineering, biomedical, biological, electromechanical, environmental, and telecommunications. Programs in engineering, mechanics, mining, nuclear, ceramic, software, and petroleum engineering add to a lengthy list of career options in engineering alone. Coupled with thousands of programs in science and technical training offered at hundreds of universities, colleges, and technical schools, the task of choosing the right field no doubt seems formidable (Figure 1.1).

Since you are reading this book, we assume that you are interested in studying engineering or at least are trying to decide whether to do so. Up to this point in your academic life you probably have had little experience with engineering as a career and have gathered your impressions from advertising materials, counselors, educators, and perhaps a practicing engineer or two. Now you must investigate as many careers as you can as soon as possible to be sure of making the right choice.

The study of engineering requires a strong background in mathematics and the physical sciences. Section 1.5 discusses typical areas of study within an engineering

ISTUDY

Figure 1.1

Imagine the number of engineers who were involved in the design of the windmill related to construction, material choices, electrical systems, and mechanical systems.
Oorka/Shutterstock

program that lead to the bachelor's degree. You also should consult with your academic counselor about specific course requirements. If you are enrolled in an engineering program but have not chosen a specific discipline, consult with an adviser or someone on the engineering faculty about particular course requirements in your areas of interest.

When considering a career in engineering or any closely related fields, you should explore the answers to several questions:

- What is engineering?
- What are the career opportunities for engineers?
- What are the engineering disciplines?
- Where does the engineer fit into the technical spectrum?
- How are engineers educated?
- What is meant by professionalism and engineering ethics?
- What have engineers done in the past?
- What are engineers doing now? What will engineers do in the future?
- What are the workplace competencies needed to be a successful engineer?

Finding answers to such questions can be difficult and time consuming, but essential to determining the proper path for you as an individual. To assist you in assessing your educational goals, we have included a number of student profiles. These are students that have recently graduated from an accredited engineering program and selected different career paths. Each student background is unique and each career path is different. We hope you find these helpful.

ISTUDY

1.2 The Technology Team

In 1876, 15 men led by Thomas Alva Edison gathered in Menlo Park, New Jersey, to work on "inventions." By 1887, the group had secured over 400 patents, including ones for the electric lightbulb and the phonograph. Edison's approach typified that used for early engineering developments. Usually one person possessed nearly all the knowledge in one field and directed the research, development, design, and manufacture of new products in this field.

Today, however, technology has become so advanced and sophisticated that one person cannot possibly be aware of all the intricacies of a single device or process. The concept of systems engineering thus has evolved; that is, technological problems are studied and solved by a technology team.

Scientists, engineers, technologists, technicians, and craftspersons form the *technology team.* The functions of the team range across what often is called the *technical spectrum.* At one end of the spectrum are functions that involve work with scientific and engineering principles. At the other end of this technical spectrum are functions that bring designs into reality. Successful technology teams use the unique abilities of all team members to bring about a successful solution to a human need.

Each of the technology team members has a specific function in the technical spectrum, and it is of utmost importance that each specialist understands the role of all team members. It is not difficult to find instances where the education and tasks of team members overlap. For any engineering accomplishment, successful team performance requires cooperation that can be realized only through an understanding of the functions of the technology team. The technology team is one part of a larger team that has the overall responsibility for bringing a device, process, or system into reality. This team, frequently called a project or design team, may include managers, sales representatives, field service persons, financial representatives, and purchasing personnel in addition to the technology team members. These project teams meet frequently from the beginning of the project to ensure that schedules and design specifications are met, and that potential problems are diagnosed early. We will now investigate each of the team specialists in more detail.

1.2.1 Scientist

Scientists have as their prime objective increased knowledge of nature (see Figure 1.2). In the quest for new knowledge, the scientist conducts research in a systematic manner. The research steps, referred to as the *scientific method,* are often summarized as follows:

1. Formulate a hypothesis to explain a natural phenomenon.
2. Conceive and execute experiments to test the hypothesis.
3. Analyze test results and state conclusions.
4. Generalize the hypothesis into the form of a law or theory if experimental results are in harmony with the hypothesis.
5. Publish the new knowledge.

An open and inquisitive mind is an obvious characteristic of a scientist. Although the scientist's primary objective is that of obtaining an increased knowledge of nature, many scientists are also engaged in the development of their ideas into new and useful

ISTUDY

Figure 1.2

Scientists use the laboratory for discovery of new knowledge.
SDI Productions/Getty Images

say that the true scientist seeks to understand more about natural phenomena, whereas the engineer primarily engages in applying new knowledge. Science degree programs include chemistry, physics, agronomy, biology, horticulture, botany, genetics, earth science, geology, meteorology, and many more.

1.2.2 Engineer

The profession of engineering takes the knowledge of mathematics and natural sciences gained through study, experience, and practice and applies this knowledge with judgment to develop ways to utilize the materials and forces of nature for the benefit of all humans.

An engineer is a person who possesses this knowledge of mathematics and natural sciences, and through the principles of analysis and design applies this knowledge to the solution of problems and the development of devices, processes, structures, and systems. Both the engineer and scientist are thoroughly educated in the mathematical and physical sciences, but the scientist primarily uses this knowledge to acquire new knowledge, whereas the engineer applies the knowledge to design and develops usable devices, structures, and processes. In other words, the scientist seeks to know, the engineer aims to do.

You might conclude that the engineer is totally dependent on the scientist for the knowledge to develop ideas for human benefit. Such is not always the case. Scientists learn a great deal from the work of engineers. For example, the science of thermodynamics was developed by a physicist from studies of practical steam engines built by

ISTUDY

the principles of nuclear fission discovered by scientists to develop nuclear power plants and numerous other devices and systems requiring nuclear reactions for their operation. The scientist's and engineer's functions frequently overlap, leading at times to a somewhat blurred image of the engineer. What distinguishes the engineer from the scientist in broad terms, however, is that the engineer often conducts research but does so for the purpose of solving a problem.

The end result of an engineering effort—generally referred to as *design*—is a device, structure, system, or process that satisfies a need. A successful design is achieved when a logical procedure is followed to meet a specific need. The procedure, called the *design process,* is similar to the scientific method with respect to a step-by-step routine, but it differs in objectives and end results. The design process encompasses the following activities (all of which must be completed):

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

As the designer proceeds through each step, new information may be discovered and new objectives may be specified for the design. If so, the designer must backtrack and repeat steps. For example, if none of the alternatives appears to be economically feasible when the final solution is to be selected, the designer must redefine the problem or possibly relax some of the constraints to admit less expensive alternatives. Thus, because decisions must frequently be made at each step as a result of new developments or unexpected outcomes, the design process becomes iterative.

As you progress through your engineering education, you will solve problems and learn the design process using the techniques of analysis and synthesis. Analysis is the act of separating a system into its constituent parts, whereas synthesis is the act of combining parts into a useful system. In the design process you will observe how analysis and synthesis are utilized to generate a solution to a human need.

1.2.3 Technologist and Technician

Much of the actual work of converting the ideas of scientists and engineers into tangible results is performed by technologists and technicians (see Figure 1.3). A technologist generally possesses a bachelor's degree and a technician an associate's degree. Technologists are involved in the direct application of their education and experience to make appropriate modifications in designs as the need arises. Technicians primarily perform computations and experiments and prepare design drawings as requested by engineers and scientists. Thus technicians (typically) are educated in mathematics and science but not to the depth required of scientists and engineers. Technologists and technicians obtain a basic knowledge of engineering and scientific principles in a specific field and develop certain manual skills that enable them to communicate technically with all members of the technology team. Some tasks commonly performed by technologists and technicians include draft-

ISTUDY

Figure 1.3

Technicians modify a tabletop robot for use in a research project.
Goran Bogicevic/Shutterstock

servicing, and specification. Often they are the vital link between the idea on paper and the idea in practice.

1.2.4 Skilled Tradespersons/Craftspersons

Members of the skilled trades possess the skills necessary to produce parts specified by scientists, engineers, technologists, and technicians. Craftspersons do not need to have an in-depth knowledge of the principles of science and engineering incorporated in a design (see Figure 1.4). They often are trained on the job, serving an apprenticeship during which the skills and abilities to build and operate specialized equipment are developed. Specialized positions include welder, machinist, electrician, carpenter, plumber, and mason.

1.3 The Engineering Profession

Engineering is an exciting profession. Engineers don't just sit in a cubicle and solve mathematical equations; they work in teams to solve challenging engineering problems to make life safer, easier, and more efficient for the world we live in. Engineers must demonstrate competence in initiative, professionalism, engineering knowledge, teamwork, innovation, communication, cultural adaptability, safety awareness, customer focus, general knowledge, continuous learning, planning, analysis and judgment, quality orientation, and integrity. In addition, engineers are expected to be leaders. Engineers help to shape government policies, international development, and education at all

ISTUDY

Figure 1.4

Skilled craftspersons are key in building specialized equipment as designed by the engineers.
Don Hammond/Design Pics

1.4 The Engineering Functions

As we alluded to in Section 1.2, engineering feats dating from earliest recorded history up to the Industrial Revolution could best be described as individual accomplishments. The various pyramids of Egypt were usually designed by one individual, who directed tens of thousands of laborers during construction. The person in charge called every move, made every decision, and took the credit if the project was successful or accepted the consequences if the project failed.

The Industrial Revolution brought a rapid increase in scientific findings and technological advances. One-person engineering teams were no longer practical or desirable. Today, no single aerospace engineer is responsible for a jumbo jet and no one civil engineer completely designs a bridge. Automobile manufacturers assign several thousand engineers to the design of a new model. So we not only have the technology team as described earlier, but we have engineers from many disciplines who are working together on single projects.

One approach to explaining an engineer's role in the technology spectrum is to describe the different types of work that engineers do. For example, agricultural, biological, civil, electrical, mechanical, and other engineers become involved in design, which is an engineering function. The *engineering functions,* which are discussed briefly in this section, are research, development, design, production, testing, construction, operations, sales, management, consulting, and teaching. Several of the *engineering disciplines* will be discussed later in the chapter.

To avoid confusion between "engineering disciplines" and "engineering functions,"

ISTUDY

chemical, mechanical) either before or soon after admission to an engineering program. When and how the choice is made varies with each school. The point is, the student does not choose a function but rather a discipline. To illustrate further, consider a student who has chosen mechanical engineering. This student will, during an undergraduate education, learn how mechanical engineers are involved in the engineering functions of research, development, design, and so on. Some program options allow a student to pursue an interest in a specific subdivision within the curriculum, such as energy conversion in a mechanical engineering program. Most other curricula have similar options.

Upon graduation, when you accept a job with a company, you will be assigned to a functional team performing in a specific area such as research, design, or sales. Within some companies, particularly smaller ones, you may become involved in more than one function—design *and* testing, for example. It is important to realize that regardless of your choice of discipline, you may become involved in one or more of the functions discussed in the following paragraphs:

Space Exploration: Where Do We Go from Here?

Clayton Anderson

NASA

Clayton Anderson received his undergraduate degree in Physics from Hastings College, Nebraska, and an MS in Aerospace Engineering from Iowa State University. He joined the Johnson Space Center (JSC) in 1983 in Mission Planning and Analysis, before moving to the Missions Operations Directorate and leading the trajectory design team for the Galileo planetary mission. He became supervisor of the Ascent Flight Design Section in 1992, which was then reorganized into the Flight Design Engineering Group. In 1993 he was named chief of the Flight Design Branch and in 1996 he assumed the role of manager of the Emergency Operations Center at JSC.

His broad expertise in space operations at JSC led to his selection as a NASA Mission Specialist astronaut in 1998. Intensive training for missions to the International Space Station (ISS) included physiological aspects and flight training in a T-38 aircraft, as well as underwater training and wilderness survival techniques. In 2007, Anderson embarked on his first space adventure aboard the Space Shuttle *Atlantis* to the ISS. Aboard the ISS he served as the Flight Engineer and Science Officer. During the 152-day stay, he performed three EVAs (extravehicular activity or spacewalks) totaling 18 hours. His second mission came in 2010 when he rode Space Shuttle *Discovery* on a resupply mission to the ISS. During this short 15-day stay, he performed three more EVAs totaling 20 hours, 17 minutes.

Anderson retired from NASA in 2013 very proud of his accomplishments and filled with a strong desire to educate the public on the knowledge, research, and training necessary to conduct continued space exploration in a logical and safe manner. To this end, he has traveled extensively around the country giving keynote presentations on his experiences and visions for future space endeavors. Recently there have been efforts to develop commercial launching rockets to transport travelers into space (and the ISS), to the moon, and possibly to Mars. Anderson asks, "What capabilities does the commercial space industry need to have in order to transport spacefaring neophytes safely? Will passengers need three years of intensive astronaut training? How could engineers design controls and user interfaces to better serve inexperienced space travelers?"

Anderson believes we must take measured steps in educating and training the public for space travel and he believes the first step is using our Moon. ". . . Theoreticians claim that the surface of Mars or the Moon may provide on-site (in situ) resources that could be used. They tout our ability to concoct fuel, extract water, and create oxygen, simply by living off the land. While this may be true, *how* do we do this? What technologies are needed?

ISTUDY

It does not seem completely practical to commit to Mars before we have answers to these fundamental questions. We can use our 35 years of space experience with moon missions and space station operations to develop the foundation for longer missions. A mission to Mars and its 20-minute communication lapses introduce new psychological implications within an 18-month trip requiring sufficient fuel, food, water, spare parts, clothing, etc. Planning and training for such a mission is a huge and, as yet, not completely defined task."

In 2014, Anderson was named an Iowa State University Distinguished Faculty Fellow in Aerospace Engineering. He has developed a prototype workshop in space flight operations intended to expose students to training events similar to those completed by astronauts. For example, scuba diving certification will help students learn how to work in a hazardous environment while following distinctly operational procedures. Wilderness survival training uniquely introduces students to the basic concepts of mission planning, expeditionary behavior, and teamwork. Aircraft flight simulation training reinforces procedural concepts while introducing more "big picture" and anticipatory thinking. Further, in an effort to provide ISU graduating students with a new and different thought process, the workshop attempts to address the needs of the emerging commercial spaceflight companies, by providing students whose decision analysis and leadership capabilities reflect this more operational background. Supplemented with general training in spacecraft subsystems, space physiology, and space suits, the workshop experience is coupled with virtual reality spaceflight scenarios using the C6 virtual reality room in the Virtual Reality Applications Center at Iowa State University. Anderson is collaborating with Dr. Nir Keren, Associate Professor in the Department of Agricultural and BioSystems Engineering and a Graduate Faculty member at the Virtual Reality Applications Center. Dr. Keren utilizes VirtuTrace, a powerful simulation engine he developed with his research team, to simulate the main U.S. living section of the ISS and the exterior of the station in full scale three-dimension in exquisite detail. Students experience the space station environment and the inherent stressors associated with combating an in-flight emergency situation.

1.4.1 Research

Successful research is one catalyst for starting the activities of a technology team or, in many cases, the activities of an entire industry. The research engineer seeks new findings, as does the scientist; but keep in mind that the research engineer also seeks a way to use the discovery.

Key qualities of a successful research engineer are perceptiveness, patience, and self-confidence. Most students interested in research will pursue the master's and doctor's degrees in order to develop their intellectual abilities and the necessary research skills. An alert and perceptive mind is needed to recognize nature's truths when they are encountered. When attempting to reproduce natural phenomena in the laboratory, cleverness and patience are prime attributes. Research often involves tests, failures, retests, and so on for long periods of time (see Figure 1.5). Research engineers therefore are often discouraged and frustrated and must strain their abilities and rely on their self-confidence in order to sustain their efforts to a successful conclusion.

Billions of dollars are spent each year on research at colleges and universities, industrial research laboratories, government installations, and independent research institutes. The team approach to research is predominant today primarily because of the need to incorporate a vast amount of technical information into the research effort. Individual research also is carried out but not to the extent it was several years ago. A large share of research monies are channeled into the areas of energy, environment, health, defense, and space exploration. A fast growing research area is nanotechnology. The Royal Academy of Engineering describes it this way: "Nanotechnology is the application of nanoscale science, engineering and technology to produce novel materi-

ISTUDY