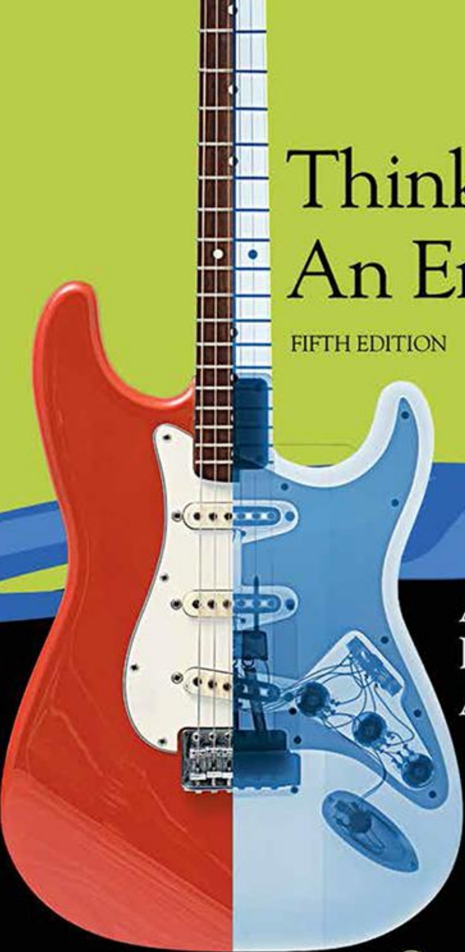

Thinking Like An Engineer

FIFTH EDITION

An Active Learning Approach

Stephan | Bowman
Park | Martin | Ohland

Resources for Success

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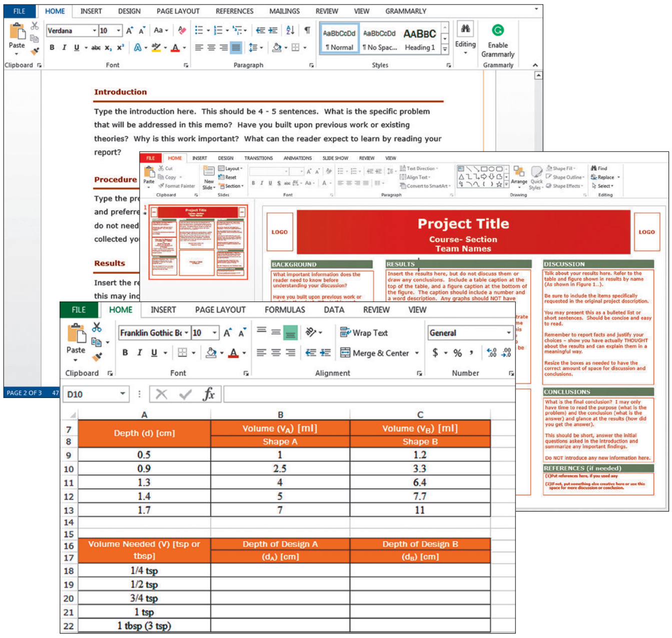

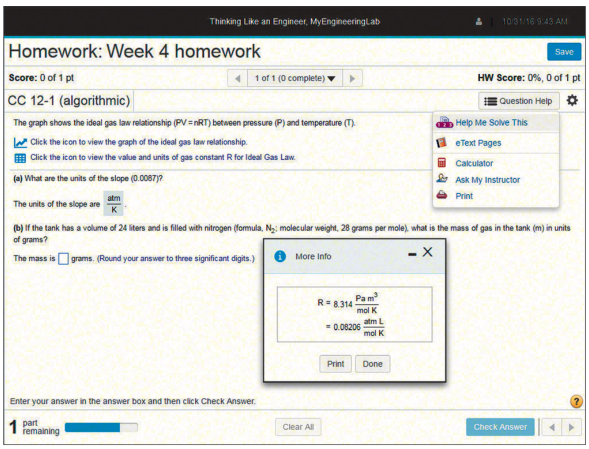

Question Help and Support

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- MATLAB Introduction
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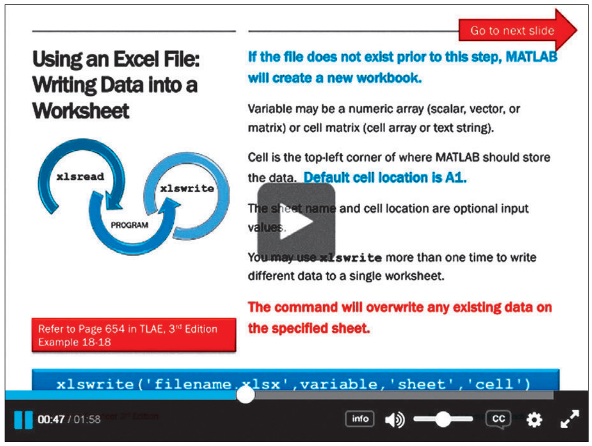

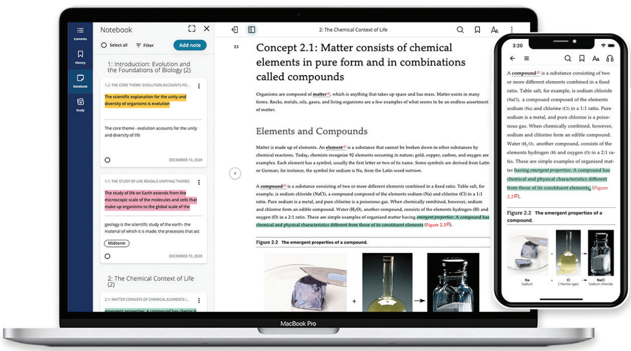

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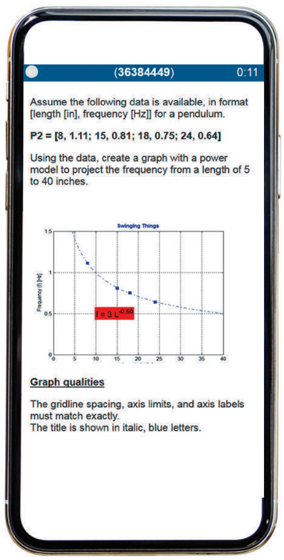

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Thinking Like An Engineer

An Active Learning Approach

Fifth Edition

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Contents

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Preface

At Clemson University, all students who wish to major in engineering begin in the General Engineering Program, and after completing a core set of classes, they can declare a specific engineering major. Within this core set of classes, students are required to take math, physics, chemistry, and a two-semester engineering sequence. Our courses have evolved to address not only the changing qualities of our students, but also the changing needs of the engineering profession. The material taught in our courses is the foundation upon which the upper-level courses depend for the skills necessary to master more advanced material. It was for these first-year courses that this text was created.

We didn't set out to write a textbook: we simply set out to find a better way to teach our students. Our philosophy was to help students move from a mode of learning where everything was neatly presented as lecture and handouts where the instructor was looking for the "right" answer, to a mode of learning driven by self-guided inquiry. We wanted students to advance beyond "plug-and-chug" and memorization of problem-solving methods—to ask themselves if their approaches and answers make sense in the physical world. We couldn't settle on any textbooks we liked without patching materials together—one chapter from this text, four chapters from another—so we wrote our own notes. Through them, we tried to convey that engineering isn't always about having the answer—sometimes it's about asking the right questions, and we want students to learn how to ask those sorts of questions. Real-world problems rarely come with all of the information required for their solutions. Problems presented to engineers typically can't be solved by looking at how someone else solved the exact same problem. Part of the fun of engineering is that every problem presents a unique challenge and requires a unique solution. Engineering is also about arriving at an answer and being able to justify the "why" behind your choice, and equally important, the "why not" of the other choices.

We realized quickly, however, that some students are not able to learn without sufficient scaffolding. Structure and flexibility must be managed carefully. Too much structure results in rigidity and unnecessary uniformity of solutions. On the other hand, too much flexibility provides insufficient guidance, and students flounder down many blind alleys, thus making it more difficult to acquire new knowledge. The tension between these two must be managed constantly. We are a large public institution, and our student body is very diverse. Our hope is to provide each student with the amount of scaffolding they need to be successful. Some students will require more background work than others. Some students will need to work five problems, and others may need to work 50. We talk a great deal to our students about how each learner is unique. Some students need to listen to a lecture, some need to read the text over three times, and others just need to try a skill and make mistakes to discover what they still don't understand. We have tried to provide enough variety for each type of learner throughout.

Over the years, we have made difficult decisions on exactly what topics, and how much of each topic, to teach. We have refined our current text to focus on mastering four areas, each of which is introduced below.

Part 1: Engineering Essentials

There are three threads that bind the first six chapters in *Engineering Essentials* together. The first is expressed in the part title: all are essential for a successful career in engineering. The second is communications. The third and final thread is an introduction to a problem-solving methodology.

First, as aspiring engineers, students should try to verify that engineering is not only a career that suits their abilities but also one in which they will find personal reward and satisfaction.

Second, practicing engineers often make decisions that will affect not only the lives of people but also the viability of the planetary ecosystem that affects all life on Earth. Without a firm grounding in making decisions based on ethical principles, there is an increased probability that undesirable or even disastrous consequences may occur.

Third, most engineering projects are too large for one person to accomplish alone; thus, practicing engineers must learn to function effectively on teams, putting aside their personal agendas and combining their unique talents, perspectives, and ideas to achieve the goal.

Finally, communications bind it all together. Communication, whether written, graphical, or spoken, is essential to success in engineering.

This part ends where all good problem solving should begin—with estimation and a methodology. It's always best to have a good guess at any problem before trying to solve it more precisely. SOLVEM provides an example of a framework for solving problems that encourages creative observation as well as methodological rigor.

Part 2: Ubiquitous Units

The world can be described using relatively few dimensions. We need to know what these are and how to use them to analyze engineering situations. Dimensions, however, are worthless in allowing engineers to find the numeric solution to a problem. Understanding units is essential to determine the correct numeric answers to problems. Different disciplines use different units to describe phenomena (particularly with respect to the properties of materials such as viscosity, thermal conductivity, density, and so on). Engineers must know how to convert from one unit system to another. Knowledge of dimensions allows engineers to improve their problem-solving abilities by revealing the interplay of various parameters.

Part 3: Spectacular Spreadsheets

When choosing an analysis tool to teach students, our first pick is Excel. Students enter college with varying levels of experience with Excel. To allow students who are novice users to learn the basics without hindering more advanced users, we have placed the basics of Excel in the appendix material, which is available online. To help students determine if they need to review the appendix material, an activity has been included in the introductions to Chapter 10 (Excel Workbooks), Chapter 11 (Graphical Solutions), and Chapter 12 (Models and Systems) to direct students to Appendices B, C, and D, respectively.

Once students have mastered the basics, each chapter in this part provides a deeper usage of Excel in each category. Some of this material extends beyond a simple introduction to Excel, and often, we teach the material in this unit by jumping around, covering half of each chapter in the first semester, and the rest of the material in the second semester course.

Chapter 12 introduces students to the idea of similarities among the disciplines, and how understanding a theory in one application can often aid in understanding a similar theory in a different application. We also emphasize the understanding of models (trendlines) as possessing physical meaning. Chapter 13 discusses a process for determining a mathematical model when presented with experimental data and some advanced material on dealing with limitations of Excel.

Univariate statistics and statistical process control wrap up this part of the book by providing a way for engineering students to describe both distributions and trends.

Part 4: Programming Prowess

Part 4 (Programming Prowess) covers a variety of topics common to any introductory programming textbook. In contrast to a traditional programming textbook, this part approaches each topic from the perspective of how each can be used in unison with the others as a powerful engineering problem-solving tool. The topics presented in Part 4 are introduced as if the student has no prior programming ability and are continually reiterated throughout the remaining chapters.

For this textbook we chose MATLAB as the programming language because it is commonly used in many engineering curricula. The topics covered provide a solid foundation for using computers as problem-solving tools, and they provide enough scaffolding for transfer of programming knowledge into other languages commonly used by engineers (such as C, C++, and Java).

The "Other" Stuff We've Included . . .

Throughout the book, we have included sections on surviving engineering, time management, goal setting, and study skills. We did not group them into a single chapter but have scattered them throughout the part introductions to assist students on a topic when they are most likely to need it. For example, we find students are much more open to discussing time management in the middle of the semester rather than the beginning.

In addition, we have called upon many practicing and aspiring engineers to help us explain the "why" and "what" behind engineering. They offer their "Wise Words" throughout this text. We have included our own set of "Wise Words" as the introduction to each topic here as a glimpse of what inspired us to include certain topics.

New to This Edition

The Fifth Edition of *Thinking Like an Engineer: An Active Learning Approach* contains new material and revisions based on the comments from faculty who teach with our textbook, reviewer recommendations, and most importantly, the feedback from our students. We continue to strive to include the latest software releases; in this edition, we have upgraded to Microsoft Office (Excel) 2019 / Microsoft Office 365 / Microsoft Excel Online and MATLAB 2020a. We have added a significant number of new problems in Chapters 7 and 8. This edition also features substantial upgrades to the integration with MyLab and MATLAB Grader.

New to this edition, by part:

- Part 2: Ubiquitous Units
  - Substantial additions and revisions to ICA and Review problems in Chapters 7 and 8.
- Part 3: Spectacular Spreadsheets
  - Revised to be consistent with the appearance and operation of Excel 2019 / Microsoft Office 365 / Microsoft Excel Online.
- Part 4: Programming Prowess
  - Substantial revision to Chapter 15 to describe character arrays and string arrays and how they function differently.
  - Revised to be consistent with the appearance and operation of MATLAB 2020a.
- Online appendix materials
  - Umbrella Projects in the online materials have been reviewed, revised when necessary, and separated into individual projects to allow for easier customizing of the projects for each class. Those projects have also been added to the eText.
  - Curriculum materials for alternative problem-solving approaches.

How to Use

This text contains many different types of instruction to address different types of learners. There are two main components to this text: hardcopy and online.

In the hardcopy, the text is presented topically rather than sequentially, but hopefully with enough autonomy for each piece to stand alone. For example, we routinely discuss only part of the Excel material in our first-semester course and leave the rest to the second semester. We hope this will give you the flexibility to choose how deeply into any given topic you wish to dive, depending on the time you have, the starting abilities of your students, and the outcomes of your course. More information about topic sequence options can be found in the instructor's manual.

Within the text, there are several checkpoints for students to see if they understand the material. Within the reading are **Comprehension Checks**, with the answers provided in the back of the book. Our motivation for including Comprehension Checks within the text rather than including them as end-of-part questions is to maintain the active spirit of the classroom within the reading, which allows students to evaluate their own understanding of the material in preparation for class—to encourage students to be self-directed learners, we must encourage them to self-evaluate regularly. At the end of each chapter, **In-Class Activities** are given to reinforce the material in each chapter. In-Class Activities exist to stimulate active conversation within pairs and groups of students working through the material. We generally keep the focus on student effort and ask them to keep working the problem until they arrive at the right answer. This provides them with a set of worked-out problems, using their own logic, before they are asked to tackle more difficult problems. The **Review Questions** sections provide additional questions, often combining skills learned in the current chapter with previous concepts to help students climb to the next level of understanding. By providing these three types of practice, students are encouraged to reflect on their understanding in preparing for class, during class, and at the end of each chapter as they prepare to transfer their knowledge to other areas. Finally we have provided a series of online **Umbrella Projects** to allow students to apply skills that they have mastered to larger-scope problems. We have found the use of these problems extremely helpful in providing context for the skills that they learn throughout a unit.

Understanding that every student learns differently, we have included several media components in addition to traditional text. Each section within each chapter has an accompanying set of **video lecture slides**. Within these slides, the examples presented are unique from those in the text to provide another set of sample solutions. The slides are presented with **voiceover**, which has allowed us to move away from traditional in-class lecture. We expect the students to listen to the slides outside of class, and then in class we typically spend time working problems, reviewing assigned problems, and providing **"wrap-up" lectures**, which are mini-versions of the full lectures to summarize what they should have gotten from the assignment. We expect the students to come to class with questions from the reading and lecture that we can then help clarify. We find with this method, the students pay more attention, as the terms and problems are already familiar to them, and they are more able to verbalize what they don't know. Furthermore, they can always go back and listen to the lectures again to reinforce their knowledge as many times as they need.

Some sections of this text are difficult to lecture, and students will learn this material best by **working through examples**. This is especially true with Excel and MATLAB, so you will notice that many of the lectures in these sections are shorter than previous material. The examples are scripted the first time a skill is presented, and students are expected to have their laptops open and to work through the examples (not just read them). When students ask us questions in this section, we often start the answer by asking them to "show us your work from Chapter XX." If the student has not actually worked the examples in that chapter, we tell them to do so first; often, this will answer their questions.

After the first few basic problems, in many cases where we are discussing more advanced skills than data entry, we have **provided starting worksheets and code**. Students can access the starting data in the MyLab Engineering. In some cases, though, it is difficult to explain a skill on paper, or even with slides, so for these instances we have included **videos**.

Finally, for the communication section, we have provided **templates** for several types of reports and presentations. These are available on the Instructor Resource Center at www.pearsonhighered.com/irc and with the adoption of MyLab Engineering. Visit www.pearson.com/mylab/engineering for more information.

MyLab Engineering™

Thinking Like an Engineer, Fifth Edition, together with MyLab Engineering provides an engaging in-class experience that will inspire your students to stay in engineering, while also giving them the practice and scaffolding they need to keep up and be successful in the course. It's a complete digital solution featuring:

- **Book-Specific Exercises**—MyLab Engineering's varied homework and practice questions are correlated to the textbook and many regenerate algorithmically to give students unlimited opportunity for practice and mastery. Question features include: Learning aids and immediate feedback; Show My Work functionality to view all student work; and downloadable templates in Microsoft® PowerPoint, Word, and Excel.

- **Integrated MATLAB assessment**—Edition specific automated assessment of MATLAB® code submissions with real-time feedback.
- **Question Help and Support**—Many exercises provide step-by-step instruction, input-specific feedback, hints, and videos. They also provide links to spreadsheets, example problems, and contextually appropriate links to the eText.
- **Student Videos**—Short videos are available to help explain concepts and skills that may be difficult to explain on paper. Topics include: Engineering Ethics, Functions in Excel, MATLAB Introduction, and Conditional Statements.
- **eText**—Pearson eText is optimized for mobile and offers: offline access and downloading for most iOS and Android devices; seamlessly integrated videos and other rich media; accessibility (screen-reader ready); and note-taking, highlighting, bookmarking, and search for instructors and students.

For a fully digital offering, learn more at www.pearson.com/mylab/engineering.

Resources for Instructors

Instructor's Manual—Available to all adopters, this provides a complete set of solutions for all activities and review exercises. For the In-Class Activities, suggested guided inquiry questions along with time frame guidelines are included. Suggested content sequencing and descriptions of how to couple assignments to the Umbrella Projects are also provided.

PowerPoints—A complete set of lecture PowerPoint slides make course planning as easy as possible.

Sample Exams—Available to all adopters, these will assist in creating tests and quizzes for student assessment.

MyLab Engineering—Provides web-based assessment, tutorial, homework and course management. www.pearson.com/mylab/engineering

Learning Catalytics™—Learning Catalytics helps generate class discussion, customize lectures, and promote peer-to-peer learning with real-time analytics. As a student response tool, it uses students' own mobile devices to engage them in more interactive tasks and thinking. Help students develop critical thinking skills. Monitor responses to find out where students are struggling. Rely on real-time data to adjust your teaching strategy. Automatically group students for discussion, teamwork, and peer-to-peer learning.

All requests for instructor resources are verified against our customer database and/or through contacting the requestor's institution. Contact your local Pearson representative for additional information.

What Does Thinking Like an Engineer Mean?

We are often asked about the title of the book. We thought we'd take a minute and explain what this means, to each of us. Our responses are included in alphabetical order.

> *For me, thinking like an engineer is about creatively finding a solution to some problem. In my pre-college days, I was very excited about music. I began my musical pursuits by learning the fundamentals of music theory by playing in middle school band and eventually worked my way into different bands in high school (orchestra, marching and jazz band) and branching off into teaching myself how to play guitar. I love playing and listening to music because it gives me an outlet to create and dis-*

cover art. I pursued engineering for the same reason; as an engineer, you work in a field that creates or improves designs or processes. For me, thinking like an engineer is exactly like thinking like a musician—through my fundamentals, I'm able to be creative, yet methodical, in my solutions to problems.

D. Bowman, Computer Engineer

It seems that many students come into our classes with the belief that "thinking like an engineer" is equivalent to "being good at math." To be honest, that is what I thought before I started college. However, thinking like an engineer is not about solving the math, it is about figuring out what that problem is in the first place. To think like an engineer is to be able to identify a problem, logically process all the information you have, and to arrive at an optimal solution using all your skills (not just math). Thinking like an engineer is a framework that allows you to solve any problem.

W. Martin, Civil Engineer

Thinking like an engineer is about solving problems with whatever resources are most available—or fixing something that has broken with materials that are just lying around. Sometimes, it's about thinking ahead and realizing what's going to happen before something breaks or someone gets hurt—particularly in thinking about what it means to fail safe—to design how something will fail when it fails. Thinking like an engineer is figuring out how to communicate technical issues in a way that anyone can understand. It's about developing an instinct to protect the public trust—an integrity that emerges automatically.

M. Ohland, Civil Engineer

To me, understanding the way things work is the foundation on which all engineering is based. Although most engineers focus on technical topics related to their specific discipline, this understanding is not restricted to any specific field, but applies to everything! One never knows when some seemingly random bit of knowledge, or some pattern discerned in a completely disparate field of inquiry, may prove critical in solving an engineering problem. Whether the field of investigation is Fourier analysis, orbital mechanics, Hebert boxes, personality types, the Chinese language, the life cycle of mycetozoans, or the evolution of the music of Western civilization, the more you understand about things, the more effective an engineer you can be. Thus, for me, thinking like an engineer is intimately, inextricably, and inexorably intertwined with the Quest for Knowledge. Besides, the world is a truly fascinating place if one bothers to take the time to investigate it.

W. Park, Electrical Engineer

Engineering is a bit like the game of golf. No two shots are ever exactly the same. In engineering, no two problems or designs are ever exactly the same. To be successful, engineers need a bag of clubs (math, chemistry, physics, English, social studies) and then need to have the training to be able to select the right combination of clubs to move from the tee to the green and make a par (or if we are lucky, a birdie). In short, engineers need to be taught to THINK.

B. Sill (author Emeritus), Aerospace Engineer

I like to refer to engineering as the color grey. Many students enter engineering because they are "good at math and science." I like to refer to these disciplines as black and white—there is one way to integrate an equation and one way to balance a chemical reaction. Engineering is grey, a blend of math and science that does not *necessarily have one clear answer. The answer can change depending on the criteria of the problem. Thinking like an engineer is about training your mind to conduct the methodical process of problem solving. It is examining a problem from many different angles, considering the good, the bad and the ugly in every process or product. It is thinking creatively to discover ways of solving problems, or preventing issues from becoming problems. It's about finding a solution in the grey and presenting it in black and white.*

E. Stephan, Chemical Engineer

Lead author note: When writing this preface, I asked each of my coauthors to answer this question. As usual, I got a wide variety of interpretations and answers. This is typical of the way we approach everything we do, except that I usually try and mesh the responses into one voice. In this instance, I let each response remain unique. As you progress throughout this text, you will (hopefully) see glimpses of each of us interwoven with the one voice. We hope that through our uniqueness, we can each reach a different group of students and present a balanced approach to problem solving, and, hopefully, every student can identify with at least one of us.

—Beth Stephan
Clemson University
Clemson, SC

Acknowledgments

When we set out to formalize our instructional work, we wanted to portray engineering as a reality, not the typical flashy fantasy portrayed by most media forums. We called on many of our professional and personal relationships to help us present engineering in everyday terms. During a lecture to our freshmen, Dr. Ed Sutt [PopSci's 2006 Inventor of the Year for the HurriQuake Nail] gave the following advice: ***A good engineer can reach an answer in two calls: the first, to find out who the expert is; the second, to talk to the expert.*** Realizing we are not experts, we have called on many folks to contribute articles. To our experts who contributed articles for this text, we thank Dr. Lisa Benson, Dr. Neil Burton, Jan Comfort, Jessica (Pelfrey) Creel, Jason Huggins, Leidy Klotz, and Troy Nunmaker.

To Dr. Lisa Benson, thank you for allowing us to use "Science as Art" for the basis of many photos that we have chosen for this text. To explain "Science as Art": *Sometimes, science and art meet in the middle. For example, when a visual representation of science or technology has an unexpected aesthetic appeal, it becomes a connection for scientists, artists and the general public. In celebration of this connection, Clemson University faculty and students are challenged to share powerful and inspiring visual images produced in laboratories and workspaces for the "Science as Art" exhibit.* For more information, please visit www.scienceasart.org. To the creators of the art, thank you for letting us showcase your work in this text: Martin Beagley, Dr. Caye Drapcho, Eric Fenimore, Dr. Scott Husson, Dr. Jaishankar Kutty, Dr. Kathleen Richardson, and Dr. Ken Webb. A special thanks to Russ Werneth for getting us the great Hubble teamwork photo.

To the Rutland Institute for Ethics at Clemson University: The four-step procedure outlined in Chapter 2 on Ethics is based on the toolbox approach presented in the Ethics Across the Curriculum Seminar. Our thanks to Dr. Daniel Wueste, director, and the other Rutlanders (Kelly Smith, Stephen Satris, and Charlie Starkey) for their input into this chapter.

To Jonathan Feinberg and all the contributors to the Wordle (http://www.wordle.net) project, thank you for the tools to create the Wordle images in the introduction sections. We hope our readers enjoy this unique way of presenting information and are inspired to create their own Wordles!

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To the thousands of students who used this text in various forms over the years—thanks for your patience, your suggestions, and your criticism. You have each contributed not only to the book, but to our personal inspiration to keep doing what we do.

To all the reviewers who provided such valuable feedback to help us improve: We appreciate the time and energy needed to review this material, and your thoughtful comments have helped push us to become better.

Emily Ohland's project management skills kept this edition on schedule. Working with this team has been more like herding squirrels than herding cats. We are forever grateful.

To the great folks at Pearson—this project would not be a reality without all your hard work. To Eric Hakanson, without that chance meeting this project would not have begun! Thanks to Holly Stark for her belief in this project and in us! Thanks to Erin Ault for keeping us on track and having such a great vision to display our hard work. You have put in countless hours on this edition—thanks for making us look great! Thanks to Tim Galligan, Demetrius Hall, and the fabulous Pearson sales team all over the country for promoting our book to other schools and helping us allow so many students to start "Thinking Like Engineers"! We would not have made it through this without all of the Pearson team efforts and encouragement!

Finally, on a Personal Note

DRB: To my parents, siblings, and in-laws for always being supportive of my creative endeavors with nothing but encouragement and enthusiasm. To my grandparents, who instilled values in learning and practicing science, engineering, and education to make the world safer, more secure, and more connected. To my coauthors, who continue to teach me to think like an engineer. To my employers and coworkers past, present, and future, thank you for encouraging my growth and service as an engineer, with special acknowledgement of those who have gone above and beyond to take an active interest in my professional development and capability as an innovator over the years—Matthew Ohland, Elizabeth Stephan, Miriam Grace, John Glatfelter, Brian Laughlin, and many other members of the Boeing Technical Fellowship. To Dana and Elliott, you are the glue that keeps me from falling to pieces. Thank you for your support, love, laughter, inspiration, and determination, among many other things. Dana, you have the hardest job on earth—being married to an engineer—but do know that I love you exponentially, iteratively, and infinitely more every day. Elliott, you have the second hardest job on earth—being raised by an engineer—and I'm so excited I get to be the person that "lifts the hood" on the world for you and show you how everything works, how things should work, and how we all have a duty to make things better.

WDM: Thanks to my coauthors who have invited me to join their work which they have invested so much into over the past years. They helped me along my path to becoming an engineer and I hope I can support many more students along that same path. To my parents and sister, thanks for putting up with my endless "What if…" questions and supporting me on my first steps of thinking like an engineer. To Lucy and Amelia, I love you both and look forward to watching you grow and explore the possibilities that the world holds for you. To Emily, thanks for your love and support. I know I do not say it enough, but you mean the world to me.

MWO: My wife Emily has my love, admiration, and gratitude for all she does, including holding the family together. For my children, who share me with my students—Everett, whose "old soul" and courage touch so many; Carson, who models how to be inspiring without drawing attention to yourself; and Allie, who is discovering who she wants to be. My father Theodor inspired me to be an educator, my mother Nancy helped me understand people, my sister Karen lit a pathway for me in engineering, my brother Erik showed me that one doesn't need to be loud to be a leader, and my mother-in-law Nancy Winfrey shared the wisdom of a long career. I recognize those who helped me create an engineering education career path, most prominently: Fred Orthlieb, Marc Hoit, Tim Anderson, Ben Sill, Sue Kemnitzer, and Purdue's School of Engineering Education.

WJP: Choosing only a few folks to include in an acknowledgment is a seriously difficult task, but I have managed to reduce it to five. First, Beth Stephan has been the guiding force behind this project, without whom it would never have come to fruition. In addition, she has shown amazing patience in putting up with my shenanigans and my weird perspectives. Next, although we exist in totally different realities, my parents have always supported me, particularly when I was a newly married, destitute graduate student fresh off the farm. Third, my son Isaac, who has the admirable quality of being willing to confront me with the truth when I am behaving badly, and for this I am grateful. Finally, and certainly most importantly, to Lila, my partner of more than four decades, I owe a debt beyond anything I could put into words. Although life with her has seldom been easy, her influence has made me a dramatically better person.

BLS (author Emeritus): To my amazing family, who always picked up the slack when I was off doing "creative" things, goes all my gratitude. To Anna and Allison, you are wonderful daughters who both endured and "experienced" the development of many "in class, hands on" activities—know that I love you and thank you. To Lois who has always been there with her support and without whining for over 40 years, all my love. Finally, to my coauthors who have tolerated my eccentricities and occasional tardiness with only minimum grumbling, you make great teammates.

EAS: To my coauthors, for hanging in there to the Fifth Edition and always keeping things interesting! To my mom, Kay and Denny—thanks for your love and support. To Khadijah, Steven and Miles, wishes for you to continue to conquer the world! To Brock and Katie, I love you both a bushel and a peck. It is amazing to me to look at how much you both have grown since the first time we did this, and how much you now give me insight into what I design for my students—who are now your peers. Finally, to Sean . . . one more time! I love you more than I can say—and know that even when I forget to say it, I still believe in us. "Show a little faith, there's magic in the night . . ."

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Thinking Like An Engineer

An Active Learning Approach

Fifth Edition

PART

1 Engineering Essentials

You are no doubt in a situation where you have an idea you want to be an engineer. Someone or something put into your head this crazy notion—that you might have a happy and successful life working in the engineering profession. Maybe you are good at math or science, or you want a job where creativity is as important as technical skill. Maybe someone you admire works as an engineer. Maybe you are looking for a career that will challenge you intellectually, or maybe you like to solve problems.

You may recognize yourself in one of these statements from practicing engineers on why they chose to pursue an engineering degree.

I chose to pursue engineering because I enjoyed math and science in school, and always had a love for tinkering with electronic and mechanical gadgets since I was old enough to hold a screwdriver.

S. Houghton, Computer Engineer

I chose to pursue engineering because I always excelled in science and math and I really enjoy problem solving. I like doing hands-on activities and working on "tangible" projects.

M. Koon, Mechanical Engineer

Learning Objectives

The overall learning objectives for this part include the following:

Chapter 1:

- Explore the variety of collegiate and career opportunities of an engineering discipline.

Chapter 2:

- Conduct research on ethical issues related to engineering; formulate and justify positions on these issues.

Chapter 3:

- Demonstrate an ability to design a system, component, or process to meet desired needs.
- Demonstrate an ability to function on multidisciplinary teams.

Chapter 4:

- Communicate technical information effectively by composing clear and concise oral presentations and written descriptions of experiments and projects.

Chapter 5:

- Identify process variability and measurement uncertainty associated with an experimental procedure, and interpret the validity of experimental results.
- Use "practical" skills, such as visualizing common units and conducting simple measurements, calculations, and comparisons to make estimations.

Chapter 6:

- Classify types of problems and how to approach them.

I wanted to pursue engineering to make some kind of positive and (hopefully) enduring mark on the world.

J. Kronberg, Electrical Engineer

I was good at science and math, and I loved the environment; I didn't realize how much I liked stream and groundwater movement until I looked at BioSystems Engineering.

C. Darling, Biosystem Engineer

My parents instilled a responsibility to our community in us kids. As an engineer, I can serve my community through efficient and responsible construction while still satisfying my need to solve challenging problems.

J. Meena, Civil Engineer

I asked many different majors one common question: "What can I do with this degree?" The engineering department was the only one that could specifically answer my question. The other departments often had broad answers that did not satisfy my need for a secure job upon graduating.

L. Johnson, Civil Engineer

Engineering is a highly regarded and often highly compensated profession that many skilled high school students choose to enter for the challenge, engagement, and ultimately the reward of joining the ranks of the esteemed engineers of the world. But what, exactly, does an engineer do? This is one of the most difficult questions to answer because of the breadth and depth of the engineering field. So, how do the experts define engineering?

The National Academy of Engineering (NAE) says:

Engineering has been defined in many ways. It is often referred to as the "application of science" because engineers take abstract ideas and build tangible products from them. Another definition is "design under constraint," because to "engineer" a product means to construct it in such a way that it will do exactly what you want it to, without any unexpected consequences.

I am a first-generation college student, and I wanted to have a strong foundation when I graduated from college.

C. Pringle, Industrial Engineer

Since I knew I wanted to design computers, I had a choice between electrical and computer engineering. I chose computer engineering, so I could learn about both the hardware and software. It was my interests in computers and my high school teachers that were the biggest influence in my decision.

E. D'Avignon, CpE

My first choice in majors was mechanical engineering. I changed majors after taking a drafting class in which I did well enough to get a job teaching the lab portion, but I did not enjoy the work. After changing to electrical and computer engineering, I took a Statics and Dynamics course as part of my required coursework and that further confirmed my move as I struggled with that material.

A. Flowerday, EE

Some people come into college knowing exactly what they want their major and career to be. I, on the other hand, was not one of those people. I realized that I had a wide spectrum of interests, and college allows you to explore all those options. I wanted a major that was innovative and would literally change the future of how we live. After looking through what I loved and wanted to do, my choice was computer engineering.

S. Belous, CpE

WISE WORDS: WHAT WAS THE HARDEST ADJUSTMENT FROM HIGH SCHOOL TO COLLEGE?

The biggest adjustment was the overwhelming amount of responsibility that I had to take on. There was no longer anybody there to tell me what to do or when to do it. I had to rely on myself to get everything done. All the things I took for granted when I was at home—not having to do my own laundry, not preparing all of my meals, not having to rely on my alarm clock to wake me up, etc.—quickly became quite apparent to me after coming to college. I had to start managing my time better so that I would have time to get all of those things done.

T. Andrews, CE

For me, the most difficult adjustment from high school to college has been unlearning some of the study habits adopted early on. In high school, you can easily get by one semester at a time and just forget what you "learned" when you move into a new semester or a new chapter of your text.

The National Academy of Engineering (NAE) is an independent, nonprofit institution that serves as an adviser to government and the public on issues in engineering and technology. Its members consist of the nation's premier engineers, who are elected by their peers for their distinguished achievements. Established in 1964, NAE operates under the congressional charter granted to the National Academy of Sciences. http://www.nae.edu/About.aspx

According to the Merriam-Webster online dictionary:

> *Engineering is the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people.*

Engineering is a broad, hard-to-define field requiring knowledge of science and mathematics and other fields to turn ideas into reality. The ideas and

College is just a little bit different. To succeed, you have to really make an effort to keep up with your studies—even the classes you have finished already. If you do not, chances are that a topic mentioned in a prerequisite course is going to reappear in a later class, which requires mastery of the previous material in order to excel.

R. Izard, CpE

The hardest adjustment was learning how to study. I could no longer feel prepared for tests by simply paying attention in class. I had to learn to form study groups and begin studying for tests well in advance. You can't cram for engineering tests.

M. Koon, ME

The hardest adjustment was taking full personal responsibility for everything from school work, to social life, and to finances. Life becomes a lot more focused when you realize that you are paying for your education and that your decisions will greatly impact your future. The key is to manage your time between classes, studying, having fun, and sleeping.

S. Belous, CpE

Studying, networking, talking to my professors about my strengths and weaknesses, taking responsibility for my actions, just the whole growing up into an adult was tough.

C. Pringle, IE

The hardest adjustment I had to make going from high school to college was realizing that I was on my own—and not just for academics, either. I was responsible for making sure I remembered to eat dinner, for not eating candy bars for lunch everyday, for balancing my social life with my studies, for managing my money . . . for everything.

J. Sandel, ME

The hardest adjustment from high school to college was changing my study habits. In high school, teachers coordinated their tests so we wouldn't have several on the same day or even in the same week. I had to learn how to manage my time more efficiently. Moreover, it was difficult to find a balance between both the social and academic aspects of college.

D. Walford, BioE

Since the tests cover more material and have more weight in college, I had to alter my study habits to make myself start studying more than a day in advance. It was overwhelming my first semester because there was always something that I could be studying for or working on.

A. Zollinger, CE

problems posed to engineers often do not require a mastery-level knowledge of any particular scientific field, but instead require the ability to put together all of the pieces learned in those fields.

Because engineers solve real-life problems, their ultimate motivation is to work toward making life better for everyone. In "The Heroic Engineer" (*Journal of Engineering Education*, January 1997) by Taft H. Broome (Howard University) and Jeff Peirce (Duke University), those authors claimed:

> *Engineers who would deem it their professional responsibility to transcend self-interests to help non-experts advance their own interests may well prove indispensable to free societies in the twenty-first century.*

Broome and Peirce go on to explain that the traits and behaviors of engineers can be compared to those of a hero. The motivation of any hero is to save someone's life; engineers create products, devices, and methods to help save lives. Heroes intervene to protect from danger; engineers devise procedures, create machines, and improve processes to protect people and the planet from danger. While learning an engineering discipline can be challenging, the everyday engineer does not see it as an obstacle: It is merely an opportunity to be a hero.

You will see many quotes from practicing engineers. As a good engineering team would, we recognize that we (the authors) are not experts at all things, and request input and advice when needed. We asked engineers we know who work at "everyday engineering" jobs to reflect on the choices they made in school and during their careers. We hope you benefit from their collective knowledge. When asked for advice to give to an incoming freshman, one gave the following reply, summing up this section better than we ever could have imagined.

> *[A career in engineering] is rewarding both financially and personally. It's nice to go to work and see some new piece of technology—to be on the cutting edge. It's also a great feeling to know that you are helping improve the lives of other people. Wherever there has been a great discovery, an engineer is to thank. That engineer can be you.*

A. Thompson, Electrical Engineer

Engineering is an . . . Itch!

Contributed by Dr. Lisa Benson, Assistant Professor of Engineering and Science Education, Clemson University

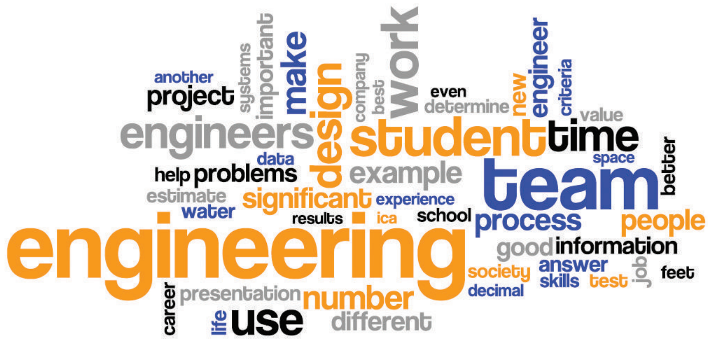
There are a lot of reasons why you are majoring in engineering. Maybe your goal is to impress someone, like your parents, or to defy all those who said you would never make it, or simply to prove to yourself that you have it in you. Maybe your goal is to work with your hands as well as your mind. Maybe you have no idea why you are here, but you know you like cars. There are about as many goals as there are students, and they all motivate students to learn. Some goals are better motivators than others.

Lots of experts have studied goals and how they affect what students do in school. Not surprisingly, there are as many ideas and theories about goals as there are experts. But most experts agree on the idea that there are mastery goals and performance goals.

> *Students who are* **mastery oriented** *try to do things well because they want to do their best. They are not driven by external factors like grades or praise, but instead they seek to learn things because they want to really understand them and not just get the correct answer.*
>
> *Students who are* **performance oriented** *seek to earn good grades to reflect how hard they've worked. They study because they know it will get them something—a scholarship, an above-average grade, or praise from their parents. Since grades are tied to their sense of achievement, students who are performance oriented tend to feel discouraged and anxious when they earn low grades. They tend to want to memorize and pattern-match to solve problems, rather than learn the underlying concepts and methods.*

Most students have been performance oriented throughout high school. In college, you will be more successful if you start thinking in terms of mastery. If you seek to really understand what you are learning in your classes, performance (i.e., good grades) will follow. But performance (a grade, an award, or praise) is not everything, and it will not be enough to keep you motivated when projects and coursework are challenging.

There is nothing like the feeling when you finally understand something that you did not get before. Sometimes it is an "aha!" moment, and sometimes it is a gradual dawning. The feeling is like an itch you can't scratch—you will want to keep at it once you get it. *When you are motivated to understand and master something, you're taking pride in your achievement of conquering the material, not just getting a good grade on an exam*. And you are going to keep scratching that itch. Keep "scratching" at the material—working, practicing, drilling skills if you need to, whatever it takes—to master that . . . itch!



CHAPTER

1 Everyday Engineering

Most students who start off in a technical major know very little about their chosen field. This is particularly true in engineering, which may not be explicitly present in the high-school curriculum. Students commonly choose engineering and science majors because someone suggested them. In this section, we help you ask the right questions about your interests, skills, and abilities; we then show you how to combine the answers with what you learn about engineering and science in order to make the right career decision.

1.1 Choosing a Career

LEARN TO: Think about the kind of career you want and training you need

In today's society, the careers available to you upon your graduation are numerous and diverse. It is often difficult as a young adult to determine exactly what occupation you want to work at for the rest of your life because you have so many options. As you move through the process, there are questions that are appropriate to ask. You cannot make a good decision without accurate information. No one can (or should) make the decision for you: not your relatives, professors, advisors, or friends. Only you know what feels right and what does not. You may not know all the answers to your questions right away. That means you will have to get them by gathering more information from outside resources and through your personal experience. Keep in mind that choosing your major and ultimately your career is a process. You constantly evaluate and reevaluate what you learn and experience. A key component is whether you feel challenged or overwhelmed. True success in a profession is not measured in monetary terms; it is measured in job satisfaction . . . enjoying what you do, doing what you enjoy. As you find the answers, you can choose a major that leads you into a successful career path that you enjoy.

Before you decide, answer the following questions about your tentative major choice. Start thinking about the questions you cannot answer and look for ways or resources to get the information you need. It may take a long time before you know, and that is okay!

- What do I already know about this major?
- What courses will I take to earn a degree in this major?
- Do I have the appropriate academic preparation to complete this major? If not, what will I have to do to acquire it?
- Am I enjoying my courses? Do I feel challenged or stressed?
- What time demands are involved? Am I willing to spend the time it takes to complete this major?

- What kinds of jobs will this major prepare me for? Which sounds most interesting?
- What kinds of skills will I need to do the job I want? Where can I get them?

This process will take time. Once you have the information, you can make a choice. Keep in mind, nothing is set in stone—you can always change your mind!

1.2 Choosing Engineering as a Career

LEARN TO: Understand the relationship between an engineering major and a technical industry
Think about different technical industries that might interest you
Think about different engineering majors that might interest you

In the previous section, we gave several examples of why practicing engineers wanted to pursue a career in engineering. Here are a few more:

> I was always into tinkering with things and I enjoyed working with computers from a young age. Math, science, and physics came very natural to me in high school. For me it was an easy choice.
>
> *J. Comardelle, Computer Engineer*

> My initial instinct for a career path was to become an engineer. I was the son of a mechanical engineer, performed well in science and mathematics during primary education, and was always "tinkering" with mechanical assemblies.
>
> *M. Ciuca, Mechanical Engineer*

> I chose engineering for a lot of the same reasons that the "typical" entering first-year does—I was good at math and science. I definitely did not know that there were so many types of engineering and, to be honest, I was a little overwhelmed by the decision I needed to make of what type of engineering was for me.
>
> *L. Edwards, Civil Engineer*

> I wasn't really sure what I wanted to do. My parents were not college graduates so there was not a lot of guidance from them, so my high school teachers influenced me a lot. I was taking advanced math and science classes and doing well in them. They suggested that I look into engineering, and I did.
>
> *S. Forkner, Chemical Engineer*

> I was a nighttime/part-time student while I worked full time as a metallurgical technician. I was proficient in math and science and fortunate to have a mentor who stressed the need for a bachelor's degree.
>
> *E. Basta, Materials Engineer*

> Coming into college, I knew I wanted to pursue a career in medicine after graduation. I also knew that I did not want to major in chemistry, biology, etc. Therefore, bioengineering was a perfect fit. It provides a challenging curriculum while preparing me for medical school at the same time. In addition, if pursuing a career in medicine does not go according to plan, I know that I will also enjoy a career as a bioengineer.
>
> *D. Walford, Bioengineer*

Table 1-1 Sample career paths and possible majors. (Shaded boxes indicate a good starting point for further exploration.)

Careers	Engineering										Science				
	Aerospace	Biomedical	BioSystems	Civil	Chemical	Materials	Electrical/computer	Environmental	Industrial	Mechanical	Chemistry	Computer Science	Geology	Mathematics	Physics
GENERAL															
Energy industry				■	■		■	■		■	■		■		■
Machines		■					■		■	■					
Manufacturing					■	■	■		■	■					
Materials	■	■		■	■	■					■				
Structures	■			■		■			■	■			■		
Technical sales		■	■	■	■	■	■		■	■		■			■
SPECIFIC															
Rocket/airplane	■			■		■	■			■					■
Coastal engineering			■	■	■			■					■		
Computing							■					■		■	
Cryptography							■					■		■	
Defense	■	■		■	■		■		■	■		■		■	
Environment			■	■	■			■						■	■
Fiber optics						■	■						■		
Forensics					■		■				■	■			
Groundwater			■	■	■			■					■		
Healthcare		■								■	■				
Human factors	■								■	■		■			
Industrial sensors	■				■		■		■						
Intelligent systems		■					■					■		■	
Management	■	■	■	■	■	■	■	■	■	■					
Operations research									■			■		■	
Outdoor work			■	■				■					■		
Pharmaceutical		■	■		■						■				
Plastics					■	■				■	■				
Robotics	■						■			■					
Semiconductors	■					■	■		■						■
Telecommunications	■					■	■					■		■	
Transportation				■				■	■	■			■		
Waste management			■	■	■			■							

Table 1-1 describes the authors' perspective on how various engineering and science disciplines might contribute to different industries or innovations. This table is only an interpretation by a few engineers and does not handle every single possibility of how an engineer might contribute toward innovation. For example, an industrial engineer might be called in to work on an energy product to share a different perspective on energy efficiency. The broad goal of any engineering discipline is to solve problems, so there is often a need for a different perspective to possibly shed new light toward an innovative solution.

1.3 NAE Grand Challenges for Engineering

LEARN TO: Learn about the challenges facing the engineer of the future
Consider the NAE Grand Challenges and think about your own interests

History (and prehistory) is replete with examples of technological innovations that forever changed the course of human society: the mastery of fire, the development of agriculture, the wheel, metallurgy, mathematics of many flavors, the printing press, the harnessing of electricity, powered flight, nuclear power, and many others. The National Academy of Engineering (NAE) has established a list of 14 challenges for the twenty-first century, each of which has the potential to transform the way we live, work, and play. Your interest in one or more of the Grand Challenges for Engineering may help you select your engineering major. For more information, visit the NAE website at http://www.engineeringchallenges.org/. In case this address changes after we go to press, you can also type "NAE Grand Challenges for Engineering" into your favorite search engine.

A burgeoning planetary population and the technological advances of the last century are exacerbating many current problems, as well as engendering a variety of new ones. For example:

- Relatively inexpensive and rapid global travel make it possible for diseases to quickly span the globe, whereas a century ago, they could spread, but much more slowly.
- The reliance of the developed world on computers and the Internet makes the fabric of commerce and government vulnerable to cyberterrorism.
- Increased demand for limited resources not only drives up prices for those commodities, but also fosters strain among the nations competing for them.

These same factors can also be a force for positive change in the world:

- Relatively inexpensive and rapid global travel allows even people of modest means to experience different cultures and hopefully promote a more tolerant attitude toward those who live by different sets of social norms.
- Modern communications systems—cell phones, the Internet, etc.—make it essentially impossible for a government to control the flow of information to isolate the members of a population or to isolate that population from the political realities in other parts of the world. An excellent example was the rapid spread of rebellion in the Middle East and Africa in early 2011 against autocratic leaders who had been in power for decades.
- Increased demand for and rising prices of limited resources is driving increased innovation in alternatives, particularly in meeting the world's energy needs (desires).

As should be obvious from these few examples, technology both solves problems and creates them. A significant portion of the difficulty in the challenges put forth by the NAE to solve critical problems in the world lies in finding solutions that do not create other problems. Let us consider a couple of the stated challenges in a little more detail. You probably already have some familiarity with several of them, such as “make solar energy economical,” “provide energy from fusion,” “secure cyberspace,” and “enhance virtual reality,” so we will begin with one of the NAE Grand Challenges for Engineering that is perhaps less well known.

Manage the Nitrogen Cycle

Nitrogen is an element required for all known forms of life, being part of every one of the 20 amino acids that are combined in various ways to form proteins, all five bases used to construct RNA and DNA, and numerous other common biological molecules, such as chlorophyll and hemoglobin. Fortunately, the supply of nitrogen is—for all practical purposes—inexhaustible, constituting over 75% of the Earth’s atmosphere. However, nitrogen is mostly in the molecular form N_2, which is chemically unavailable for uptake in biological systems, since the two nitrogen atoms are held together by a very strong triple bond.

For atmospheric nitrogen to be available to biological organisms, it must be converted, or fixed, by the addition of hydrogen, into ammonia, NH_3, that may then be used directly or converted by other microorganisms into other reactive nitrogen compounds for uptake by microorganisms and plants. The term “nitrogen fixation” includes conversion of N_2 into both ammonia and these other reactive compounds, such as the many oxides of nitrogen. Eventually, the cycle is completed when these more readily available forms of nitrogen are converted back to N_2 by microorganisms, a process called denitrification.

Prior to the development of human technology, essentially all nitrogen fixation was performed by bacteria possessing an enzyme capable of splitting N_2 and adding hydrogen to form ammonia, although small amounts of fixed nitrogen are produced by lightning and other high-energy processes. In the early twentieth century, a process called the Haber-Bosch process was developed that would allow conversion of atmospheric nitrogen into ammonia and related compounds on an industrial scale. Today, slightly more than a century later, approximately one-third of all fixed nitrogen is produced using this process.

The ready availability of relatively inexpensive nitrogen fertilizers has revolutionized agriculture, allowing people to increase yields dramatically and to grow crops on previously unproductive lands. However, the widespread use of synthetic nitrogen has caused many problems, including water pollution, air pollution, numerous human health problems, and disruption of marine and terrestrial ecosystems to the extent that entire populations of some organisms have died off.

Deliberate nitrogen fixation is only one part of the nitrogen cycle problem, however. Many human activities, especially those involving the combustion of fossil fuels, pump huge quantities of various nitrogen compounds into the atmosphere. Nitrous oxide (N_2O), commonly known as “laughing gas,” is particularly problematic since it is about 200 times more effective than carbon dioxide as a greenhouse gas, and it persists in the atmosphere for over a century.

Altogether, human-caused conversion of nitrogen into more reactive forms now accounts for about half of all nitrogen fixation, meaning that there is twice as much nitrogen fixed today than there was a little more than a century ago. However, we have done little to augment the natural denitrification process, so the deleterious effects of excessive fixed nitrogen continue to increase. We have overwhelmed the natural nitrogen cycle. If we are to continue along this path, we must learn to manage the use of these products more efficiently and plan strategies for denitrification to bring the cycle back into balance.

Reverse-Engineer the Brain

The development of true artificial intelligence (AI) holds possibly the most overall potential for positive change in the human race, as well as the most horrendous possible negative effects. This is reflected in science fiction, where the concept of thinking machines is a common plot device, ranging from Isaac Asimov's benevolent R. Daneel Olivaw to the malevolent Skynet in the *Terminator* movies. If history is any guide, however, the potential for disastrous consequences seldom deters technological advances, so let us consider what is involved in the development of AI.

Although great strides have been made in creating machines that seem to possess "intelligence," almost all such systems that have come to the public notice either rely on brute-force calculations, such as the chess-playing computer, Deep Blue, that defeated world champion Garry Kasparov in 1997, or reliance on incredibly fast access to massive databases, such as the Jeopardy-playing computer, Watson, that defeated both the highest money winner, Brad Rutter, and the record holder for longest winning streak, Ken Jennings, in 2011. Perhaps, needless to say, these are oversimplifications, and there are many more aspects to both of these systems. However, one would be hard-pressed to argue that these computers are truly intelligent—that they are self-aware and contain the unexplainable spark of creativity, which is the hallmark of humans, and arguably other highly intelligent creatures on Earth.

Today's robots perform many routine tasks, from welding and painting vehicles to vacuuming our homes and cutting our grass. However, all of these systems are programmed to perform within certain restrictions and have serious limitations when confronted with unexpected situations. For example, if your school utilized vacuuming robots to clean the floors in the classrooms, they would probably be unable to handle the situation effectively if someone became nauseous and regurgitated on the carpet. If we could endow such robots with more human-like intelligence, the range of tasks that they could successfully accomplish would increase by orders of magnitude, thus increasing their utility tremendously.

To date, we have almost exclusively tried merely to construct intelligent systems that mimic behavior and thought, not design systems that actually store and process information in a manner analogous to that of a biologically based computer (a brain). The human brain uses a network of interconnections between specialized subsections that makes even the most advanced computers look like a set of children's building blocks. Although some understanding has been gained, the means of encoding information and its transfer in the brain is almost completely a mystery.

Gaining even a basic understanding of brain function might allow us to develop prosthetic limbs that actually function as well as the originals, restore sight to the blind, repair brain damage, or even enhance human intelligence.

1.4 Choosing a Specific Engineering Field

LEARN TO: Compare and contrast various engineering majors
Think about engineering majors you have never considered before

The following paragraphs briefly introduce several different types of engineering majors. By no means is this list completely inclusive.

Agricultural Engineering

Agricultural engineering (AgE) focuses on producing food and fiber in environmentally sound ways. This includes the design of machines and systems supporting agricultural operations, the modeling and management of soil and water, and the development and operation of large-scale manufacture of food products.

Agricultural engineers work in such areas as irrigation systems, identification and elimination of bacteria that cause food poisoning, and grain transportation. Agricultural engineers are employed in industry, universities, research facilities, and government. In industry, they are commonly part of a team serving in food production. In government agencies, they are involved in regulation and environmental conservation.

Bioengineering or Biomedical Engineering

Bioengineering (BioE) and biomedical engineering (BME) apply engineering principles to the understanding and solution of medical problems. Bioengineers are involved in research and development in all areas of medicine, from investigating the physiological behavior of single cells to designing implants for the replacement of diseased or traumatized body tissues. Bioengineers design new instruments, devices, and software; assemble knowledge from many scientific sources to develop new procedures; and conduct research to solve medical problems.

Typical bioengineers work in such areas as artificial organs, automated patient monitoring, blood chemistry sensors, advanced therapeutic and surgical devices, clinical laboratory design, medical imaging systems, biomaterials, and sports medicine.

Bioengineers are employed in universities, industry, hospitals, research facilities, and government. In industry, they may be part of a team serving as a liaison between engineers and clinicians. In hospitals, they select appropriate equipment and supervise equipment performance, testing, and maintenance. In government agencies, they are involved in safety standards and testing.

Biosystems Engineering

Biosystems engineering (BE) is the field of engineering most closely allied with advances in biology. BE emphasizes two main areas: (1) bioprocess engineering, with its basis in microbiology, and (2) ecological engineering, with its basis in ecology. The field focuses on the sustainable production of biorefinery compounds (biofuels, bioactive molecules, and biomaterials) using metabolic pathways found in nature and green processing technologies.

My research is part of a Water Research Foundation project, which is investigating the formation of emerging disinfection byproducts (DBPs) in drinking water treatment.

DBPs are undesirable, toxic compounds that are formed when water is chlorinated. I am investigating the effects of pH, bromide, and iodide concentrations, and preoxidants on the formation of a specific family of DBPs.

D. Jones, BE

Further, BE encompasses the design of sustainable communities using low-impact development strategies (bioretention basins, rainwater harvesting) for stormwater retention and treatment—and ecologically sound food and energy-crop production. Scientific emphasis is shifting toward the biosciences. Biosystems engineers apply engineering design and analysis to biological systems and incorporate fundamental biological principles to engineering designs to achieve ecological balance.

Here are some activities of biosystems engineers:

- Design bioprocesses and systems for biofuels (biodiesel, hydrogen, ethanol), biopharmaceuticals, bioplastics, and food processing industries
- Develop ecological designs (permeable pavement, bioswales, green infrastructure) to integrate water management into the landscape
- Integrate biological sustainability concepts into energy, water, and food systems
- Provide engineering expertise for agriculture, food processing, and manufacturing
- Pursue medical or veterinary school or graduate school in the fields of BE, BME, or ecological engineering

I am a project manager for new product development.

I oversee and coordinate the various activities that need to be completed in order to get a new product approved and manufactured, and ultimately in the hands of our consumers.

S. Forkner, ChE

Chemical Engineering

Chemical engineering (ChE) incorporates a strong emphasis on three sciences: chemistry, physics, and mathematics. Chemical engineers are involved in the research and development, manufacture, sales, and use of chemicals, pharmaceuticals, electronic components, food and consumer goods, petroleum products, synthetic fibers and films, pulp and paper, and many other products. They work on environmental remediation and pollution prevention, as well as in medical and health-related fields. Chemical engineers:

- Conduct research and develop new products
- Develop and design new manufacturing processes
- Earn additional degrees to practice medicine or patent, environmental, or corporate law
- Sell and provide technical support for sophisticated chemical products to customers
- Solve environmental problems; work in biotechnology
- Troubleshoot and solve problems in chemical manufacturing facilities

Civil Engineering

Civil engineering (CE) involves the planning, design, construction, maintenance, and operation of facilities and systems to control and improve the environment for modern

My team is responsible for implementing the engineered design in the field.

We install, tune, test, and accept into operations all of the electronics that allow customers to use our state-of-the-art fiber optic network to run voice, video, and data for their residential needs.

L. Gascoigne, CE

civilizations. This includes projects of major importance, such as bridges, transportation systems, buildings, ports, water distribution systems, and disaster planning.

Here are just a few of many opportunities available for civil engineers:

- Design and analyze structures ranging from small buildings to skyscrapers to off-shore oil platforms
- Design dams and building foundations
- Develop new materials for pavements, buildings, and bridges
- Design improved transportation systems
- Design water distribution and removal systems
- Develop new methods to improve safety, reduce cost, speed construction, and reduce environmental impact
- Provide construction and project management services for large engineered projects throughout the world

My current responsibilities include:

- Analysis of traffic signal operations and safety for municipal and private clients;
- Preparation of traffic impact studies;
- Review of plans and traffic studies for municipalities and counties;
- Design of traffic signal installations and traffic signing projects.

C. Hill, CE

I am responsible for assisting in the management of commercial and healthcare projects for Brasfield & Gorrie. Working closely with the owner and architect, I maintain open lines of communication and aim to provide exceptional service to the entire project team from the preconstruction phase of the project through construction. I assist in establishing and monitoring procedures for controlling the cost, schedule, and quality of the work in accordance with the construction contract.

L. Edwards, CE

I develop, manage, and support all software systems. I also deal with system scalability, customer satisfaction, and data management.

J. Comardelle, CpE

Computer Engineering

Computer engineering (CpE) spans the fields of computer science and engineering, giving a balanced view of hardware, software, hardware-software trade-offs, and basic modeling techniques that represent the computing process involving the following technologies:

- Communication system design
- Computer interface design
- Computer networking
- Digital signal processing applications
- Digital system design
- Embedded computer design
- Process instrumentation and control
- Software design

I am a digital designer and work on the read channel for hard-disk drives. The read channel is the portion of the controller SOC (system on a chip) that decodes the analog signal read from the hard disk and converts it to digital data. I am responsible for writing Verilog RTL code, verification, synthesis into gates, and meeting timing requirements of my blocks.

E. D'Avignon, CpE

I manage global programs that help develop leadership capabilities and skills of our current and future leaders. I am a consultant, a coach, a mentor, and a guide. If leaders are interested in improving how they lead and the impact they have on their employees and on company results, we work with them to identify the best ways for them to continue their development.

A. Hu, EE

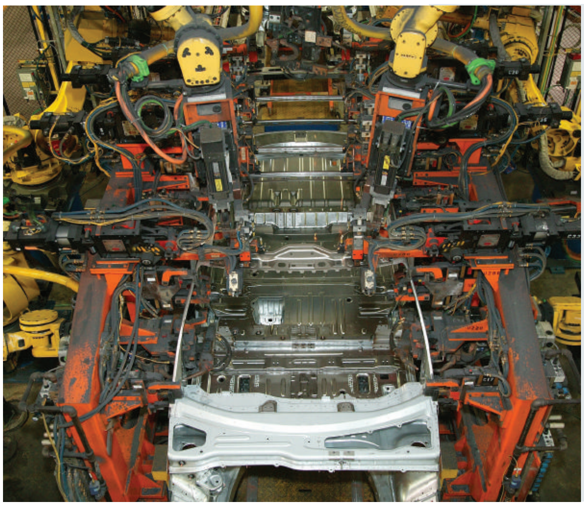
Electrical Engineering

Electrical engineering (EE) ranges from the generation and delivery of electrical power to the use of electricity in integrated circuits. The rapid development of technology, based on integrated circuit devices, has enabled the pervasive use of computers in command, control, communication, and computer-aided design. Some systems electrical engineers work on include the following:

- Communication system design
- Control systems—from aircraft to automotive
- Electrical power generation and distribution
- Electromagnetic waves
- Integrated circuit design
- Process instrumentation and control
- Robotic systems design
- Telecommunications

As a radiation effects engineer, I test the performance of electronic components in a specific application exposed to different types of radiation. Responsibilities include interfacing with design and system engineers, creating test plans, performing testing and data analysis, and authoring test reports.

A. Passman, EE



My group supports [a major automotive manufacturer's] decisions pertaining to where to put new plants around the world, what products to build in them, and at what volumes.

In particular, my work involves understanding what the other auto manufacturers are planning for the future (footprint, capacity, technology, processes, etc.), so that information can be used to affect decisions about how to compete around the globe.

M. Peterson, EE

> I work with scientists and engineers to protect their innovations by writing patent applications describing their inventions and presenting the applications before the U.S. Patent & Trademark Office. I also assist clients in determining whether another party is infringing their patents and help my clients to avoid infringing other's patents.
>
> *M. Lauer, EnvE*

Environmental Engineering

Environmental engineering (EnvE) is an interdisciplinary field of engineering that is focused on cleaning up environmental contamination, as well as designing sustainable approaches to prevent future contamination. Environmental engineers apply concepts from basic sciences (including chemistry, biology, mathematics, and physics) to develop engineered solutions to complex environmental problems.

Environmental engineers design, operate, and manage both engineered and natural systems to protect the public from exposure to environmental contamination and to develop a more sustainable use of our natural resources. These activities include the following:

- Production of safe, potable drinking water
- Treatment of wastewater so that it is safe to discharge to surface water or reuse in such applications as landscape irrigation
- Treatment of air pollutants from mobile (e.g., automobiles) and stationary (e.g., power plants) sources
- Characterization and remediation of sites contaminated with hazardous wastes (e.g., polychlorinated biphenyls, or PCBs)
- Disposal of municipal solid wastes
- Management of radioactive wastes, including characterization of how radioactive materials move through the environment and the risks they pose to human health
- Evaluation of methods to minimize or prevent waste production and inefficient use of energy by manufacturing facilities
- Reduce human health risks by tracking contaminants as they move through the environment
- Design a more sustainable future by understanding our use of resources

WISE WORDS: WHAT DID YOU DO YESTERDAY MORNING AT WORK?

I worked on completing a failure analysis report for an industrial client.

E. Basta, Materials Engineer

I reviewed the results of the overnight simulation runs. There were several failures, so I analyzed the failures and devised fixes for the problems.

E. D'Avignon, CpE

On any given day, my morning might be spent this way: in meetings, at my computer (e-mail, drafting documents/reports), making phone calls, talking to other project members, running a test on the manufacturing lines. Not glamorous, but necessary to solve problems and keep the project moving forward.

S. Forkner, ChE

I continued to design a warehouse/office building on a nuclear expansion project.

T. Hill, CE

Yesterday, I designed a spreadsheet to assist in more precisely forecasting monthly expenditures.

R. Holcomb, IE

With a BS degree in EnvE, students will find employment with consulting engineering firms, government agencies involved in environmental protection, and manufacturing industries.

As the Business Leader for Central Florida at a major power company, I develop and manage a $42 million budget. I ensure that our engineering project schedule and budget match, and report on variances monthly. I also conduct internal audits and coach employees on Sarbanes–Oxley compliance requirements.

R. Holcomb, IE

Industrial Engineering

Industrial engineering (IE) deals with the design and improvement of systems, rather than with the objects and artifacts that other engineers design. A second aspect of IE is the involvement of people in these systems—from the people involved in the design and production to the people who are ultimate end users. A common theme is the testing and evaluation of alternatives that may depend on random events. Industrial engineers use mathematical, physical, social sciences, and engineering combined with the analytical and design methods to design, install, and improve complex systems that provide goods and services to our society. Industrial engineers are called upon to:

- Analyze and model complex work processes to evaluate potential system improvements
- Analyze how combinations of people and machines work together
- Analyze how the surroundings affect the worker, and design to reduce the negative effects of this environment
- Develop mathematical and computer models of how systems operate and interact
- Improve production and service processes from the perspectives of quality, productivity, and cost
- Work on teams with other professionals in manufacturing, service industries, and government agencies

I attended the plant morning meeting and the Boardmill leadership team meeting, followed by the plant budget meeting. In between meetings, I returned e-mails and project-related phone calls. Typically, I spend about 50% of my time in meetings. I use the information I receive at these meetings to direct and focus the efforts of the engineering staff.

J. Huggins, ME

Testing some failed prototype biostimulators returned by a trial user, to determine why and how they failed and how to prevent it from happening in coming production versions.

J. Kronberg, EE

Yesterday, I worked on a patent infringement opinion involving agricultural seeding implements, a Chinese patent office response for a component placement and inspection machine used in circuit board manufacturing, and a U.S. Patent Office response for database navigation software.

M. Lauer, EnvE

In my current position, I spend much of my time reading technical manuals and interface control documents. I attended a meeting detailing lightning protection for the Ares rocket.

E. Styles, EE

My primary job responsibilities include maintaining, upgrading, and designing all the computer systems and IT infrastructure for the Vermont Railroad. I handle all the servers and take care of network equipment. When needed, I also program customized applications and websites for customers or our own internal use. I also serve as a spare conductor and locomotive engineer when business needs demand.

S. Houghton, CpE

Currently I am working on a project to determine patient priorities for evacuations from healthcare facilities during emergencies. The assumption of an evacuation is that there will be enough time to transfer all of the patients, but in the event of limited resources, there may not be enough time to move all of the patients to safety. Further—and depending on the emergency type—it may be an increased risk to transport some patient types. Based on certain objectives, we are developing guidelines to most ethically determine a schedule for choosing patients for emergency evacuations.

A. Childers, IE

As a metallurgical engineer, my duties include

- Consulting firm management/administration
- Failure analysis
- Subcontracted metals testing services
- Metallurgical quality systems design/auditing
- Metallurgical expert in litigation cases
- Materials selection and design consultant, in-process and final inspection and testing services

E. Basta, Materials Engineer

Materials Engineering

Materials engineering or metallurgical engineering focuses on the properties and production of materials. Nature supplied only 92 naturally occurring elements to serve as building blocks to construct all modern conveniences. A materials engineer works to unlock the relationship between atomic, molecular, and larger-scale structures and the resultant properties. This category includes such majors as ceramic engineering, metallurgical engineering, and polymer science and engineering.

Here is a partial list of products designed and manufactured by material engineers:

- Brick, tile, and whitewares research and manufacturing for the home and workplace
- Ceramic spark plugs, oxygen sensors, and catalytic converters that optimize engine performance
- Metal and ceramic materials that enable biomedical implants and prosthetics
- Microwave responsive ceramics that stabilize and filter cellular phone reception
- Nanotechnology, including silver nanoparticles used as antibacterial agents in socks and t-shirts and carbon nanotubes used to reinforce the forks of racing bicycles
- Plastics found in bulletproof vests, replacement heart valves, and high tension wires on bridges
- Superconducting metals that are used in medical imaging devices, such as magnetic resonance imaging (MRI) equipment
- Ultrapure glass optical fibers that carry telephone conversations and Internet communications

I implement technology to protect national assets against adversaries.

J. Dabling, ME

Mechanical Engineering

Mechanical engineering (ME) involves areas related to machine design, manufacturing, energy production and control, materials, and transportation. Areas supported by mechanical engineers include:

- Construction
- Energy production and control
- Environmental systems
- Food production
- Management
- Materials processing
- Medicine
- Military service
- Propulsion and transportation systems
- Technical sales

As plant engineering manager I report directly to the plant manager. My primary responsibilities are managing all the capital investments; providing technical support and expertise to the plant leadership team; and mentoring and developing the plant's engineering staff and technical resources.

J. Huggins, ME

I am a salesman, so at the end of the day I'm looking to grow my market share while trying to protect the market share I already have. I help companies maintain a safe, reliable, and efficient steam and condensate system by utilizing the many products and services that we have to offer. This is mostly done by designing and installing upgrades and improving my customer's existing steam systems.

T. Burns, ME

I am an aerospace engineering manager responsible for developing unique astronaut tools and spacewalk procedures and for testing and training for NASA's Hubble Space Telescope servicing missions. My job ranges from tool and procedure design and development to underwater scuba testing to real-time, on-console support of Space Shuttle missions.

R. Werneth, ME

> In my job as a management consultant, I address CEO-level management decisions as part of a project team by helping clients identify, analyze, and solve business-related problems. My responsibilities include generating hypotheses, gathering, and analyzing data, conducting benchmarking and best practices assessments, recommending actions, and working with clients to develop implementation plans.
>
> *M. Ciuca, ME*

Nuclear Engineering

Nuclear engineering (NucE) focuses on the application of the breakdown (fission) and fusion of atomic nuclei. It relies heavily on principles from nuclear physics. While the most commonly recognized applications of nuclear processes are power-generating nuclear reactors and nuclear weapons, a broad range of opportunities is available. Nuclear engineers do the following:

- Provide electrical energy needs
- Assist in space exploration through nuclear propulsion systems, radiation power sources, and detector systems
- Apply radiation-based methods to sterilize medical instruments and food processing systems and preserve food
- Design radiation-based systems to diagnose and eradicate cancer and other diseases
- Apply plasma technology in material processing and other technologies
- Contribute to national security through the stewardship of nuclear weapons and engineering safeguards against nuclear proliferation
- Design systems to protect people and equipment from radiation and for the safe storage of nuclear waste.

1.5 Engineering Technology—A Related Field

LEARN TO: Understand the difference between engineering and engineering technology
Understand differences in curricula and in career paths for the two disciplines

As its name suggests, engineering technology is related to engineering. In a formal sense, the two fields use different requirements for accreditation and are accredited by different commissions. While it is possible to earn an associate's degree in engineering technology, it is clearer to compare the bachelor's degrees in engineering technology and engineering to observe the formal differences. The student outcomes required of accredited engineering technology programs are shown in the table below alongside those required of accredited engineering programs. Note that the criteria do not appear in the same order in the two sets of criteria. The notable differences between the two are noted. In some cases, whereas the wording may be very different between the two criteria, the sense is very similar. For example, engineering student outcome "(g), an ability to communicate effectively," is similar to engineering technology student outcome "g. an ability to apply written, oral, and graphical communication in both technical and nontechnical environments; and an ability to identify and use appropriate technical literature." Whereas the engineering technology outcome provides much greater detail, there is no reason to suggest that these are different outcomes.

Engineering Technology (1)	Engineering (2)
a. an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly defined engineering technology activities;	(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
b. an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies;	(a) an ability to apply knowledge of mathematics, science, and engineering
c. an ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes;	(b) an ability to design and conduct experiments, as well as to analyze and interpret data
d. an ability to design systems, components, or processes for broadly defined engineering technology problems appropriate to program educational objectives;	(c) an ability to design a system, component, or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
e. an ability to function effectively as a member or leader on a technical team;	(d) an ability to function on multidisciplinary teams
f. an ability to identify, analyze, and solve broadly defined engineering technology problems;	(e) an ability to identify, formulate, and solve engineering problems
g. an ability to apply written, oral, and graphical communication in both technical and nontechnical environments; and an ability to identify and use appropriate technical literature;	(g) an ability to communicate effectively
j. a knowledge of the impact of engineering technology solutions in a societal and global context;	(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i. an understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity;	(f) an understanding of professional and ethical responsibility
	(j) a knowledge of contemporary issues
h. an understanding of the need for and an ability to engage in self-directed continuing professional development;	(i) a recognition of the need for, and an ability to engage in lifelong learning
k. a commitment to quality, timeliness, and continuous improvement.	

Sources: (1) http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-technology-programs-2016-2017/#studentoutcomes
(2) http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2016-2017/#outcomes

Differences in Academic Curricula

Generally, engineering program curricula are more academic, focusing more on theory and concepts, whereas engineering technology program curricula are more practical, focusing on applications and skills. This difference can be seen in the table above, whereas E(b) requires that engineering graduates are able to design and conduct experiments, ET(c) does not require engineering technology graduates to be able to design experiments. Engineering outcome E(e) requires the more theory-oriented ability to "formulate" problems, an outcome that is missing from ET(f).

This difference is often noted in a more general treatment in engineering curricula compared to a more specific treatment in engineering technology curricula.

Whereas engineering graduates must learn to face a wide variety of design constraints in E(c), engineering technology graduates have the more application-oriented option in ET(d) of focusing on a narrower set of constraints appropriate to a particular context. Similarly, while ET(j) addresses societal and global impact, E(h) additionally includes economic and environmental impact. Whereas engineering graduates must function on "multidisciplinary" teams per E(d), engineering technology graduates are required in ET(e) to function on "technical" teams that need not be multidisciplinary. In some cases, the application-oriented focus of engineering technology appears easier—conducting experiments that others design, solving problems that others formulate. Yet even in the criteria above, it is clear that engineering technology students must figure out how to act on things that engineering students must only understand—whereas E(f) requires that engineering graduates understand professional and ethical responsibility, ET(i) also requires that engineering technology graduates have a commitment to address those issues, including a respect for diversity; whereas engineering students are required by E(b) to be able to design and conduct experiments, engineering technology graduates are expected to be able to apply the results of experiments.

Differences in Typical Career Pathways

Engineering graduates have wide-ranging jobs ranging from design to analysis, office work to field work, from companies that make things to companies that design things that are made by others. Graduates of four-year engineering technology programs are more often found in jobs where things are made or sold and are more often engaged in field work. Four-year technology graduates are called technologists—the term "technician" is appropriate for two-year engineering technology graduates. Generally, engineering careers are more flexible, whereas engineering technology careers tend to result in more tangible accomplishments (rather than accomplishments on paper).

1.6 Gathering Information

LEARN TO: Research different professional organizations for engineering disciplines

You will need to gather a lot of information in order to answer your questions about engineering or any other major. Many resources are available on your campus and online.

The Career Center

Most universities have a centralized campus career center. The staff specializes in helping students explore various occupations and make decisions. They offer testing and up-to-date information on many career fields. Professional counselors are available by appointment to assist students with job and major selection decisions.

Table 1-2 Website research starting points

Society	Abbreviation
American Ceramic Society	ACerS
American Indian Science and Engineering Society	AISES
American Institute of Aeronautics and Astronautics	AIAA
American Institute of Chemical Engineers	AIChE
American Nuclear Society	ANS
American Society of Agricultural and Biological Engineers	ASABE
American Society of Civil Engineers	ASCE
American Society for Engineering Education	ASEE
American Society of Mechanical Engineers	ASME
American Society of Metals International	ASM Int'l.
Association for Computing Machinery	ACM
Audio Engineering Society	AES
Biomedical Engineering Society	BMES
Engineers Without Borders	EWB
Institute of Biological Engineering	IBE
Institute of Electrical and Electronics Engineers	IEEE
Institute of Industrial Engineers	IIE
Institute of Transportation Engineers	ITE
Materials Research Society	MRS
National Academy of Engineering	NAE
National Society of Black Engineers	NSBE
National Society of Professional Engineers	NSPE
Society of Automotive Engineers International	SAE Int'l.
Society of Hispanic Professional Engineers	SHPE
Society of Petroleum Engineers	SPE Int'l.
Society of Plastics Engineers	SPE
Society of Women Engineers	SWE
Tau Beta Pi, The Engineering Honor Society	TBP

Career Websites

To learn more about engineering and the various engineering fields, you can find a wealth of information from engineering professional societies. Each engineering field has a professional society dedicated to promoting and disseminating knowledge about that particular discipline. Table 1-2 provides a list of most major engineering professional socities in the United States. In some cases, more than one society is connected with different subdisciplines. Other regions of the world may have their own professional societies.

Perusing the various societies' websites can provide you with information invaluable in helping you decide on a future career. We have not given URLs for the societies, since these sometimes change. To find the current address, simply use an online search engine with the name of the society.

In addition, a few engineering societies are not specific to a discipline, but to their membership:

- American Indian Science and Engineering Society (AISES)
- National Society of Black Engineers (NSBE)
- National Society of Professional Engineers (NSPE)
- Society of Hispanic Professional Engineers (SHPE)
- Society of Women Engineers (SWE)
- Tau Beta Pi, The Engineering Honor Society (TBP)

Most engineering schools have student chapters of the relevant organizations on campus. These organizations provide an excellent opportunity for you to learn more about your chosen discipline or the ones you are considering, and they also help you meet other students with similar interests. Student membership fees are usually nominal, and the benefits of membership far outweigh the small cost.

Active participation in these societies while in school not only gives you valuable information and experience, but also helps you begin networking with professionals in your field and enhances your résumé.

1.7 Pursuing Student Opportunities

LEARN TO: Understand what a cooperative experience entails
Understand what an internship experience entails
Understand what a study abroad experience entails

In addition to the traditional educational experience, many students seek experience outside of the classroom. Many engineering colleges and universities have special departments that help place students in programs to gain real engineering work experience or provide them with a culturally rich study environment. Ask a professor or advisor if your university provides experiences similar to those described in this section.

Cooperative Education

Contributed by Dr. Neil Burton, Executive Director of Career Services, Michelin® Career Center, Clemson University

People learn things in many different ways. Some people learn best by reading; others by listening to others; and still others by participating in a group discussion. One very effective form of learning is called **experiential learning**, also referred to as engaged learning in some places. As the name suggests, experiential learning means learning through experience, and there is a very good chance you used this method to learn how to ride a bike, bake a cake, change a flat tire, or perform any other complex process that took some practice to perfect. The basic assumption behind experiential learning is that you learn more by doing than by simply listening or watching.

Becoming a good engineer is a pretty challenging process, so it seems only natural that experiential learning would be especially useful to an engineering student. In 1906, Herman Schneider, the Dean of Engineering at the University of Cincinnati, developed

WISE WORDS: ADVICE ABOUT SOCIETY PARTICIPATION

Get involved! It is so much fun! Plus, you're going to meet a ton of cool people doing it!

T. Andrews, CE

I am a very involved person, and I love it. I definitely recommend participating in professional societies because not only do they look good on a résumé but they also provide you with useful information for your professional life. It also allows you to network with others in your field which can be helpful down the road. Also, do something fun as it is a nice stress relief and distraction when life seems to become really busy.

C. Darling, BE

My advice to students willing to participate on student activities is for them to not be shy when going to a student organization for the first couple of times. It takes time to get well known and feel comfortable around new people, but don't let that prevent you from being part of a student organization that can bring many benefits to you. Always have a positive attitude, be humble, and learn to listen to others; these are traits which you will use in your professional life.

V. Gallas Cervo, ME

My advice to first-year students is to not get involved with too many organizations all at once. It is easy to get distracted from your class work with all the activities on campus. Focus on a couple and be a dedicated officer in one of them. This way you have something to talk about when employers see it on your résumé. I would recommend that you are involved with one organization that you enjoy as a hobby and one organization that is a professional organization.

D. Jones, BE

The most important thing to do when joining any group is to make sure you like the people in it. This is probably even more important than anything the group even does. Also make sure that if the group you're joining has a lot of events they expect you to be at, you have the time to be at those events.

R. Kriener, EE

The field of engineering is a collaborative project; therefore, it is important to develop friendships within your major.

S. Belous, CpE

Make the time to participate in student activities. If possible, try to get a leadership position in one of the activities because it will be useful in interviews to talk about your involvement. While employers and grad schools may not be impressed with how you attended meetings occasionally as a general member, they will be interested to hear about the projects that you worked on and the challenges that you faced in a leadership position.

K. Smith, ChE

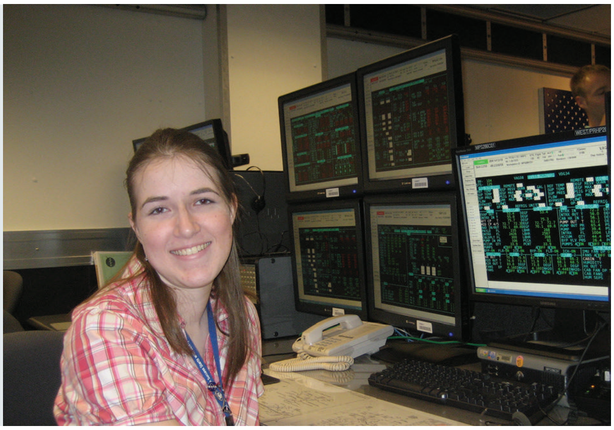
Get involved! College is about more than just academics. Participating in student activities is a lot of fun and makes your college experience more memorable. I've made so many friends not just at my school, but all over the country by getting involved. It is also a great way to develop leadership and interpersonal skills that will become beneficial in any career.

A. Zollinger, CE

On my co-op, I worked on the hazard analysis for the new Ares I launch vehicle that NASA designed to replace the Space Shuttles when they retired in 2010.

Basically, we looked at the design and asked: What happens if this part breaks, how likely is it that this part will break, and how can we either make it less likely for the part to break or give it fault tolerance so the system can withstand a failure?

J. Sandel, ME



an experiential learning program for engineering students because he felt students would understand the material in their engineering classes much better if they had a chance to put that classroom knowledge into practice in the workplace. Schneider called this program **Cooperative Education**, and more than 100 years later, colleges and universities all over the world offer cooperative (co-op) education assignments to

WISE WORDS: WHAT DID YOU GAIN FROM YOUR CO-OP OR INTERNSHIP EXPERIENCE?

I was able to learn how to practically apply the knowledge I was gaining from college. Also, the pay allowed me to fund my schooling.

B. Dieringer, ME

The best part about that experience was how well it meshed with my courses at the time. My ability to apply what I was learning in school every day as well as to take skills and techniques I was learning from experienced engineers and use them toward the projects I was working on in school was invaluable.

A. Flowerday, CpE

My internships were a great introduction to the professional workplace—the skills and responsibilities that are expected; the relationships and networks that are needed.

S. Forkner, ChE

I decided to pursue a co-op because I had trouble adapting to the school environment in my first years and taking some time off to work at a company seemed a good way to rethink and reorganize myself. I made a good decision taking some time off, since it allowed me to learn a lot more about myself, how I work, how I learn, and how I operate. I learned that the biggest challenges were only in my mind and believing in me was, and still is, the hardest thing.

V. Gallas Cervo, ME

My internship taught me that I could be an engineer—and a good one too. I had a lot of self-doubt before that experience, and I learned that I was better than I thought I was.

B. Holloway, ME

The value of the cooperative education was to apply the classroom material to real-world applications, develop an understanding of the expectations post-grad, and provide the opportunity for a trial run for a future career path in a low-risk environment.

M. Ciuca, ME

students in just about every major, although engineering students remain the primary focus of most co-op programs.

There are many different kinds of co-op programs, but all of them offer engineering students the chance to tackle real-world projects with the help and guidance of experienced engineers. One common model of cooperative education allows students to alternate semesters of co-op with semesters of school. In this model, students who accept co-op assignments spend a semester working full-time with a company, return to school for the following academic term, go back out for a second co-op **rotation**, return to school the following term, and continue this pattern until they have spent enough time on assignment to complete the co-op program.

Students learn a lot about engineering during their co-op assignments, but there are many other benefits as well. Engineering is a tough discipline, and a co-op assignment can often help a student determine if he or she is in the right major. It is a lot better to figure out that you do not want to be an engineer before you have to take thermodynamics or heat transfer! Students who participate in co-op programs also have a chance to develop some great professional contacts, and these contacts are very handy when it comes time to find a permanent job after graduation. The experience students receive while on a co-op assignment is also highly valued by employers who want to know if a student can handle the challenges and responsibilities of a certain position. In fact, many students receive full-time job offers from their co-op employers upon graduation.

Being able to immediately apply the things I learned in school to real-world applications helped reinforce a lot of the concepts and theories. It also resulted in two job offers after graduation, one of which I accepted.

J. Huggins, ME

This was an amazing opportunity to get a real taste for what I was going to be doing once I graduated. I began to realize all the different types of jobs I could have when I graduated, all working in the same field. In addition, my work experience made my résumé look 100 times more appealing to potential employers. The experience proved that I could be a team player and that I could hit the ground running without excessive training.

L. Johnson, CE

It gave me a chance to see how people work together in the "real world" so that I could learn how to interact with other people with confidence, and also so that I could learn what kind of worker or manager I wanted to be when I "grew up."

M. Peterson, ME

Without a doubt, the best professional decision of my life. After my co-op rotation finished, I approached school as more like a job. Furthermore, co-oping makes school easier! Imagine approaching something in class that you have already seen at work!

A. Thompson, EE

I did my research, and it really made sense to pursue a co-op—you get to apply the skills you learn in class, which allows you to retain the information much better, as well as gain an increased understanding of the material.

As for choosing a co-op over an internship, working for a single company for an extended period of time allows students to learn the ropes and then progress to more intellectually challenging projects later in the co-op. And, if you really put forth your best effort for the duration of your co-op, you could very well end up with a job offer before you graduate!

R. Izard, ME

I wanted some practical experience, and I wasn't exactly sure what career I wanted to pursue when I graduated. My experience at a co-op set me on a completely different career path than I had been on previously.

K. Smith, ChE

Perhaps the most important benefit a co-op assignment can provide is improved performance in the classroom. By putting into practice the theories you learn about in class, you gain a much better understanding of those theories. You may also see something on your co-op assignment that you will cover in class the following semester, putting you a step ahead of everyone else in the class. You will also develop time management skills while on a co-op assignment, and these skills should help you complete your school assignments more efficiently and effectively when you return to the classroom.

Companies that employ engineers often have cooperative education programs because co-op provides a number of benefits to employers as well as students. While the money companies pay co-op students may be double or even triple than what those students would earn from a typical summer job, it is still much less than companies would pay full-time engineers to perform similar work. Many employers also view cooperative education as a recruiting tool—what better way to identify really good employees than to bring aboard promising students and see how they perform on co-op assignments!

Internship

Contributed by Mr. Troy Nunamaker, Director of Graduate and Internship Programs, Michelin Career Center, Clemson University

Internships offer the unique opportunity to gain career-related experience in a variety of settings. Now, more than ever, employers look to hire college graduates with internship experience in their field.

Employers indicate that good grades and participation in student activities are not always enough to help students land a good, full-time job. In today's competitive job market, the students with career-related work experience are the students getting the best interviews and job offers. As an added bonus, many companies report that over 70% of full-time hires come directly from their internship program.

Searching for an Internship

Although a number of students will engage in an internship experience during their first and sophomore years, most students pursue an internship during their junior and senior years. Some students might participate in more than one internship during their college career. Allow plenty of time for the search process to take place, and be sure to keep good records of all your applications and correspondences.

- **Figure out what you are looking for.** You should not start looking for an internship before you have answered the following questions:
  - What are my interests, abilities, and values?
  - What type of organization or work environment am I looking for?
  - Are there any geographical constraints, or am I willing to travel anywhere?
- **Start researching internship opportunities.** Start looking one to two semesters before your desired start date. Many students find that the search process can take anywhere from 3 to 4 weeks up to 5 to 6 months before securing an internship. You should utilize as many resources as possible in order to have the broadest range of options.
  - Visit your campus's career center office to do the following: meet with a career counselor; attend a workshop on internships; find out what positions and resources are available; and look for internship postings through the career center's recruiting system and website resources.
  - Attend a career fair on your campus or in your area. Career fairs typically are not just for full-time jobs, but are open to internship applicants as well. In addition, if there are specific companies where you would like to work, contact them directly and find out if they offer internships.
  - Network. Network. Network. Only about a quarter of internship opportunities are actually posted. Talk to friends, family, and professors and let them know that you are interested in an internship. Networking sites like LinkedIn and Facebook are also beginning to see more use by employers and students. However, be conscious what images and text are associated with your profile.
- **Narrow down the results and apply for internships.** Look for resources on your campus to help with developing a résumé and cover letter. *Each résumé and cover letter should then be tailored for specific applications.* As part of the application

The biggest project I worked on was the Athena model. The Athena is one of NASA's launch platforms.

Before I came here to the contract, several other interns had taken and made SolidWorks parts measured from the actual Athena. My task was to take their parts, make them dimensionally correct and put it together in a large assembly.

I took each individual part (about 300 of them!) and made them dimensionally correct, then put them together into an assembly. After I finished the assembly, I animated the launcher and made it move and articulate.

E. Roper, ME

process, do not be surprised if a company requests additional documents, such as references, transcripts, writing samples, and formal application packets.

- **Wait for responses.** It may take up to a month to receive any responses to your applications. One to two weeks after you have submitted your application, call the organization to make sure they received all the required documents from you.
- **Interview for positions.** Once you have your interviews scheduled, stop by the career center to see what resources they have available to help you prepare for the interview. Do not forget to send a thank you note within 24 hours of the interview, restating your interest in the position.

Why Choose An Internship?

- Bridge classroom applications to the professional world
- Build a better résumé
- Possibly receive higher full-time salary offers upon graduation
- Gain experience and exposure to an occupation or industry
- Network and increase marketability
- Potentially fulfill academic requirements and earn money

Accepting an Internship

Once you have secured an internship, look to see if academic internship coursework is available on your campus so that the experience shows up on your transcripts. If you were rejected from any organizations, take it as a learning experience and try to determine what might have made your application stronger.

WISE WORDS: DESCRIBE A PROJECT YOU WORKED ON DURING YOUR CO-OP OR INTERNSHIP

The large project I worked on was an upgrade of an insulin production facility. A small project I worked on for two weeks was the design of a pressure relief valve for a heat exchanger in the plant.

D. Jones, BE

I have been working on a series of projects, all designed to make the production of electric power meters more efficient. I am rewriting all the machine vision programs to make the process more efficient and to provide a more sophisticated graphical user interface for the operators. These projects have challenged me by requiring that I master a new "machine vision" programming language, as well as think in terms of efficiency rather than simply getting the job done.

R. Izard, ME

A transmission fluid additive was not working correctly and producing harmful emissions, so I conducted series of reactions adding different amounts of materials in a bioreactor. I determined the best fluid composition by assessing the activation energy and how clean it burned.

C. Darling, BE

POINTS TO PONDER

Am I eligible for an internship?
Most companies look to hire rising juniors and seniors, but a rising sophomore or even a first-year student with relevant experience and good grades can be a strong candidate.

Will I be paid for my internship?
The pay rate will depend on your experience, position, and the individual company. However, most engineering interns receive competitive compensation; averages are $14–$20 per hour.

When should I complete an internship?
Contrary to some popular myths, an internship can be completed not only during summers, but also during fall and spring semesters. Be sure to check with your campus on how to maintain your student enrollment status while interning.

Will I be provided housing for an internship?
Do not let the location of a company deter you. Some employers will provide housing, while others will help connect you with resources and fellow interns to find an apartment in the area.

At Boeing, I worked with Liaison Engineering. Liaison engineers provide engineering solutions to discrepancies on the aircraft that have deviated from original engineering plans. As one example, I worked closely with other engineers to determine how grain properties in titanium provide a sound margin or safety in the seat tracks.

J. Compton, ME

The site I worked at designs and manufactures radar systems (among others). During my internship I wrote C code that tests the computer systems in a certain radar model. The code will eventually be run by an operator on the production floor before the new radars are sent out to customers.

D. Rollend, EE

One of my last projects I worked on during my first term was building a new encoder generator box used to test the generator encoder on a wind turbine. The goal was to make a sturdier box that was organized inside so that if something had broken, somebody who has no electrical skills could fix it. I enjoyed this project because it allowed me to use my skills I have learned both from school and my last internship.

C. Balon, EE

Study Abroad

Contributed by Mrs. J. P. Creel, (previous) International Programs Coordinator, College of Engineering and Science, Clemson University

In today's global economy, it is important for engineering students to recognize the importance of studying abroad. A few reasons to study abroad include the following:

- Taking undergraduate courses abroad is an exciting way to set your résumé apart from those of your peers. Prospective employers will generally inquire about your international experiences during the interview process, giving you the chance to make a lasting impression that could be beneficial.
- Studying abroad will give you a deeper, more meaningful understanding of a different culture. These types of learning experiences are not created in traditional classrooms in the United States and cannot be duplicated by traveling abroad on vacation.
- Students who study abroad generally experience milestones in their personal development as a result of stepping outside of their comfort zone.
- There is no better time to study abroad than now! Students often think that they will have the opportunity to spend significant amounts of time traveling the world after graduation. In reality, entering the workforce typically becomes top priority.

I think that first-year students in engineering should do a co-op or internship. It was extremely valuable to my education. Now that I am back in the classroom, I know what to focus on and why what I am learning is important.

Before the experience I did not know what I wanted to do with my major, and I didn't fully understand word problems that were presented in a manner that applied to manufacturing or real life. Being in industry and working in a number of different departments, I figured out that I liked one area more than any other area, and that is where I am focusing my emphasis area studies during my senior year.

K. Glast, IE

I studied abroad twice. The first time I spent a semester in the Netherlands, experiencing a full immersion in the Dutch culture and exploring my own heritage, and the second time I spent a summer in Austria taking one of my core chemical engineering classes. Both countries are beautiful and unique places and they will always hold a special place in my heart.

Through studying abroad, I was able to expand my own comfort zone by encountering novel situations and become a more confident individual. Although the experiences were amazing and the memories are truly priceless, the biggest thing I gained from studying abroad was that I was able to abandon many perceptions about other cultures and embrace new perspectives.

R. Lanoie, studying abroad in the Netherlands and Austria