GLOBAL EDITION

Thinking Like an Engineer

An Active Learning Approach

THIRD EDITION

Stephan • Bowman • Park • Sill • Ohland

ALWAYS LEARNING

PEARSON

CONVERSIONS

Angle

1 rad	= 57.3 deg
π rad	**= 180 deg**

Area

1 acre	= 4047 m^2
	= 0.00156 mi^2

Energy

1 J	= 0.239 cal
	= 9.48×10^{-4} BTU
	= 0.7376 ft lb_f
1 kW h	**= 3,600,000 J**

Force

1 N	= 0.225 lb_f
	= 1 E 5 dyne
1 kip	**= 1,000 lb_f**

Length

1 m	= 3.28 ft
1 km	= 0.621 mi
1 in	**= 2.54 cm**
1 mi	**= 5280 ft**
1 yd	**= 3 ft**

Mass

1 kg	= 2.205 lb_m
1 slug	= 32.2 lb_m
1 ton	**= 2,000 lb_m**

Power

1 W	= 3.412 BTU/h
	= 0.00134 hp
	= 14.34 cal/min
	= 0.7376 ft lb_f/s

Pressure

1 atm	= 1.01325 bar
	= 33.9 ft H_2O
	= 29.92 in Hg
	= 760 mm Hg
	= 101,325 Pa
	= 14.7 psi

Time

1 d	**= 24 h**
1 h	**= 60 min**
1 min	**= 60 s**
1 yr	= 365 d

Temperature

1 K	**= 1 °C**
	= 1.8 °F
	= 1.8 °R

Volume

1 L	= 0.264 gal
	= 0.0353 ft^3
	= 33.8 fl oz
1 mL	**= 1 cm^3 = 1 cc**

Named Units

1 F	= 1 A s/V
1 H	= 1 V s/A
1 Hz	= 1 s^{-1}
1 J	= 1 N m

1 N	= 1 kg m/s^2
1 P	= g/(cm s)
1 Pa	= 1 N/m^2
1 St	= 1 cm^2/s

1 V	= 1 W/A
1 W	= 1 J/s
1 Ω	= 1 V/A

Conversions shown in bold text above indicate exact conversions

SI PREFIXES

Numbers Less Than One		
Power of 10	**Prefix**	**Prefix Abbreviation**
10^{-1}	deci-	d
10^{-2}	centi-	c
10^{-3}	milli-	m
10^{-6}	micro-	μ
10^{-9}	nano-	n
10^{-12}	pico-	p
10^{-15}	femto-	f
10^{-18}	atto-	a
10^{-21}	zepto-	z
10^{-24}	yocto-	y

Example: 1 millimeter [mm] = 1×10^{-3} meters [m]

Numbers Greater Than One		
Power of 10	**Prefix**	**Prefix Abbreviation**
10^{1}	deca-	da
10^{2}	hecto-	h
10^{3}	kilo-	k
10^{6}	Mega-	M
10^{9}	Giga-	G
10^{12}	Tera-	T
10^{15}	Peta-	P
10^{18}	Exa-	E
10^{21}	Zetta-	Z
10^{24}	Yotta-	Y

Example: 1 Megajoule [MJ] = 1×10^{6} joules [J]

THINKING LIKE AN ENGINEER

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AN ACTIVE LEARNING APPROACH

Third Edition

Global Edition

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Edinburgh Gate Harlow
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British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

10 9 8 7 6 5 4 3 2 1
15 14 13 12 11

ISBN 13: 978-1-292-01945-1
ISBN 10: 1-292-01945-X

Typeset in 10/12 Times Ten LT STD Roman by Jouve India Private Limited
Printed by Ashford Colour Press, United Kingdom

CONTENTS

PREFACE

At our 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 our customers. 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 freshman 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. Part 1 concludes with an introduction to a problem-solving methodology.

First, as an aspiring engineer, it is important that students attempt 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 individual to accomplish alone; thus, practicing engineers must learn to function effectively as a team, putting aside their personal differences 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 off 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 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: SCRUPULOUS WORKSHEETS

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 (Worksheets), Chapter 11 (Graphing), and Chapter 12 (Trendlines) 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: PUNCTILIOUS PROGRAMMING

Part 4 (Punctilious Programming) 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 of how computers can be used as a tool for problem solving and provide enough scaffolding for transfer of programming knowledge into other languages commonly used by engineers (such as C/C++/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 discuss 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 third edition of *Thinking Like an Engineer: An Active Learning Approach* (TLAE) contains new material and revisions based off of the comments from faculty teaching with our textbook, the recommendations of the reviewers of our textbook, 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) 2013 and MATLAB 2013. We have added approximately 30% new questions. In addition, we have added new material that reflects the constant changing face of engineering education because many of our upperclassman teaching assistants frequently comment to us "I wish I had ___ when I took this class."

New to this edition, by chapter:

- Chapter 1: Everyday Engineering
  - New section on the field of Engineering Technology.
- Chapter 3: Design and Teamwork
  - New sequence of topics, to allow expanded discussion on defining the problem, determining criteria, brainstorming, making decisions and testing solutions.
- Chapter 8: Universal Units
  - New section on Electrical Concepts.
- Chapter 14: Statistics
  - Combined material from Chapters 14 (Excel) and 18 (MATLAB) in TLAE 2e to make a single unified chapter on Statistics.
- Chapter 16: Variables and Data Types
  - New material on the various ways MATLAB stores and processes data.
  - Selected material from TLAE 2e has been moved to this chapter, including cell arrays.
- Chapter 18: Input/Output in MATLAB
  - Combined material from Chapter 20 in TLAE 2e on using Microsoft Excel to input data to and output data from MATLAB.
- Chapter 19: Logic and Conditionals
  - New sections on Switch Statements and using Errors and Warnings.

HOW TO USE

As we have alluded to previously, this text contains many different types of instruction to address different types of learners. There are two main components to this text: hard copy 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 include them as end of part questions is to maintain the active spirit of the classroom within the reading, allowing the students to self-evaluate their understanding of the material in preparation for class—to enable 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** sections provide additional questions, often combining skills 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.

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**. Students are expected to have their laptop open and 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**.

Finally, for the communication section, we have provided **templates** for several types of reports and presentations. All of these can be accessed at www.pearsonglobaleditions.com/TLAE.

ADDITIONAL 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.

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.

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 discover 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

> *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, 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 co-authors 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 freshman, 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 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 for 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 Wordle!

To our friends and former students who contributed their Wise Words: Tyler Andrews, Corey Balon, Ed Basta, Sergey Belous, Brittany Brubaker, Tim Burns, Ashley Childers, Jeremy Comardelle, Matt Cuica, Jeff Dabling, Christina Darling, Ed D'Avignon, Brian Dieringer, Lauren Edwards, Andrew Flowerday, Stacey Forkner, Victor Gallas Cervo, Lisa Gascoigne, Khadijah Glast, Tad Hardy, Colleen Hill, Tom Hill, Becky Holcomb, Beth Holloway, Selden Houghton, Allison Hu, Ryan Izard, Lindy Johnson, Darryl Jones, Maria Koon, Rob Kriener, Jim Kronberg, Rachel Lanoie, Mai Lauer, Jack Meena, Alan Passman, Mike Peterson, Candace Pringle, Derek Rollend,

Eric Roper, Jake Sadie, Janna Sandel, Ellen Styles, Adam Thompson, Kaycie (Smith) Timmons, Devin Walford, Russ Werneth, and Aynsley Zollinger.

To our fellow faculty members, for providing inspiration, ideas, and helping us find countless mistakes: Dr. Steve Brandon, Dr. Ashley Childers, Andrew Clarke, Dr. David Ewing, Dr. Sarah Grigg, Dr. Richard Groff, Dr. Apoorva Kapadia, Dr. Sabrina Lau, Dr. Jonathan Maier, Dr. William Martin, Jessica Merino, and John Minor. You guys are the other half of this team that makes this the best place on earth to work! We could not have done this without you.

To the staff of the GE program, we thank you for your support of us and our students: Kelli Blankenship, Lib Crockett, Chris Porter, and all of our terrific advising staff both past and present. To the administration at Clemson, we thank you for your continued support of our program: Associate Dean Dr. Randy Collins, Interim Director Dr. Don Beasley, Dean Dr. Anand Gramopadhye, Provost Nadim Aziz. Special thanks to President Jim Barker for his inspirational leadership of staying the course and giving meaning to "One Clemson." We wish him all the best as he retired from the Presidency this December.

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 inspirations 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.

To the great folks at Prentice Hall—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 Scott Disanno 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 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: Thanks to my parents and sister for supporting my creative endeavors with nothing but encouragement and enthusiasm. To my grandparents, who value science, engineering, and education to be the most important fields of study. To my co-authors, who continue to teach me to think like an engineer. To Dana, 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. You are entirely too rad. I love you.

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—Charlotte, whose "old soul" touches all who take the time to know her; Carson, who is quietly inspiring; and Anders, whose love of life and people endears him to all. I acknowledge my father Theodor, who inspired me to be an educator; my mother Nancy, who helped me understand people; my sister Karen, who lit a pathway in engineering; my brother Erik, who showed me that one doesn't need to be loud to be a leader; and my mother-in-law Nancy Winfrey, who shared the wisdom of a long career. I recognize those who helped me create an engineering education career path: Fred Orthlieb, Civil and Coastal

Engineering at the University of Florida, Marc Hoit, Duane Ellifritt, Cliff Hays, Mary Grace Kantowski, and John Lybas, the NSF's SUCCEED Coalition, Tim Anderson, Clemson's College of Engineering and Science and General Engineering, Steve Melsheimer, Ben Sill, 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 one-third century, 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: 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 co-authors who have tolerated my eccentricities and occasional tardiness with only minimum grumbling, you make great teammates.

EAS: To my co-authors, for tolerating all my strange demands, my sleep-deprived ravings and the occasional "I need this now" hysteria—and it has gotten worse with the third edition—you guys are the best! To my mom, Kay and Denny—thanks for your love and support. To Khadijah & Steven, wishes for you to continue to conquer the world! To Brock and Katie, I love you both a bushel and a peck. You are the best kids in the world, and the older you get the more you inspire me to be great at my job. Thank you for putting up with all the late nights, the lack of home-cooked meals, and the mature-beyond-your-years requirements I've asked of you. Finally, to Sean . . . last time I swore the rough parts were done, but man this edition was tough to finish up! 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 . . ."

Pearson would like to thank and acknowledge the following contributors and reviewers for their work on the Global Edition:

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Arup Kumar Bhattacharjee, Assistant Professor, RCC Institute of Information Technology

Soumen Mukherjee, Assistant Professor, RCC Institute of Information Technology

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Part 1 ENGINEERING ESSENTIALS

LEARNING OBJECTIVES

The overall learning objectives for this unit 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:

- Use the problem solving method SOLVEM to assist in devising a solution.

As the reader of this text, 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

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 ground water movement until I look 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

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

C. Pringle, Industrial Engineer

> "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

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."

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.*

More or less, 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 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.

Scattered throughout this text, you will find quotes from practicing engineers. As a good engineering team would, we recognize 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 serve to motivate students to learn. Some goals are better motivators than others.

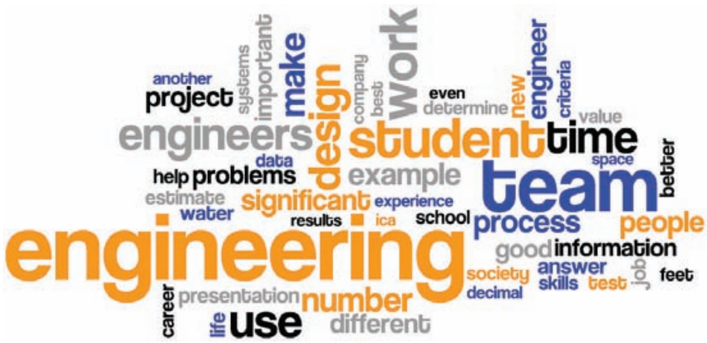
Lots of experts have studied goals and how they affect what students do in school. Not surprisingly, there are as many ideas and theories about goals as there are experts. But most experts agree on the idea that there are mastery goals and performance goals.

> *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!



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 the text. 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

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 is not generally 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 freshman 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, 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 night time/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, BioEngineering*

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

	Engineering										Science				
Careers	Aerospace	Biomedical	BioSystems	Civil	Chemical	Materials	Electric/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 into 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.

MORE WISE WORDS: HOW DID YOU CHOOSE A MAJOR IN COLLEGE?

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

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 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 cyber terrorism.
- 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.

As should be obvious from these few examples, technology not only solves problems, but also 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.

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