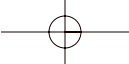


THINKING LIKE AN ENGINEER

AN ACTIVE LEARNING APPROACH



THINKING LIKE AN ENGINEER

AN ACTIVE LEARNING APPROACH

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CONTENTS

| | |
|------------------|------|
| PREFACE | ix |
| ACKNOWLEDGEMENTS | xvii |

PART 1 ENGINEERING ESSENTIALS 1

| | |
|---|----|
| CHAPTER 1 | |
| EVERYDAY ENGINEERING | 5 |
| 1.1 CHOOSING A CAREER | 5 |
| 1.2 CHOOSING ENGINEERING AS A CAREER | 6 |
| 1.3 CHOOSING A SPECIFIC ENGINEERING FIELD | 8 |
| 1.4 GATHERING INFORMATION | 16 |
| 1.5 PURSUING STUDENT OPPORTUNITIES | 18 |

| | |
|-----------------------------|----|
| CHAPTER 2 | |
| ETHICS | 28 |
| 2.1 ETHICAL DECISION-MAKING | 29 |
| 2.2 ENGINEERING CREED | 34 |
| IN-CLASS ACTIVITIES | 36 |

| | |
|--|----|
| CHAPTER 3 | |
| DESIGN AND TEAMWORK | 43 |
| 3.1 THE DESIGN PROCESS | 43 |
| 3.2 BRAINSTORMING IN THE DESIGN PROCESS | 45 |
| 3.3 EXPERIMENTAL DESIGN: PERIOD ANALYSIS | 46 |
| 3.4 PROJECT TIMELINE | 48 |
| 3.5 CRITERIA AND EVALUATION | 50 |
| 3.6 WORKING IN TEAMS | 55 |
| IN-CLASS ACTIVITIES | 58 |

| | |
|--|----|
| CHAPTER 4 | |
| ENGINEERING COMMUNICATION | 63 |
| 4.1 BASIC PRESENTATION SKILLS | 64 |
| 4.2 SAMPLE PRESENTATIONS | 66 |
| 4.3 BASIC TECHNICAL WRITING SKILLS | 69 |
| 4.4 COMMON TECHNICAL COMMUNICATION FORMATS | 72 |
| IN-CLASS ACTIVITIES | 79 |

| | |
|--------------------------------------|----|
| ENGINEERING ESSENTIALS REVIEW | 89 |
|--------------------------------------|----|

PART 2 PROBLEM PARADIGMS 97

| | |
|----------------------------------|-----|
| CHAPTER 5 | |
| ESTIMATION | 101 |
| 5.1 GENERAL HINTS FOR ESTIMATION | 104 |
| 5.2 SIGNIFICANT FIGURES | 105 |
| 5.3 REASONABLENESS | 109 |
| 5.4 NOTATION | 113 |
| IN-CLASS ACTIVITIES | 116 |

| | |
|--------------------------------|-----|
| CHAPTER 6 | |
| SOLVEM | 119 |
| 6.1 DEFINING SOLVEM | 119 |
| 6.2 REPRESENTING FINAL RESULTS | 125 |
| 6.3 AVOIDING COMMON MISTAKES | 125 |
| IN-CLASS ACTIVITIES | 129 |

| | |
|--------------------------------|-----|
| CHAPTER 7 | |
| GRAPHING GUIDELINES | 132 |
| 7.1 GRAPHING TERMINOLOGY | 132 |
| 7.2 PROPER PLOTS | 133 |
| 7.3 GRAPH INTERPRETATION | 140 |
| 7.4 MEANING OF THE LINE SHAPES | 143 |
| 7.5 GRAPHICAL SOLUTIONS | 149 |
| IN-CLASS ACTIVITIES | 153 |

| | |
|---------------------------|-----|
| CHAPTER 8 | |
| INTERPOLATION | 165 |
| 8.1 SINGLE INTERPOLATION | 166 |
| 8.2 COMPLEX INTERPOLATION | 169 |
| IN-CLASS ACTIVITIES | 172 |

| | |
|--------------------------|-----|
| CHAPTER 9 | |
| STATISTICS | 176 |
| 9.1 HISTOGRAMS | 177 |
| 9.2 STATISTICAL BEHAVIOR | 180 |
| 9.3 DISTRIBUTIONS | 183 |

vi CONTENTS

| | | |
|------------|-----------------------------------|-----|
| 9.4 | CUMULATIVE DISTRIBUTION FUNCTIONS | 190 |
| 9.5 | STATISTICAL PROCESS CONTROL (SPC) | 192 |
| | IN-CLASS ACTIVITIES | 200 |

| | |
|---------------------------------|-----|
| PROBLEM PARADIGMS REVIEW | 206 |
|---------------------------------|-----|

PART 3

UBIQUITOUS UNITS 223

CHAPTER 10

FUNDAMENTAL DIMENSIONS AND BASE UNITS 235

| | | |
|-------------|--------------------------------------|-----|
| 10.1 | THE METRIC SYSTEM | 236 |
| 10.2 | OTHER UNIT SYSTEMS | 239 |
| 10.3 | CONVERSION PROCEDURE FOR UNITS | 239 |
| 10.4 | CONVERSIONS INVOLVING MULTIPLE STEPS | 242 |
| 10.5 | CONVERSIONS INVOLVING "NEW" UNITS | 247 |
| 10.6 | DERIVED DIMENSIONS AND UNITS | 248 |
| 10.7 | EQUATION LAWS | 250 |
| 10.8 | CONVERSION INVOLVING EQUATIONS | 253 |
| | IN-CLASS ACTIVITIES | 256 |

CHAPTER 11

UNIVERSAL UNITS 261

| | | |
|--------------|---------------------|-----|
| 11.1 | FORCE | 261 |
| 11.2 | WEIGHT | 263 |
| 11.3 | DENSITY | 264 |
| 11.4 | AMOUNT | 269 |
| 11.5 | TEMPERATURE | 272 |
| 11.6 | PRESSURE | 275 |
| 11.7 | GAS PRESSURE | 280 |
| 11.8 | ENERGY | 282 |
| 11.9 | POWER | 286 |
| 11.10 | EFFICIENCY | 287 |
| | IN-CLASS ACTIVITIES | 293 |

CHAPTER 12

DIMENSIONLESS NUMBERS 302

| | | |
|-------------|------------------------------|-----|
| 12.1 | COMMON DIMENSIONLESS NUMBERS | 302 |
| 12.2 | DIMENSIONAL ANALYSIS | 304 |
| 12.3 | RAYLEIGH'S METHOD | 308 |
| | IN-CLASS ACTIVITIES | 316 |

| | |
|--------------------------------|-----|
| UBIQUITOUS UNITS REVIEW | 320 |
|--------------------------------|-----|

PART 4

SCRUPULOUS SPREADSHEETS 333

CHAPTER 13

EXCEL WORKBOOKS 341

| | | |
|-------------|----------------------------|-----|
| 13.1 | CELL REFERENCES | 341 |
| 13.2 | FUNCTIONS IN EXCEL | 344 |
| 13.3 | LOGIC AND CONDITIONALS | 349 |
| 13.4 | LOOKUP AND DATA VALIDATION | 355 |
| 13.5 | CONDITIONAL FORMATTING | 358 |
| 13.6 | SORTING AND FILTERS | 361 |
| | IN-CLASS ACTIVITIES | 367 |

CHAPTER 14

EXCEL GRAPHS 376

| | | |
|-------------|------------------------|-----|
| 14.1 | AVAILABLE GRAPH TYPES | 377 |
| 14.2 | STATISTICS IN EXCEL | 379 |
| 14.3 | AUTOMATED CALCULATIONS | 383 |
| | IN-CLASS ACTIVITIES | 389 |

CHAPTER 15

MODELS AND SYSTEMS 396

| | | |
|-------------|-----------------------|-----|
| 15.1 | LINEAR FUNCTIONS | 397 |
| 15.2 | LINEAR RELATIONSHIPS | 400 |
| 15.3 | POWER FUNCTIONS | 414 |
| 15.4 | EXPONENTIAL FUNCTIONS | 417 |
| | IN-CLASS ACTIVITIES | 423 |

CHAPTER 16

MATHEMATICAL MODELS 429

| | | |
|-------------|-----------------------------------|-----|
| 16.1 | SELECTING A TRENDLINE TYPE | 429 |
| 16.2 | INTERPRETING LOGARITHMIC GRAPHS | 438 |
| 16.3 | CONVERTING SCALES TO LOG IN EXCEL | 445 |
| 16.4 | DEALING WITH LIMITATIONS OF EXCEL | 445 |
| | IN-CLASS ACTIVITIES | 452 |

| | |
|---------------------------------------|-----|
| SCRUPULOUS SPREADSHEETS REVIEW | 459 |
|---------------------------------------|-----|

PART 5
PUNCTILIOUS
PROGRAMMING 483**CHAPTER 17**
ALGORITHMS, PROGRAMS,
AND FUNCTIONS 489

- 17.1** SCOPE 489
- 17.2** WRITTEN ALGORITHMS 491
- 17.3** GRAPHICAL ALGORITHMS 493
- 17.4** PROGRAMS IN MATLAB 498
- 17.5** DEBUGGING MATLAB CODE 510
- 17.6** FUNCTIONS IN MATLAB 511
- IN-CLASS ACTIVITIES 516

CHAPTER 18
INPUT/OUTPUT IN MATLAB 519

- 18.1** INPUT 519
- 18.2** OUTPUT 521
- 18.3** PLOTTING 523
- 18.4** STATISTICS 527
- IN-CLASS ACTIVITIES 532

CHAPTER 19
LOGIC & CONDITIONALS 540

- 19.1** TRUTH TABLES 540
- 19.2** BINARY NUMBERS 542

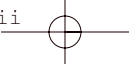
- 19.3** LOGIC AND RELATIONAL OPERATORS IN MATLAB 544
- 19.4** CONDITIONAL STATEMENTS IN MATLAB 545
- IN-CLASS ACTIVITIES 549

CHAPTER 20
LOOPING STRUCTURES 554

- 20.1** `for` LOOPS 554
- 20.2** `while` LOOPS 560
- IN-CLASS ACTIVITIES 563

PUNCTILIOUS PROGRAMMING REVIEW 566

- COMPREHENSION CHECK ANSWERS 577
- INDEX 588
- EXCEL FUNCTIONS 598
- MATLAB FUNCTIONS 599
- GREEK LETTERS 600
- NOMENCLATURE AND UNIT ABBREVIATIONS 601
- MISCELLANEOUS EQUATIONS 602
- EQUATIONS AND GEOMETRIC FORMULAS 603
- SI UNITS AND PHYSICAL CONSTANTS 604



PREFACE

Tell me and I forget. Teach me and I may remember. Involve me and I learn.

Benjamin Franklin

Education is what survives when what has been learnt has been forgotten.

B. F. Skinner

The larger the island of knowledge, the longer the shoreline of wonder.

Ralph W. Sockman

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. Over the past 10 years, 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 this one—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 the text.

X PREFACE

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 five areas, each of which is introduced below.

Part 1: Engineering Essentials

You could be an engineering major if: when your professor asks you where your homework is, you claim to have accidentally determined its momentum so precisely, that according to Heisenberg, it could be anywhere in the universe.

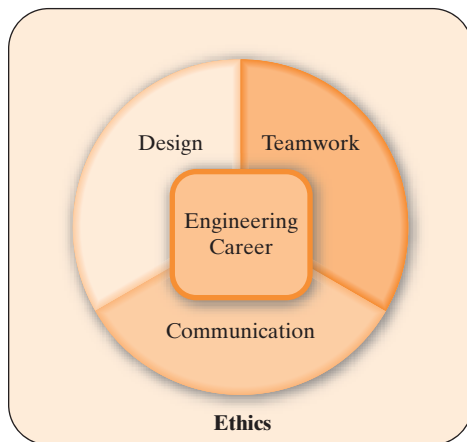
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The best way to have a good idea is to have a lot of ideas.

Linus Pauling

A scientist describes what is, and an engineer creates what never was.

Theodore von Karman



There are two threads that bind the first four chapters in Engineering Essentials together. The first is expressed in the section title: all are essential for a successful career in engineering. The other is communications, as will be discussed further below.

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.

Part 2: Problem Paradigms

Engineering problems are under-defined; there are many solutions, good, bad and indifferent. The art is to arrive at a good solution. This is a creative activity, involving imagination, intuition and deliberate choice.

Ove Arup

When the only tool you own is a hammer, every problem begins to resemble a nail.

Abraham Maslow

It is better to know some of the questions than all of the answers.

James Thurber

Part 2 of the book, Problem Paradigms, starts off where all good problem solving should—with estimation. 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. Graphing Guidelines is included because graphs are needed both to understand a system and

to communicate it to others. A chapter on interpolation supports the interpretation of graphs and tabular data. Univariate statistics and statistical process control wraps up this part of the book by providing a way for engineering students to describe both distributions and trends.

Part 3: Ubiquitous Units

The wise man knows all things, as far as possible, although he has not knowledge of each of them in detail.

Aristotle

A mind stretched to a new idea never goes back to its original dimension.

Oliver Wendell Holmes

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 4: Scrupulous Spreadsheets

A theory may be so rich in descriptive possibilities that it can be made to fit any data.

Philip Johnson-Laird

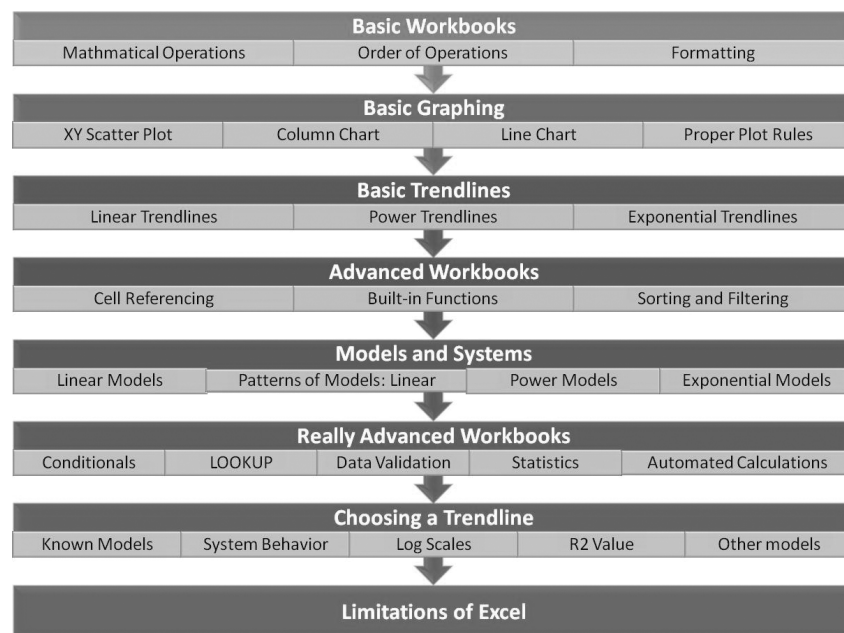
What is commonly overlooked in using the computer is the fact that the central goal of design is still to obviate failure, and thus it is critical to identify exactly how a structure may fail. The computer cannot do this by itself.

Henri Petroski

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 13 (Worksheets), Chapter 14 (Graphing) and Chapter 15 (Trendlines) to direct students to Appendices B, C, and D, respectively.

Once students have mastered the basics, each chapter in this section 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 15 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 16 discusses a process for determining a mathematical model when presented with experimental data, and some advanced material on dealing with limitations of Excel.



Part 5: Punctilious Programming

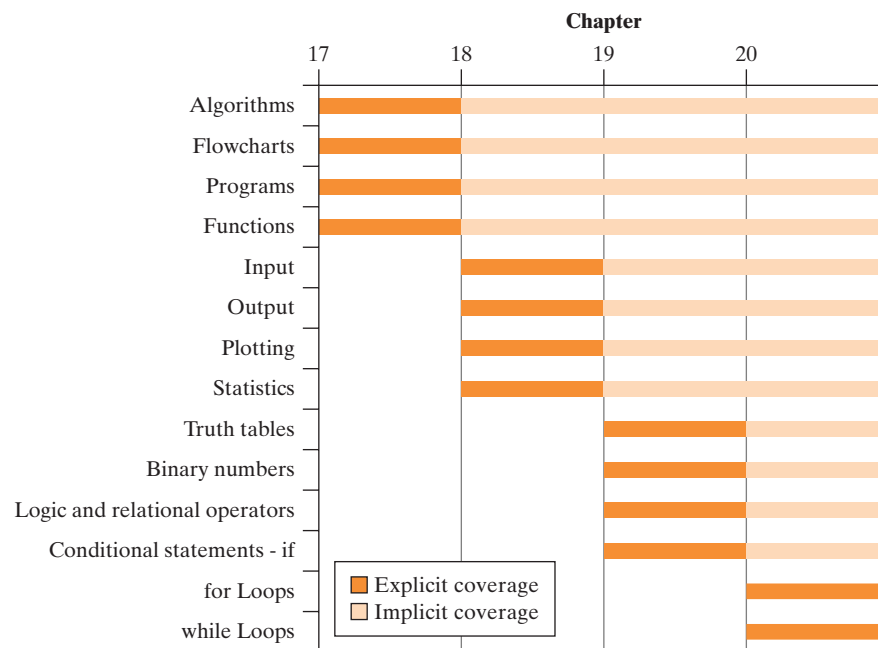
If debugging is the process of removing bugs, then programming must be the process of putting them in.

Edsger W. Dijkstra

Measuring programming progress by lines of code is like measuring aircraft building progress by weight.

Bill Gates

Part 5 (Punctilious Programming) covers a variety of topics common to any introductory programming textbook. In contrast to a traditional programming textbook, this



section 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 5 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...

The bad news is time flies. The good news is you’re the pilot.

Michael Altshuler

All who have accomplished great things have had a great aim, have fixed their gaze on a goal which was high, one which sometimes seemed impossible.

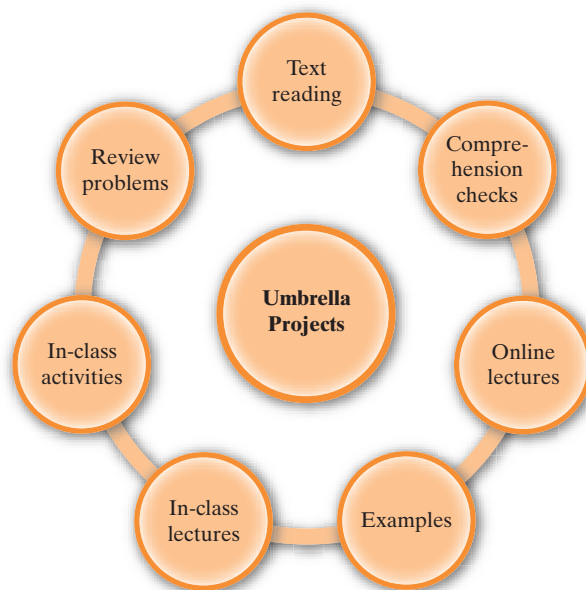
Orison Swett Marden

Do or do not. There is no try.

Yoda

Throughout the book, we have included sections on surviving engineering, time management and goal setting, personality types and study skills. We did not group them into a single chapter, but have scattered them throughout the section 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.



How to Use this Text

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. There are some topics (such as interpolation) that we simply tell our students that we expect them to know and do not spend any class time discussing. 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 are provided in the back of the book. Our motivation for including Comprehension Checks within the text rather than include them as end of section 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 at the end of each part provide additional questions, often combining skills within the part 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 and part* as they prepare to transfer their knowledge to other areas. Finally in the instructor's manual, we have provided a series of **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 the 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 **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, so you will notice that many of the Excel lectures are shorter than previous material. With Excel, the examples are scripted the first time a skill is presented, and 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** in the online version by “hanging” the worksheets within the online text. Students can access the starting data through the online copy of the book. 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**.

The following text markers indicate corresponding online materials are available.



Excel file



Word file



PowerPoint file



Video file

Finally, for the communication section, we have provided **templates** for several types of reports and presentations. These can also be accessed in the Pearson eText version.

Additional Resources for Instructors

Instructor's Manual—Available to all adopters, this provides a complete set of solutions for all activities and homework 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, available with voiceover or as standard 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/Prentice Hall 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.



Author team: Ohland, Park, Stephan, Bowman, Sill

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 band, 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

xvi PREFACE



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
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