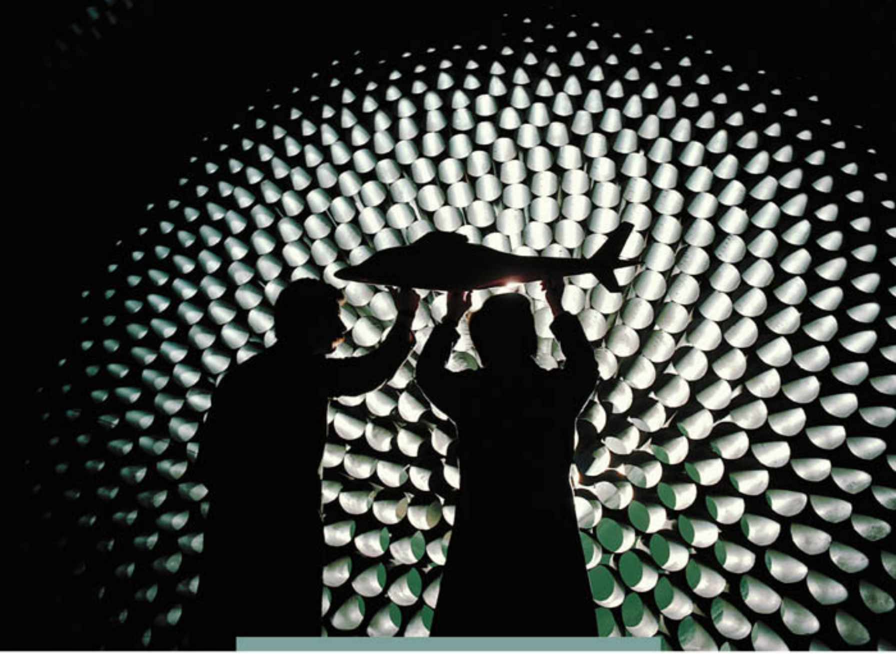
Basic Engineering Series and Tools

TEAMWORK and PROJECT MANAGEMENT

FOURTH EDITION



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Teamwork and Project Management

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With chapters by Constance Kampf, Russell Korte, Robert MacNeal, Curt McNamara, Şenay Purzer and Nicholas D. Fila, and Cliff Whitcomb and Leslie Whitcomb; and box features and other contributions by Eric Berkowitz, Shannon Ciston, P. K. Imbrie, Kathryn Jablokow, David Johnson, Shawn Jordan, Billy Koen, Holly Matusovich, Tamara Moore, Matthew Ohland, Randy Pausch, Mary Pilotte, David Radcliffe, Anthony Starfield, Ruth Streveler, and Khairiyah Mohd Yusof.

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Preface

In the early 1990s I designed and started teaching a project management course for third- and fourth-year civil engineering students at the University of Minnesota. I had been teaching an engineering systems course that was problem driven and made use of project teams and used a similar approach in the project management course. I also started teaching project management and teamwork courses for graduate students in professional master's programs, especially at the University of Minnesota's Technological Leadership Institute, and for participants in short courses for government agencies, such as the Minnesota Department of Transportation (Mn/DOT), and private companies.

When McGraw-Hill invited me in 1997 to write a book on project management and teamwork for their BEST series, I thought, What a terrific idea! Real world engineering problems require teamwork to be solved. Involving first-year engineering students in teamwork and project management as soon as possible would help them prepare for engineering practice. I immediately embraced the idea and started working on a book for them.

Along with colleagues and undergraduate student teaching assistants I had taught an introductory engineering course for first-year students at the University of Minnesota for more than 20 years. It evolved into a course titled How to Model It: Building Models to Solve Engineering Problems, which I have taught with colleagues and undergraduate student teaching assistants. We also wrote a book to accompany the course—*How to Model It: Problem Solving for the Computer Age* (Starfield, Smith, and Bleloch, 1990, 1994). Since the course made extensive use of project teams, I knew that a book on project management and teamwork was needed. Teamwork and projects are at the heart of the approach I use in teaching students at all levels, including participants in faculty development workshops. I've learned that it isn't easy for students to work effectively in project teams or for faculty to organize and manage them, but the potential for extraordinary work from teams makes it worth the effort. Also, projects and teamwork are a central part of engineering work in the world outside the classroom.

The book went through two iterations prior to the Fourth Edition. Though the first edition of *Project Management and Teamwork* was designed for first-year students, we found that other students used it, especially those in senior-level capstone design courses. So the second edition, retitled *Teamwork and Project Management*, was redesigned to be accessible to first-year students but also to be applicable for upper-division students who hadn't had an opportunity to focus on teamwork and project management skills in earlier courses and programs and for students in graduate and professional programs. The third edition was primarily an update to the second and included some collaboration with P. K. Imbrie. The nearby box feature summarizes P. K.'s connection to the third edition.

A number of years ago I attended a workshop on cooperative learning given by Prof. Smith (yes the same Prof. Smith that is the principal author of this book). At that time, I strongly believed "the lecture" was the quintessential way to promote student learning and I saw no value (from a learning perspective) in using student teams. After his workshop I came to realize the most important thing we do as a faculty member is help students learn how to learn—or, another way of saying it, we need to prepare them for the idea of lifelong learning. What I discovered is through a traditional lecture class, we teach them (our students) how to be stenographers and to memorize whatever it is we teach. However, in the active, cooperative classroom, students actually have to learn how to learn, because they have to learn how to communicate their ideas to other individuals while they're in a team environment.

So you might be asking yourself, what does this have to do with "teaming"? What I have found is whether you are in the classroom, working on homework, or completing a term-long project, moving from being individualistic learners to partner learners and moving from a textbook, faculty-centered learning style to "my peers and everybody else can be equal contributors in this" can provide a phenomenal learning experience. However, it requires you to learn how to be an effective team member. To be an effective member of a team (or an informal learning group) one must learn how to work interdependently, specify goals, develop a sense of cohesiveness, and communicate (and, if you are on a formal team, one needs clearly defined roles and rules of accountability, or norms). The teaming chapters of this book will help you understand what we have found to be important and will hopefully make your teaming experience more enjoyable.

P. K. Imbrie

Since the engineering method involves progressive refinement, that is, taking what we know at the present (labeled state of the art, $sota_{2013}$) and identifying opportunities for improvement, the changes in this edition continue to reflect a focused emphasis on preparing engineering students for professional practice. In the spirit of advancing the state of the art, I've made major changes to several chapters and have updated the entire book.

The Fourth Edition represents a major redesign and includes an expanded number of collaborators. There are new chapters by Constance Kampf, Russell Korte, Robert MacNeal, Curt McNamara, Şenay Purzer and Nicholas D. Fila, and Cliff Whitcomb and Leslie Whitcomb; and box features and other contributions by Eric Berkowitz, Shannon Ciston, P. K. Imbrie, Kathryn Jablokow, David Johnson, Shawn Jordan, Billy Koen, Holly Matusovich, Tamara Moore, Matthew Ohland, Randy Pausch, Mary Pilotte, David Radcliffe, Anthony Starfield, Ruth Streveler, and Khairiyah Mohd Yusof. I am confident that these new chapters and larger collection of contributions by other authors have strengthened the book considerably.

Chapter 1, which is an introduction and overview, was extensively revised to reflect the changing landscape of teamwork and project management. Chapter 2 is new and provides a framework for project management based on the clarity of the goal as well as the clarity of the process. The framing is based on March's (1991) work on exploration versus exploitation and also draws on Wysocki's (2012) *Effective Project Management: Traditional, Agile, Extreme*. Chapters 3 and 4, the teamwork chapters, were updated and expanded. Chapters 5, 6, 7 and 8 are new and contributed by Cliff Whitcomb and Leslie Whitcomb, Russell Korte, Şenay Purzer and Nicholas Fila, and Robert MacNeal, respectively. Each of these chapters represents cutting-edge ideas in teamwork and project management. Chapters 9, 10 and 11, on project management basics, were updated. Chapter 12, on project monitoring and evaluation, was updated to include team functioning and detailed material on team and project charters. Chapter 12, on communication and documentation, was extensively revised by Constance Kampf. Chapters 14 and 16 were updated to include some of the latest technology, as well as speculations on the future of teamwork and project management. Chapter 15, contributed by Curt McNamara, provides an introduction to complex adaptive systems in the teamwork and project management arena. I continue to provide my own Reflections, have added the many new features by others, and encourage you to reflect on your experience and learning and add your stories to dialogues you engage in.

Overall, my goals for readers of *Teamwork and Project Management* are the following:

- To improve your understand of the dynamics of team development and interpersonal problem solving.
- To identify strategies for accelerating the development of true team effectiveness.
- To help you frame the project and team and identify and use an appropriate project management approach.
- To understand the critical dimensions of project scope, time, and cost management.
- To understand critical technical competencies in project management.
- To explore a variety of "best practices" including anticipating, preventing, and overcoming barriers to project success.

As you engage with this book, be sure to continually reflect on what you're learning and how you can apply what you are learning to the projects and teams you work on each day, in classes, on the job, and in social, professional, and community organizations. An important key to success in projects and teams is to routinely work at a "meta level." That means you are simultaneously thinking about the task and how well the team is working. Talk with others about how the projects and teams you're involved with are going, share successes and insights, and work together to identify and solve team problems. The personal story in the accompanying box about "Engineering Problem Solving" describes some of the questions I've grappled with and how I got interested in this project. I encourage you to develop your own stories as you work your way through this book.

One of the messages of the story in the "Engineering Problem Solving" box is the importance of checking a variety of resources to help formulate and solve the problems you encounter. Another message is that, although engineers spend some of their time working alone, engineering is not individual, isolated work. Collaborative problem solving and teamwork are central to engineering. Engineers must learn to solve problems by themselves, of course, but they must also learn to work collaboratively to effectively solve the other 95 percent of the problems they will face as professional engineers. There may be a tendency to think that this 95 percent—this asking questions and searching other sources for the solution—is either trivial or else unrelated

Engineering Problem Solving

I have been involved in engineering, as a student and as a professional, for over 40 years. Frequently I have grappled with the questions, What is the engineering method? Is it applied science? Is it design? As a professor I have struggled with the question, What should my students learn and how should they learn it? These concerns prompted me to address the question, What is the nature of engineering expertise and how can it be developed effectively (Smith, 1988, 2011)?

A study conducted by one of my colleagues (Johnson, 1982) provides valuable insight into the activities of engineers. My colleague was hired to collect protocol from engineering experts while they solved difficult problems. Working with a team of professors, he developed a set of difficult and interesting problems, which he took to chief engineers in large companies. In case after case the following scenario was repeated.

The engineer would read the problem and say, "This is an interesting problem."

My colleague would ask, "How would you solve it?"

The engineer would say, "I'd check with the engineers on the floor to see if any of them had solved it."

In response, my colleague would say, "Suppose that didn't work."

"I'd assign the problem to one of my engineers to check the literature to see if a solution was available in the literature."

"Suppose that didn't work," retorted my colleague.

"Well, then I'd call my friends in other companies to see if any of them had solved it."

Again my colleague would say, "Suppose that didn't work."

"Then I'd call some vendors to see if any of them had a solution."

My colleague, growing impatient at not hearing a solution, would say, "Suppose that didn't work."

At some stage in this interchange, the engineer would say, "Well, gee, I guess I'd have to solve it myself."

To which my colleague would reply, "What percentage of the problems you encounter fall into this category?"

Engineer after engineer replied, "About five percent"!

to engineering. However, working with others to formulate and solve problems and accomplish joint tasks is critical to success in engineering.

Acknowledgments

Many people deserve credit for their guidance in this project. Former students with whom I've taught and worked on project management for many years provided enormous insight into the process of what will work for students and were a source of constant support and encouragement. My heartfelt thanks to my many mentors, and especially to David and Roger Johnson, Billy Koen, and Tony Starfield for generously sharing their insights and enthusiasm and permitting me to stand on the shoulders of these giants. Billy Koen has been an inspiration to me since we first met in the early 80s. His wonderful ideas show up in several places in the book. Anthony M. Starfield, co-creator of the first-year course, How to Model It, and co-author of the book by the same title encouraged me to use the questioning format of the *How to Model It* book to engage the reader. David and Roger Johnson (whose cooperative learning model provides the theoretical basis for this book) generously provided their great ideas and steadfast support.

I thank the hundreds of students who learned from and with me in project management courses for their patience, perseverance, wonderful suggestions and ideas, and interest and enthusiasm in project management and teamwork.

The team at McGraw-Hill, beginning with the initial editors, Holly Stark and Eric Munson, and Byron Gottfried, Consulting Editor, provided guidance throughout. Editors for the second edition, Kelly Lowery and John Griffin, encouraged extensive redesign and the title change from *Project Management and Teamwork* to *Teamwork and Project Management*. Bill Stenquist, editor for the Third edition and new Fourth edition, has been both delightful to work with and demanding. His support for my vision for the future of the book made it possible to increase the length and include six new chapters.

A special note of thanks to my daughters, Riawa Thomas-Smith and Sharla Stremski, who helped with the editing and graphics; and to my wonderful wife, Lila M. Arduser Smith, for her patience and unwavering support.

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Comments and Suggestions

Please send your comments and suggestions to me at ksmith@umn.edu.

Teamwork and Project Management in Engineering and Related Disciplines

Teamwork and Project Management is designed to help you prepare for professional practice in the global economy. Teamwork is receiving increased emphasis from employers, leaders in engineering education, and researchers. The world has gotten smaller and our sense of interdependence has greatly increased; the importance of professional responsibility and ethics has magnified (although engineering ethics has always been central to engineering); and projects (and project-type organizations) are becoming much more common. All these changes, as well as further changes that are likely to occur, highlight the importance of learning, practicing, and continually refining the skills, concepts, principles, and heuristics in this book.

More and more the broader community is calling for engineering graduates who have not only the traditionally expected technical skills and widely sought-after problem-solving orientation, but also the set of six "professional" skills from the ABET list (Shuman, Besterfield-Sacre, and McGourty, 2005). These skills include communication, teamwork, and understanding ethics and professionalism, which Shuman et al. label "process skills," and engineering within a global and societal context, lifelong learning, and a knowledge of contemporary issues, which they designate as "awareness skills."

Thomas Friedman wrote in 2000 that "the world is ten years old." Friedman's central notion was *globalization*, that is, "the inexorable integration of markets, nation-states, and technologies to a degree never witnessed before—in a way that is enabling individuals, corporations, and nation-states to reach around the world farther, faster, deeper, and cheaper than ever before, and in a way that is enabling the world to reach into individuals, corporations, and nation-states farther, faster, deeper, and cheaper than ever before" (p. 9). Four years later Friedman claimed that "the world is flat." He addressed the graduating class at Washington University in St. Louis on May 21, 2004, with the following assertion: "The job world you are entering is an increasingly flat world. That's right. I know that this great scientific university taught you that the world was round. I am here to tell you that the world is flat, or at least in the process of being flattened. That is actually the title of my next book, *The World Is Flat: A Brief History of the 21st Century*. By that I mean the competitive playing field is being leveled. You are entering a world where more people have PCs. More people have Internet connections and the bandwidth to communicate. More people have good educations, and more people have the enabling softwares, like Google, Microsoft Net Meeting, or Instant Messaging, to gain knowledge, to innovate, and to spread new ideas."

Friedman argued that in this increasingly flat world, collaboration and connectivity as well as adaptability and a creative imagination are essential attributes. We're increasing the emphasis on collaboration and connectivity (networking) and creativity and innovation in this edition of *Teamwork and Project Management*.

Friedman (2005) described 10 flatteners, the first three of which provide a platform for collaboration:

1. November 9, 1989: The Berlin wall came down and six months later Microsoft Windows came up.
2. August 9, 1995: Netscape went public.
3. Work Flow Software, such as that supporting around-the-clock design work (sometimes referred to as work that follows the sun).

Interestingly, these first three "flatteners" occurred within the life span of even the youngest engineering college student and they created the need for expanded skill and knowledge sets. Friedman argues that we need to "horizontalize" ourselves, that is, we need to learn how to connect and collaborate with others. Tim Brown (2009), CEO at IDEO, the product design firm, states that IDEO recruits T-shaped people—people with both disciplinary thinking (vertical) strengths and design thinking (horizontal) strengths.

Friedman's latest book (Friedman and Mandelbaum, 2011), *That Used to Be Us: How America Fell Behind the World It Invented and How We Can Come Back*, notes that "Today's major challenges are different." The authors argue that globalization, the IT revolution, deficits and debt, and energy demand and climate change are occuring incrementally, that is, they are creeping up on us. Their formula for addressing the challenges involves focusing on five pillars that together constitute the country's strengths:

1. Providing public education for more and more Americans.
2. Building and continual modernizing of our infrastructure.
3. Keeping America's doors open to immigration.
4. Government support for research and development.
5. Implementation of necessary regulations on private economic activity.

All of these pillars involve projects and teamwork and several of them, numbers 2 and 5 especially, require the involvement and commitment of engineers.

As I was reading Friedman and Mandelbaum's new book, I was reminded of Jane Jacobs' classic work, *The Death and Life of Great American Cities*, and especially how she helped reshape our thinking about urban planning. Jacobs' latest book, *Dark Age Ahead* (2004) argues that North American civilization is showing signs of decline due to the collapse of "five pillars of our culture that we depend on to stand firm," which can be summarized as family and community, education, science, representational government and taxes, and corporate and professional accountability. Note the similarity among the "pillars" and concerns about their demise.

In *A Whole New Mind: Moving from the Information Age to the Conceptual Age*, Dan Pink (2005) makes a compelling case for moving from the knowledge age to the conceptual age. In the conceptual age it is creators and empathizers who will have the most influence! According to Pink the drivers of this change are affluence, technology, and globalization. Note the similarities and differences to Friedman's flatteners.

This is the world in which you'll be working. It is very different from the world I started working in as an engineer in 1969, but it is the world I try to cope with every semester especially with graduate students in two professional masters programs in which I teach, Management of Technology and Infrastructure Systems Management and Engineering. The engineering graduates in these one-day-per-week, two-year programs are working full-time and most of the participants work globally. Their extensive international interaction and collaboration as well as their international travel (both physical and virtual) are indicative of the lives of many if not most engineers in the future.

The essence of the globalization economy (according to Surowiecki, 1997) is this notion: "Innovation replaces tradition. The present—or perhaps the future—replaces the past." Surowiecki's view is shared by the authors of the 2005 National Academy of Engineering report *Assessing the Capacity of the U.S. Engineering Research Enterprise,* who wrote in their introduction, "American success has been based on the creativity, ingenuity, and courage of innovators, and innovation will continue to be critical to American success in the twenty-first century" (p. 7).

Surowiecki argues in a subsequent work, *The Wisdom of Crowds* (2004), that "under the right circumstances, groups are remarkably intelligent, and are often smarter than the smartest people in them." David Perkins (2002) makes similar claims in *King Arthur's Round Table: How Collaborative Conversations Create Smart Organizations.* Perkins' (2002) central question is "What is organizational intelligence, why is it so hard to come by, and how can we get more of it?" (p. 14). His general reply is: "How smart an organization or community is reflects the kind of conversations that people have with one another, taking conversation in a broad sense to include all sorts of interactions" (p. 14). Surowiecki's and Perkins' ideas and recommendations are elaborated upon in this chapter.

The principal goal of this book is to provide you, the reader, guidance on how to engage in intelligent teamwork in engineering contexts that emphasize design and innovation. As we start this journey together, I offer you the following suggestions that will help you get the most from this book. The essence of the suggestions is reflected in the words *activity, reflection,* and *collaboration*. First, I encourage you to engage in the *activities,* especially the exercises, in the book, as they will help you connect with the material and its real-world applications. Second, periodically throughout the book I'll ask you to stop and *reflect.* Take advantage of the opportunity. The goal is to give you a chance to describe to yourself what you already know and to get you to think. Then when you read on about the topic, you'll have a basis for comparing and contrasting. Finally, I encourage you to *collaborate* with others. Working together is the norm in projects. Working together to learn the material in this book will make it easier, and very likely you'll remember it longer.

Ruth Streveler's reflection on a sports metaphor for learning (in the nearby box) will help many readers maximize their benefit from the book.

A Sports Metaphor

Karl and I have worked together for many years on a variety of projects. During the past few years we co-designed and have been co-teaching a course, Content, Assessment and Pedagogy: An Integrated Engineering Design Approach. The course is project based and the participants redesign a course that they are teaching or plan to teach in the future. We use a variety of resources, and for the past few years have been using the book, *Making Learning Whole: How Seven Principles of Teaching Can Transform Education*, in which Harvard psychologist David Perkins uses baseball as a metaphor for explaining exemplary instructional methods. Perkins' seven principles summarized below are relevant and applicable well beyond designing a course. I offer them to you as heuristics for preparing for teamwork and project management.

1. **Play the whole game.** When learning the kind of complex task often involved in project management, it is important to find a way to see the "big picture," the larger context of what you are learning. Because the complexity of the real situation may be overwhelming, Perkins suggests creating a "junior game" which simplifies the situation while maintaining all the elements of the real task. Junior games should be constructed to approximate practice, without getting bogged down with all the details. An example of a junior game in a business context would be creating and running a small business for a short period of time. Even if the business is selling lemonade at a school's sports events, you will still have the experience of learning about market research, customer service, bookkeeping, etc.
2. **Make the game worth playing.** Motivation plays an important role in learning. Find ways to link what you are learning to things that motivate you. Allow your curiosity to flourish. Switch your perspective. Instead of viewing an assignment as being "given" to you, think about how you can use it to learn something that interests you.
3. **Work on the hard parts.** Find ways to deliberately practice aspects of a learning task that are difficult for you. Don't avoid the hard parts—embrace them! Bumps in the road of learning are opportunities to excel! Remember that composers created études that provided creative and beautiful ways for musicians to practice difficult scales. How can you construct your own études? Find inventive ways to practice difficult elements in your learning.
4. **Play out of town.** Applying knowledge in a new setting, called *transfer*, is notoriously difficult to accomplish. You can help yourself transfer what you have learned by thinking of examples of how the target knowledge is used in different domains. Perkins calls this "low road transfer." "High road transfer," which is more robust, is promoted when you strengthen your conceptual understanding of what you are learning and then reflect on how this fundamental knowledge might be used in different ways.
5. **Uncover the hidden game.** When learning in a new area, find ways to discover the "unwritten rules" of that domain. Tap into the tacit knowledge of experts in the field by asking them to talk you through their approach to a problem. Seeing their approach will give you insights into how you can tackle similar problems.
6. **Learn from the team.** Think about how you can *learn from* your teammates. When approaching a project with your team, employ strategies that encourage you to socially construct knowledge through true collaboration, rather than simply dividing to conquer.
7. **Learn the game of learning.** Become aware of the strategies you use to understand, retain, and apply new material. Learning about how you learn (called metacognition) will help you learn more efficiently and effectively.

I hope you will find these seven principles useful. May they help you attain your learning goals!

Ruth Streveler

My goal for this first chapter is to create a context for teamwork and project management in engineering. Let's start by exploring the nature of engineering. But before you read ahead for various answers to the question "What is engineering?" please complete the following reflection.

> REFLECTION What is engineering? What does it mean to learn to engineer in school? What is your experience with engineering? Did you learn about engineering in high school? Do you have a brother or sister, mother or father, or other family relative or friend who is an engineer? Take a minute to reflect on where you learned about engineering and what your impressions of engineering are.
>
> What did you come up with?

What Is Engineering?

Because there are few high school courses in engineering, most first-year students have not had much exposure to engineering. Yet we are surrounded by engineering accomplishments; they are so ubiquitous that we don't notice most of them. One of the foremost thinkers and writers on engineering, mechanical engineering professor Billy Koen, is noted for asking four probing questions of his audiences (Koen, 1984, 2002). The first is this:

1. Can you name one thing in the room in which you are sitting (excluding yourself, of course) that was not developed, produced, or delivered by an engineer?

Koen finds that the question is usually greeted with bewildered silence. I have posed Koen's questions to hundreds of first-year students, and they come up with some great suggestions: the air (but how does it get into the room?), dirt (trapped in people's shoes), electromagnetic radiation (but the lights generate much more than the background). Almost everything that we encounter was developed, produced, or delivered by engineers.

Here is Koen's second question:

2. Can you name a profession that is affecting your life more incisively than engineering?

Again, students name several professions but on reflection note that if it were not for engineering, politicians would have a difficult time spreading their ideas; doctors, without their tools, would be severely limited in what they could do; lawyers wouldn't have much to read; and so forth. Things such as telephones, computers, airplanes, and skyscrapers—which have enormous effects on our lives—are all products of engineering.

Koen's third question is this:

3. Since engineering is evidently very important, can you now define the engineering method for solving a problem?

Many students respond with a puzzled look, as if being asked an unfair question. They note that they have a ready response to the question "What is the scientific method?" Students list things like "applied science," "problem solving," and "trial and error," but very few (over the 20 or so years that I've been asking this question) say "design." Fortunately, the portion answering "design" is increasing.

If you were to ask practicing engineers what the engineering method is, they would likely respond "Engineering is design!" A group of national engineering leaders has said:

> Design in a major sense is the essence of engineering; it begins with the identification of a need and ends with a product or system in the hands of a user. It is primarily concerned with synthesis rather than the analysis which is central to engineering science. Design, above all else, distinguishes engineering from science. (Hancock, 1986)

Distinguished engineers such as von Kármán and Wulf support this claim:

> A scientist discovers that which exists. An engineer creates that which never was.
>
> —Theodore von Kármán (1881–1963)

> The engineering method is design under constraints.
>
> —Wm. Wulf, past president, U.S. National Academy of Engineering

Koen (1971, 2003) argued that "The engineering method is the use of heuristics to cause the best change in a poorly understood situation within the available resources." He updated his definition at a presentation in 2011 (Koen, 2011). He argued that "The engineering method (design) is the use of state-of-the-art heuristics to create the best change in an uncertain situation within the available resources."

We'll explore the concept of engineering design next, and save Koen's fourth and final question for the end of the chapter. But first, let's explore the history of the term *engineer* and elaborate on engineering as a profession.

The term *engineer* is derived from the French term *ingénieur.* Vitruvius, author of *De Architecture*, written in about 20 B.C.E., wrote in the introduction that master builders were ingenious, or possessed *ingenium*. From the eleventh century, master builders were called *ingeniator* (in Latin), which through the French, *ingénieur,* became the English *engineer* (Auyang, 2004). Recapturing some of the ingeniousness of engineering is one of our goals in this edition.

Referring to engineers as "master builders" reminds me of another French connection, *bricoleur*. A *bricoleur* is a handyman or handywoman who uses the tools available to complete a task (Kincheloe and Berry, 2004). Using the tools available to complete a task is a central idea in this book, and engineer as *bricoleur* captures it very well.

A distinguishing feature of engineering is that it is a profession (Davis, 1998). Graduates of accredited engineering programs are expected to abide by the Codes of Ethics of Engineers for their respective professional organization. The Codes of Ethics consist of two parts, Fundamental Principles and Fundamental Canons. Here are these elements from the American Society of Civil Engineers (ASCE) (www.asce.org):

Fundamental Principles: Engineers uphold and advance the integrity, honor, and dignity of the engineering profession by:

1. Using their knowledge and skill for the enhancement of human welfare and the environment;
2. Being honest and impartial and serving with fidelity the public, their employers, and clients;
3. Striving to increase the competence and prestige of the engineering profession; and
4. Supporting the professional and technical societies of their disciplines.

Fundamental Canons:

1. Engineers shall hold paramount the safety, health, and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.
2. Engineers shall perform services only in areas of their competence.
3. Engineers shall issue public statements only in an objective and truthful manner.
4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.
5. Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others.
6. Engineers shall act in such a manner as to uphold and enhance the honor, integrity, and dignity of the engineering profession.
7. Engineers shall continue their professional development throughout their careers, and shall provide opportunities for the professional development of those engineers under their supervision.

In 1996 the ASCE added "sustainable development" to its Fundamental Canons, and in 2004 the *Civil Engineering Body of Knowledge for the 21st Century* added four outcomes to the eleven ABET outcomes:

1. An ability to apply knowledge in a specialized area related to civil engineering.
2. An understanding of the elements of project management, construction, and asset management.
3. An understanding of business and public policy and administration fundamentals.
4. An understanding of the role of the leader and leadership principles and attitudes.

Please notice that three of the four additional outcomes involve "soft skills" or what are increasingly being referred to as professional skills (Shuman, Besterfied-Sacre, and McGourty, 2005).

The Fundamental Canons have a long history, and can be traced in part to the Code of Hammurabi (ca 1700 B.C.E.):

> If a builder builds a house for a man and does not make its construction sturdy and the house collapses and causes the death of the owner of the house, then that builder shall be put to death. If it destroys property, he shall restore whatever is destroyed, and because he did not make the house sturdy he shall rebuild the house that collapsed at his own expense. If a builder builds a house for a man and does not make its construction meet the requirements and a wall falls, then that builder shall strengthen the wall at his own expense.

The reflection by David Radcliffe (in the nearby box) on the death of engineer Roger Boisjoly articulates how difficult it can be to uphold these principles.

The Courage to Engineer

Roger Boisjoly, a mechanical engineer who worked at Morton Thiokol, passed away in January 2012, although news of his death did not reach the mainstream media immediately. Why is this significant? Roger Boisjoly exemplified the moral courage that it takes to be an engineer. Based on his technical expertise and supporting evidence, he became concerned that the seals on solid booster rockets, made by Morton Thiokol, and which power the space shuttle on take-off, might fail in very cold weather. He strenuously warned his management and that of NASA of the possible consequences if the Challenger was launched in the very cold conditions that prevailed on the morning of January 28, 1986. His warning was not heeded, and we all know what happened.

But rather than being seen as a hero who tried to sound the alarm, Boisjoly was ostracized and suffered significantly as a result of being a true professional. An article in the *New York Times* has outlined some of the pressure he endured (for this, see Martin, 2012).

Engineering is not just applied mathematics and science; it is a deeply value-laden enterprise that involves choices that have real consequences for people and the planet. Decisions we make as engineers about what we choose to work on and how we choose to do things have an unavoidable moral and ethical dimension. I recommend you explore this case of an engineer who had the moral courage to stick by his professional opinion and hang the personal or social consequences; see the Online Ethics Center for Engineering and Research: http://www.onlineethics.org/cms/7123.aspx.

In a famous minority opinion to the official report on the Challenger disaster, Appendix F, Nobel Prize–winning physicist Richard Feynman concluded with the following statement: "For a successful technology, reality must take precedence over public relations, for nature cannot be fooled." Even if we have a perfect set of calculations, if these do not model the actuality of nature, then there could be dire consequences. To engineer is to have the courage to make critical judgment calls.

Even if we are not called upon to display the moral courage shown by Roger Boisjoly in raising the alarm about the Challenger, we all have a role to play. In his *New York Times* article, Douglas Martin (2012) recalls that Boisjoly "was sustained by a single gesture of support. Sally Ride, the first American woman in space, hugged him after his appearance before the commission. 'She was the only one,' he said in a whisper to a *Newsday* reporter in 1988. 'The only one.'"

Food for thought and cause for deep reflection on what it takes to engineer.

David Radcliffe

An article by Sheppard, Colby, Macatangay, and Sullivan (2005) exploring the question, "What is engineering practice?" opens with the following statement: "Professions, such as engineering, medicine, teaching, nursing, law, and the clergy share a common set of tenets; namely to:

1. provide worthwhile service in the pursuit of important human and social ends;
2. possess fundamental knowledge and skill (especially an academic knowledge base and research);
3. develop the capacity to engage in complex forms of professional practice;
4. make judgments under conditions of uncertainty;
5. learn from experience; and
6. create and participate in a responsible and effective professional community."

David Billington (1985) summarizes one of the challenges of professional practice as follows: "Engineers are always confronted with two ideals, efficiency and economy, and the world's best computer could not tell them how to reconcile the two. There is never 'one best way.' Like doctors or politicians or poets, *engineers face a vast array of choices every time they begin work, and every design is subject to criticism and compromise."*

James Adams (1991) argues that engineering school does not necessarily prepare people for professional practice (and may even deter some):

> Engineering: In School and Out—Engineering schools recognize the overlap in industry between engineering and science, and they design their curricula accordingly. Engineering education is strongly theoretical and geared toward math and science. This is partly because of the natural interests of people who are attracted to a professorial life and who set the curriculum. It is also because engineers can learn the more applied portions of their field on the job, while they are unlikely to learn math and science on the job. But because the activities of the engineering student have little relation to the activities of many practicing engineers, it is likely that engineering education discourages some students who would make excellent engineers and encourages other who will not. *The mentality to do well in engineering schools emphasizes the ability to work problem sets and get right answers. In engineering, there are never right answers and [there are] few problem sets.*

Engineering Design

If design is the essence of engineering, the next question is, What is design? What comes to mind when you consider the term *design*? Do you think of product design (such as automobiles), architectural design, set and costume design (as in theater), or interface design (as in computer)? Take a moment to collect your thoughts on design.

ABET, the group that accredits engineering programs, defined engineering design as "the process of devising a system, component or process to meet a desired need" (ABET, 2000).