CHAPTER

1 Why Should You Learn More About Creativity and Innovation?

In a world of forces that push toward
the commoditization of everything,
creating something new and different
is the only way to survive.
—*Geoff Colvin, journalist*

Objectives:

After studying this chapter, you will be able to:

- Articulate this text's purpose
- Explain the potential connection between your desired success and significance and this text's content
- Describe *creativity* and *innovation* and develop examples of each
- Illustrate six reasons engineers need to be creative and innovative as one way to answer the question posed by the chapter's title
- Discuss the historic and linguistic connections between engineering and creativity

1.1 PURPOSE OF THIS TEXT

The purpose of this text is to help you acquire creativity and innovation knowledge, skills, and attitudes (KSAs) so that you can work smarter and achieve more individual and organizational success and significance in our rapidly changing world. These

KSAs will enable you to develop ideas for improved or new structures, facilities, systems, products, or processes.

This is a practical book offering knowledge and tools that enable you and your teams to work smarter—partly by being much more creative and innovative—and, as a result, advance your career, strengthen your organization, and provide more effective service. Numerous exercises at the end of chapters enable you to apply knowledge gained and use new tools, often as part of a group. While studying engineering, you can apply much of the presented information and techniques, and can later use those and other resources when you enter professional practice. The book's content is also applicable outside of study and work in your personal, family, and community life and could help you develop a creative-innovative philosophy of life.

By learning and using creativity and innovation basics as a student, you are likely to acquire habitual ways of thinking and doing that will enable you to become increasingly creative and innovative as you advance in your formal education and then progress in your career. Just as we can habitually do things the way they are traditionally done, we can also instead habitually approach our studies, work, and life with a fresh perspective.

If you become more creative and innovative, are you assured personal and/or organizational success and significance? Not necessarily. A great idea not implemented is merely a novelty; an innovative concept not pursued is an opportunity lost. However, by placing more emphasis on creativity and innovation and by learning fundamentals, obtaining tools, and practicing, you can generate new ideas and follow through to earn personal and organizational benefits.

Remember the advice of lecturer and writer Ralph Waldo Emerson: "Build a better mousetrap and the world will beat a path to your door." It turns out that he didn't say it that way. He did say: "If a man has good corn, or wood, or boards, or pigs, to sell, or can make better chairs or knives, crucibles or church organs than anybody else, you will find a broad, hard-beaten road to his house, though it be in the woods" (Bartlett 1964). Not quite as catchy but still the same message—creativity/innovation can yield personal and organizational benefits.

1.2 ACHIEVING YOUR DESIRED SUCCESS AND SIGNIFICANCE

Success refers to your personal gain, such as your current high grade point average and perhaps later the money you earn, the car you drive, and the title you acquire. In contrast, "significance" refers to your positive impact on others and society during your formal education and extending throughout your career and life. Success is about "stuff"; significance is about legacy.

PERSONAL: MEANING OF SIGNIFICANCE

As an example of significance, consider this reflection. I happen to live half time near a project I managed years ago and, as a result, I frequently see "my" project serving its intended functions and adding to the quality of life in the community. Very few people remember that I had anything to do with this project. That's not important. What is important to me is the satisfaction of seeing the project work. While I and others enjoyed some personal professional successes on the project, they pale relative to observing its significant public benefit.

Another way of looking at success and significance is to think about your epitaph. Do you want it to say something like "he drove a Porsche" or "she had a prestigious title"? Or, in contrast, would you prefer an epitaph like this: "He or she left the world a better place than he or she found it"? William James, the psychologist and philosopher, tells us that "The great use of life is to spend it for something that will outlast us." I suspect that most of us want both; we want to achieve both success and significance. Where we differ is in the relative amounts.

I raise the success–significance issue near the beginning of this book because of its connection to creativity and innovation. If you embrace the success–significance idea, then whatever your desired relative portions of each, reaching your goals will be determined in part by value added in all that you do as a result of your creativity and innovation.

1.3 CREATIVITY AND INNOVATION DEFINED AND ILLUSTRATED

Because of their importance throughout this text, let's define two terms: *create* and *innovate*. Then, some examples are presented that will illustrate their meaning.

1.3.1 Definitions

While researching for this book, I found many definitions for creativity and innovation and their related verbs, create and innovate. My hope was to find some commonality among the definitions and to distill the essence of each term. However, the definitions are quite varied. Accordingly, for the purposes of this book, I offer the following definitions:

- **Create:** Originate, make, or cause to come into existence an entirely new concept, principle, outcome, or object
- **Innovate:** Make something new by purposefully combining different existing principles, ideas, and knowledge

These definitions, which were influenced by similar ones offered by engineer and educator consultant Herrmann (1996), teacher and consultant Kao (2007), consultant Nierenberg (1982), and engineering educators Beakley, Evans, and Keats (1986), suggest that *innovate* and *create* differ by degree of originality. Whereas innovation is, in effect, "integrative and aspirational" (Kao) and "grounded in already-invented products or processes" (Herrmann), creativity is "grounded in originality" (Herrmann) and "coming up with something [completely] new" (Nierenberg).

We might think of *innovate* and *create* as actions that differ by degree of newness, where to create is the ultimate. From a practical perspective, we as individuals or teams are much more likely to innovate than to create. Creativity, as defined here, is rare.

1.3.2 Examples

Next, *create* and *innovate* are illustrated with examples. Besides further clarifying the essentials of the two actions, the following historic anecdotes begin to suggest some of the characteristics of creative and innovative individuals, such as being inquisitive, being willing to experiment, and being persistent.

Creativity

As an example of creativity, consider Velcro, invented in 1948 by Swiss electrical engineer George de Mestral. This hook-and-loop fastener is made of Teflon loops

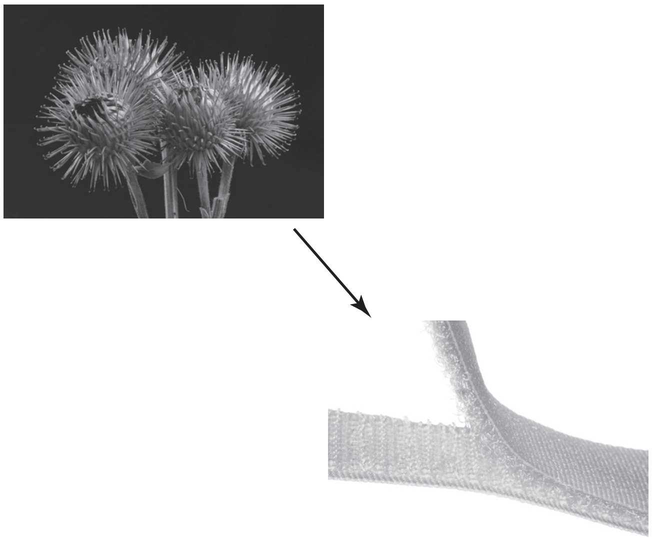


Figure 1.1
An inquisitive electrical engineer studied burrs under a microscope and creatively conceived and later developed Velcro.
(Denis Junker/Fotolia; Fuzzphoto/Fotolia)

and polyester hooks, and the company is headquartered in Manchester, New Hampshire. De Mestral was returning from a hunting trip with his dog and cockleburs (seeds) were on his clothes and on his dog's fur (Figure 1.1). When de Mestral examined the burrs under a microscope, he saw many stiff, hooked spines that caught on almost anything. Seeing this, he thought about the possibility of repeatedly binding two materials (one with hooks and one with hoops) in a reversible manner.

De Mestral worked ten years to develop a manufacturing process, while recognizing that many people did not support his idea. He persisted and commercialized the now almost omnipresent fastener. The word *Velcro* is a combination of two other words: the French words *velour*, meaning fabric with a soft nap, and *crochet*, which is needlework in which loops of thread or yarn are interwoven with a hooked needle. The manner in which Velcro was conceived is now called biomimicry or biomimetics—that is, mimicking nature, a topic that is treated in Chapter 7 (Lee 2012; Bellis 2014).

Have you ever had a "brilliant idea" while returning from hunting, taking a shower, or walking on campus—and then failed to follow up? Or tried to follow up and failed to have people take you seriously? Ideas and information shared in this book will enhance your ability to generate creative and innovative ideas and make them happen.

Innovation

For an example of innovation, consider Johannes Gutenberg developing the reusable-type printing press (Figure 1.2), which he used to begin printing books in the 1450s, including the Bible in about 1456. He borrowed ideas from the following sources (Boorstin 1985; Murray 2009; Van Doren 1991):

- Woodblock printing, which had been used for eleven centuries in China. This process involved a sheet of paper placed on an inked block.
- Weapon and coin forging, which went back to Roman times. According to Boorstin, "Gutenberg's crucial invention was his specially designed mold for casting precisely similar pieces of type quickly and in large numbers."
- The binder's wooden screw press, which was probably an innovative adaption of the screw presses used by winemakers and olive oil producers and those used to process linen.

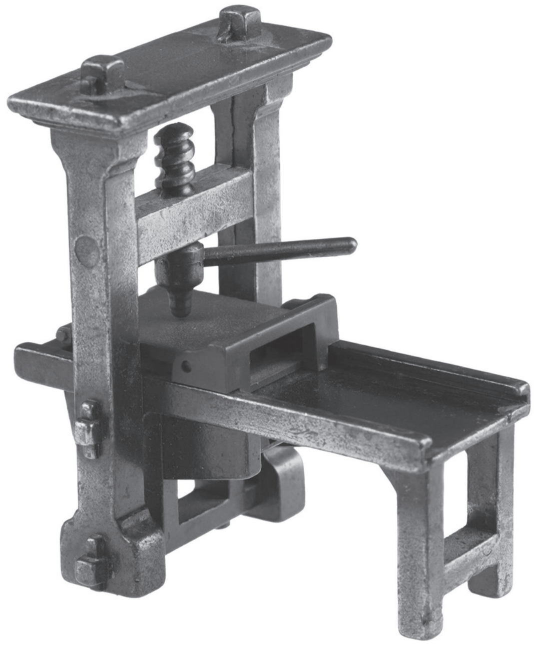


Figure 1.2
Gutenberg innovatively combined the screw press from wine making and olive oil production, Chinese woodblock printing, and Roman weapon and coin forging to develop the reusable-type printing press.
(Jan Schneckenhaus/Shutterstock)

Sorts, the individual letters, were produced by pouring liquid metal into the specially designed molds. The letters were arranged into type cases to make up pages, which were inked and printed. This process was a huge printing improvement over handwritten manuscripts and full-page woodblock printing.

Gutenberg was motivated mainly by trying to make a living, but his innovative reusable-type printing press transformed society and helped advance the Renaissance. "Once only the rich had been able to buy handwritten manuscripts. Suddenly, any scholar could own books," according to historian Van Doren (1991), who went on to say that those now readily accessible books "were filled with ideas that had been forgotten, ignored, or suppressed for centuries." In terms of a leap forward into access to ideas and information, Gutenberg's fifteenth-century innovative access to books was like the twentieth-century arrival of the World Wide Web accessed via the Internet.

1.4 WHY ENGINEERS SHOULD STUDY CREATIVITY AND INNOVATION AND WHY NOW

From the beginning of recorded history and all over the globe, individuals we would now label *engineers* have met the basic needs of communal society (Van Der Zee 1989; Walesh 1990; Weingardt 2005; White 1984). Going forward, that role will remain essentially the same; however, the stage on which that role is played will change dramatically. With the help of various thinkers, let's explore that new stage, with the hope that you will see the need to enhance your creative and innovative ability and thus be prepared for your role as an "actor" on that stage. In the following sections, you'll find six reasons to study creativity and innovation, starting now.

1.4.1 The Grand Challenges for Engineering

According to the National Academy of Engineering (NAE), engineering faces fourteen Grand Challenges in the twenty-first century (National Academy of

Engineering 2014). The challenges, which were announced in 2008, are listed here; note their variety, breadth, and implied depth:

1. Make solar energy economical.
2. Provide energy from fusion.
3. Develop carbon sequestration methods.
4. Manage the nitrogen cycle.
5. Provide access to clean water.
6. Restore and improve urban infrastructure.
7. Advance health informatics.
8. Engineer better medicines.
9. Reverse-engineer the brain.
10. Prevent nuclear terror.
11. Secure cyberspace.
12. Enhance virtual reality.
13. Advance personalized learning.
14. Engineer the tools of scientific discovery.

Based on the following statement, the Academy is confident that the engineering community will rise to the challenges: "The world's cadre of engineers will seek ways to put knowledge into practice to meet these grand challenges. Applying the rules of reason, the findings of science, the aesthetics of art, and the spark of creative imagination, engineers will continue the tradition of forging a better future." Note that the NAE believes that meeting the fourteen challenges will require that tomorrow's engineers possess many and varied qualities, including the "aesthetics of art" and "the spark of creative imagination."

1.4.2 After the Knowledge Age: The Conceptual Age?

As shown in Figure 1.3, advanced societies have evolved through the agricultural and industrial ages and into the knowledge age. Pink (2005, 2007) believes that the current knowledge age will be superseded in the United States and other advanced countries by what he calls the *conceptual age*, or the *engage the left and right brain age*—that is, the whole-brain age (Figure 1.3).

Conception means a new beginning or original idea. According to Pink, the conceptual age is "an era in which mastery of abilities that we've overlooked and undervalued" will be required (Pink 2007). Examples of these increasingly valued abilities, which reside partly or largely in the brain's right hemisphere, include

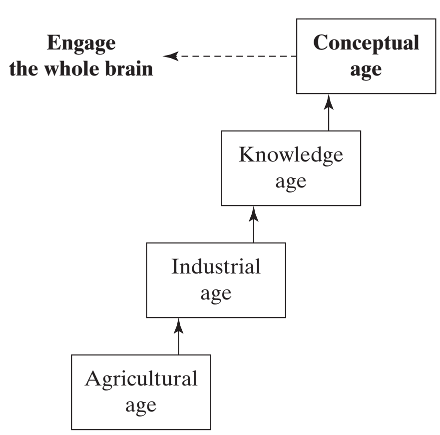


Figure 1.3
The knowledge age may be superseded by the conceptual age, with a premium on original ideas and concepts.

visualization, innovation, creativity, synthesis, empathy, and helping people find meaning.

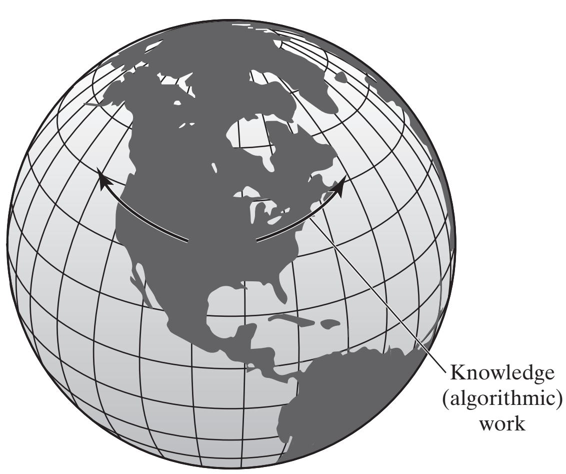
Success in the knowledge age primarily requires left-hemisphere or left-brain abilities; many engineers are prime examples of knowledge workers. They logically and sequentially obtain and analyze data, calculate, and design to meet requirements. In a similar fashion, other knowledge age professionals rely heavily on their left hemispheres, such as accountants preparing tax returns, lawyers researching lawsuits, radiologists reading diagnostic data, software experts writing code, and stockbrokers executing transactions.

Pink argues that although left-brain abilities will be necessary in the looming conceptual age, they will not be sufficient. A half-brain will be necessary, but not sufficient; a whole brain will be needed if one is to succeed in the United States and other advanced countries. Work that "can be reduced to a set of rules, routines, and instructions," the functions of the left brain, is "migrating across the oceans. . . . Now that foreigners can do left-brain work cheaper, we in the US must do right-brain work better" (Pink 2007). As suggested by Figure 1.4, the Internet and a growing number of smart, ambitious, and English-speaking workers in India, China, the Philippines, Singapore, and other countries facilitate this outsourcing process.

According to columnist Brooks (2014), "Computers are increasingly going to be able to perform important parts of even mostly cognitive jobs, like picking stocks, diagnosing diseases, and granting parole." Computers also increasingly will be used in engineering to design products, processes, structures, facilities, and systems, as suggested in part by engineer and author Steiner (2012) in his book *Automate This.* In the conceptual age, leading-edge engineers will focus less on solving problems and more on resolving complex issues and finding and developing opportunities. "In similar fashion, accountants will serve more as financial advisors, lawyers will concentrate more on convincing juries and mastering the nuances of negotiation, and stockbrokers will become financial advisors to help people realize their dreams" (Walesh 2012b). Work is increasing in cognitive complexity, and our educational system (including that for engineers) must adjust. This includes placing more emphasis on creativity and innovation knowledge, skills, and attitudes (Pink 2007); knowing how to address complex issues, problems, and opportunities (IPOs); and being adept communicators (Levy and Murname 2005).

Given the material abundance enjoyed in the United States and other well-developed countries, Pink (2007) also argues that society will increasingly place

Figure 1.4
Knowledge work will increasingly move across the oceans to be done by a growing number of smart, ambitious, and English-speaking professionals in other nations.



"a premium on the less rational sensibilities of beauty, spirituality, emotion. . . . Liberated by this prosperity [attributed to our very successful left-brain oriented work] but not fulfilled by it, more people are searching for meaning." These "sensibilities" also engage the whole brain. If Pink is correct, you will need a whole-brain approach to achieve success and significance in tomorrow's professional world.

1.4.3 After the Knowledge Age: The Opportunity Age?

Offering an intriguing view of the future, Naisbitt (2006) writes, "When you're looking for the shape of the future, look for and bet on the exploiters of opportunities, not the problem solvers." He claims that each of us tends to embrace one of two poles: stasis or dynamism, stability or evolution, predictability or surprise. Naisbitt suggests that problem solvers have one foot in the present and tend to have the other foot in the past (Figure 1.5). After all, today's problems originate in the past. In contrast, opportunity exploiters also live in the present and have one foot there, but tend to have the other foot in the future—the place of promise.

PERSONAL: MAINTAINER OR BUILDER?

As a follow-up to Naisbitt's "two poles" comment, I have concluded that each of us tends to be mostly a maintainer or a builder. Both outlooks are necessary to provide leadership, management, and production within our various organizations. Maintainers care for physical assets and develop and gradually improve processes, whereas builders search for opportunities, see new directions, and lead major changes.

Maintainers and builders exhibit different knowledge, skills, and attitudes (KSA) sets, especially the *attitudes* part. For example, although both appreciate what has been accomplished so far in a given organization, maintainers are generally satisfied subject to making continuous improvements in response to changing conditions. In contrast, builders are in a perpetual state of dissatisfaction and "just know" there is a better way.

Hopefully, this simplified model will help you to find your place on the maintainer–builder spectrum. Regardless of where you are, this text's creativity and innovation principles and tools will be useful. Apply the principles and use the tools if you are a maintainer and want to move toward being a builder or if you are already a builder (an opportunity seeker) and want to move further in that direction.

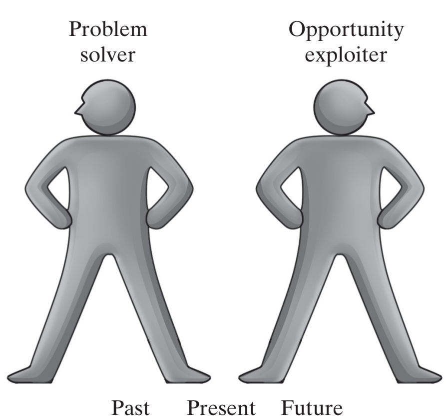


Figure 1.5
Problem solvers tend to look to the past while working in the present, whereas opportunity exploiters work in the present and look forward.

Most professions, such as engineering, law, and medicine, focus on solving problems and do a superb job. Engineering's focus on and proficiency in problem solving reflects in part engineering curricula's emphasis on problem solving and, to a lesser extent, problem prevention. Near the end of classes, I vividly recall hearing professors say things like, "For next class, solve Problems 1, 3, and 9 at the end of the chapter." Later, as a professor, I said the same thing! This approach is pedagogically sound in that principles or theories introduced, described, and discussed in lecture can be applied and further understood and appreciated by doing the homework. Furthermore, a brief discussion of the homework at the beginning of the next class period could further elucidate the topic. Understanding and applying theories and solving problems are essential aspects of engineering practice.

The teaching–learning method just described tends to be left-brained. It's linear, as in: present theory, assign problems which use the theory to reach a solution, provide students with everything needed to understand the problems, use theory to solve problems, get "the answer," and discuss how the successful students got the answer.

Engineers, beginning as students, can also perform functions besides problem solving, such as creatively and innovatively identifying and pursuing opportunities. However, rarely are students explicitly exposed to finding and pursuing opportunities, especially at the undergraduate level. This text seeks to help change that by offering creativity and innovation principles and tools that will help you be an opportunity seeker and therefore able not only to thrive in the future but also to help build it (Walesh 2012c).

1.4.4 After the Knowledge Age: The Wicked Problems Age?

Teacher, consultant, and innovation expert Kao (2007) is concerned that the United States may feel smug about its preeminence. He questions the idea that other countries will continue "to settle for being followers, mere customers, or imitators of our fabulous creations," and he asserts that "innovation has become the new currency of global competition as one country after another races toward a new high ground where the capacity of innovation is viewed as a hallmark of national success." Kao goes on to say that the security of the United States is at stake.

Continuing with the need to innovate, author Wagner (2012) states that the United States must provide "the new and better products, processes, and services that other countries want and need," and to do this "we must out innovate our economic competitors." Engineer Augustine (2011), former chairman and CEO of Lockheed Martin, says: "Innovation is the key to survival in an increasingly global economy. Today we're living off the investments we made over the past 25 years. We've been eating our seed corn. . . . We're losing our edge."

Kao's 2007 book *Innovation Nation* diagnoses the US situation, describes innovation best practices from around the globe, and explains how innovation works at the national level. Kao then proposes a US strategy to become what he calls *Innovation Nation*, "a country with a widely shared, well-understood objective of continuously improving our innovation capabilities in order to achieve world-changing goals." Innovation Nation would teach creativity and innovation to its children and young people as a matter of policy, or (to use Kao's words), would "fix the U.S. education system."

Kao envisions applying our vast resources to stimulate innovation on a huge scale. He says that America should "be in the wicked problems business," which means taking on global issues such as "climate change, environmental degradation, communicable diseases, education, water quality, poverty, population migration, and energy sufficiency." Kao believes that creative and innovative solutions to the wicked problems will be the most consequential breakthroughs of the twenty-first century. These solutions will generate "an enormous amount of social and economic value" and enable Innovation Nation—that is, the United States—to do good and do well. You can be a player in the wicked problems business if you learn and apply whole-brain principles and tools.

1.4.5 Stewardship with Aspiring Engineers and Their Gifts

As a result of working extensively in the academic and practice sectors, I've had numerous opportunities to review the credentials and accomplishments of high school and college students and observe the behavior of engineering students and engineering practitioners. You are among the brightest members of society and therefore have great potential to contribute to society. For years, I've contemplated ways to help aspiring and practicing engineers practice better stewardship with those gifts.

Now I know that one way to achieve more effective stewardship is to help student and practicing engineers gain further appreciation for the power of the right hemispheres of their brains and then show them how to engage that hemisphere to supplement their already strong left hemispheres. For this gifted group (you and your colleagues) we should settle for nothing less than a whole-brain approach, as laid out in this text.

I'm not saying that engineers are not creative and innovative—that the glass is half-empty. No, the creativity and innovation glass is half-full for most of us, but we could do more because we have the required intellect and can-do attitude. We should be more creative and innovative because of the importance of our work and because more creativity and innovation will enable us to do even more with limited resources and provide even better services. My hope is that as a result of this text and in the spirit of personal stewardship, you will at least experiment with higher levels of creativity and innovation. You have the potential within you.

HISTORIC NOTE: CONSEQUENCES OF A NATION NOT PRACTICING STEWARDSHIP WITH ENGINEERING

In his book *The Ghost of the Executed Engineer*, Graham (1993) tells the story of the Russian Engineer Peter Palchinsky. Born in 1875, Palchinsky earned an engineering degree in 1900 and went on to become "one of the best-known engineers in Soviet Russia." However, he increasingly opposed some of the positions of the Communist party because they conflicted with his intentions, which were "to assist his country by increasing its industrial strength and the welfare of its people." He believed that under socialism engineers should be major players in creating economic development plans. Increasing conflict led to Palchinsky's execution under the Stalin regime in about 1929 as a "leader of an anti-Soviet conspiracy."

In 1948, the Stalin regime arrested the twenty-two-year-old Russian inventor Genrich Altshuller and sentenced him to a twenty-five-year imprisonment in Siberia because he wrote to Stalin to criticize the Soviet Union's lack of inventive work. While in prison, he collaborated with other imprisoned intellectuals and further developed his creativity and innovation ideas. He was released from prison in 1954, after Stalin died. In 1984, he published his book about the theory of inventive problem solving known as TRIZ, which is one of the creativity and innovation tools presented in Chapter 7 (Altshuller 1996).

Graham concludes that the Soviet Union, which met its demise in 1991, failed as a modern industrialized nation even though it had a huge number of engineers and immense natural resources because of "misuse of technology and squandering of human energy," including its engineering talent. The Soviets failed to practice good stewardship with their engineering community's creative and innovative resources.

Besides offering examples of poor stewardship, the Palchinsky and Altshuller stories (which reflect very common occurrences during the Stalin era) offer another lesson. They are grim reminders that the change typically associated with creative and innovative thought and action is likely to invoke negative reactions, at least initially. Chapter 5, Section 5.5 elaborates on the often strong reluctance to change and offers remedies.

1.4.6 The Satisfaction of Doing What Has Not Been Done

Experience suggests that for most of us the magnet attracting us to engineering was excitement about creating or building something that, at least in our mind, had never existed. This pull probably started when we were children and built towers with blocks, castles with sand, and houses with cardboard boxes or drew with pencils, painted with brushes, sculpted with clay, wrote music, and modified games. These were our *originals*.

With time, study, and practice, we tended to broaden our understanding of creating and building originals. In retrospect and professionally, I value having been involved in teams that built or created original structures, facilities, systems, computer simulation models, fluid flow models, organizations within organizations, continuing education delivery methods, and approaches to engineering education.

We quietly value these professional creations and innovations because of their utility; they enhance the quality of life for many. Herbert Hoover, author, humanitarian and thirty-first US president, said this about engineering: "It is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege" (Van Der Zee 1989).

We're good at math and science, as people say, but that knowledge and skill might also prepare any of us to be productive as a banker, mathematics teacher, certified public accountant (CPA), physicist, casino manager, or auto mechanic. At a deeper level, we value the thrill of doing what has never been done, of building originals, and doing it for the benefit of many. "I do not think there is any thrill that can go through the human heart like that felt by the inventor as he sees some creation of the brain unfolding to success"; that's how the excitement of building originals was expressed by engineer Nikola Tesla, whose creative and innovative efforts include commercialization of alternating current motors, generators, and transmission lines. Therefore, my sixth and last reason for why you should study creativity and innovation and why you should start now as part of your formal education and continue on into practice is to pursue that urge to create and build originals, serve society, and enjoy the satisfaction of doing so even more proactively.

PERSONAL: ATTRACTION TO THE PROFESSION

I vividly recall my mother taking me across the highway in front of our northern Wisconsin home when I was a small boy so that I could build on the beach where a creek flowed into Lake Michigan. Near or in the creek, I constructed levees, dams, lakes, channels, and wells. Early in college, I learned that if I became a civil engineer I could continue to "play" with water, help design and build water-related facilities, have the satisfaction of being part of originals, make the world a better place, and get paid for it—which I subsequently did for over three decades.

1.4.7 Closing Thoughts about Studying Creativity and Innovation

Section 1.4 argues that you should study creativity and innovation starting now, as part of your formal education, and then continue into professional practice. Six reasons are offered: meeting the Grand Challenges; doing more conceptual work because algorithmic work is moving to increasingly capable personnel in developing countries; placing more emphasis on pursuing opportunities; addressing wicked problems; practicing better stewardship with your intellectual gifts; and experiencing the satisfaction of doing what has not been done.

Being more creative and innovative will require personal growth, including learning the basics of how the human brain functions (Chapter 2), using whole-brain tools (Chapters 3, 4, and 7), overcoming obstacles (Chapter 5), acquiring or strengthening certain personal characteristics (Chapter 6), being inspired by what others have done (Chapter 8), and learning how to implement your ideas (Chapter 9). If you make that effort, you are likely to achieve your desired success and significance, as suggested by Augustine (2009) when he said, "There will always be demand for superbly educated engineers who are capable of performing in an innovative, creative, and entrepreneurial fashion."

1.5 ENGINEERING AND CREATIVITY: THE HISTORIC AND LINGUISTIC CONNECTIONS

1.5.1 The Historic Connection between Engineering and Creativity/Innovation

As suggested by the following list and illustrated in Figure 1.6, we can note many and varied creative and innovative engineering achievements from the beginning of recorded history onward, including the following (Walesh 2012b):

- The Egyptian pyramids
- Tools developed during the Iron Age
- The Great Wall of China
- Athens' Parthenon
- The Roman Pont du Gard (in what is now France)
- China's Grand Canal
- The printing press
- The steam engine
- The telegraph system
- The transcontinental railroad in the United States
- Powered flight
- Mass production of automobiles and untold other consumer and producer products
- The Panama Canal

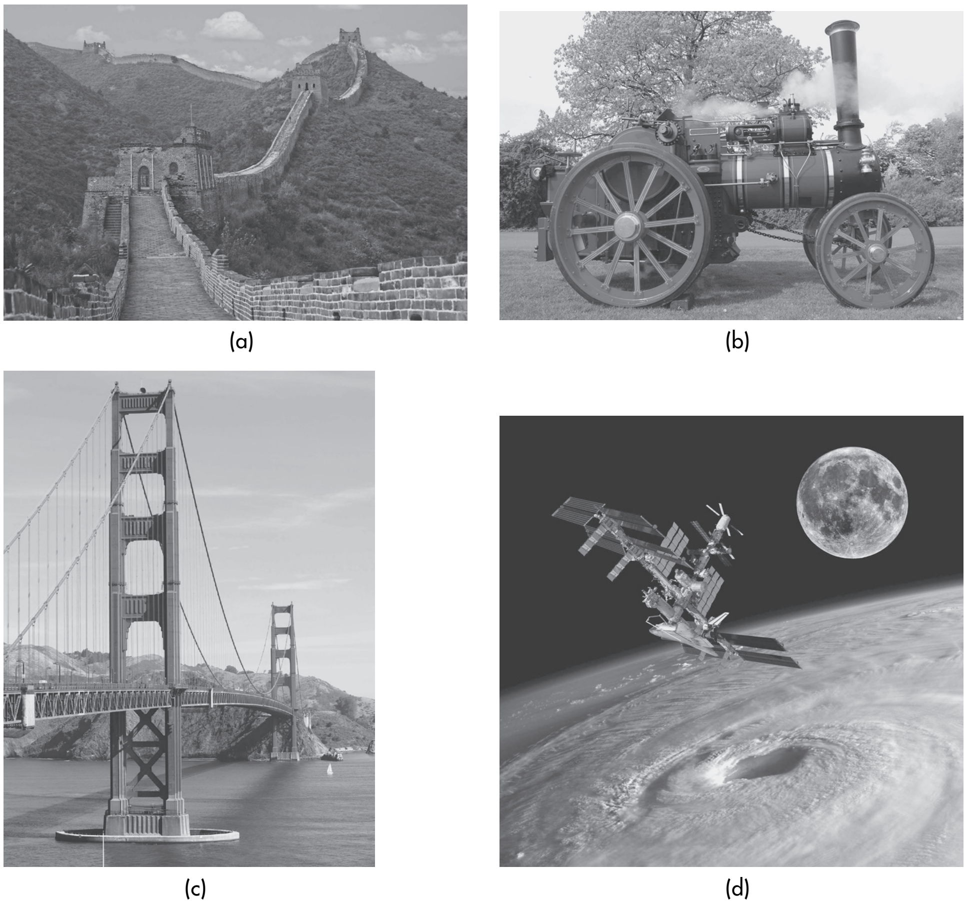


Figure 1.6
Engineering's accomplishments indicate that the profession's history is one of creativity and innovation.
((a) JonRob/Fotolia; (b) Windsor/Fotolia; (c) Oleksandr Dibrova/Fotolia; (d) Nikonomad/Fotolia)

- San Francisco's Golden Gate Bridge
- Computers
- Commercial jet aircraft
- The Eurotunnel connecting England and France
- Many electronic devices interconnected via the Internet (aka, the Internet of Things)
- Robotic prosthetics
- The International Space Station

These examples illustrate that engineering is historically connected to creativity and innovation.

1.5.2 The Linguistic Connection between Engineering and Creativity

As explained in Section 1.4.6, the possibility of creating and building attracted many of us to engineering. The words *create* and *engineer* are closely intertwined linguistically. Engineering professor Petroski (1985) and engineering practitioner Florman (1987) both explored the origins of the word *engineer*. Although they followed somewhat different routes and arrived at slightly different conclusions, they agreed that the word has its roots in *creativity*.

Petroski (1985) stated that *engineer* originally meant "one (a person) who contrives, designs, or invents." That is, *engineer was synonymous with creator*, and he noted that this use preceded by a century the idea of an engineer as one who manages an engine. According to Petroski, the association between *engineer* and *engine* began in the mid-1800s with the emergence of the railroad as the metaphor of the industrial revolution. Petroski concluded his exploration of the origins of the word *engineer* by noting that even today there is a "confusion of the contriver and the driver of the vehicle." More recently, Petroski (2011) indicated that he had moved more toward Florman's thinking, as outlined ahead, and noted that the association between *engineer* and *engine* dates to well before the 1800s.

Florman (1987) traced *engineer* back to the Latin word *ingenium*, which meant a clever thought or invention; the word was applied in about AD 200 to a military battering ram. That is, *engineer was synonymous with that which was created.* Later, in medieval times and during the Renaissance, the words *ingenieur*, *ingeniere*, and *ingeniero* (French, Italian, and Spanish, respectively) came into use, originally referring to those who designed and built military machines such as catapults and battering rams. In English, the word progressed from the fourth through seventeenth centuries as *engynour*, *yngynore*, *ingener*, *inginer*, *enginer*, and, finally, *engineer*.

Thus, Petroski and Florman agreed that the word *engineer* has deep roots in creativity: in contriving, inventing, designing, and creating (Walesh 2012b, 2012a). As engineers, we should be inspired to create, in part by virtue of the historic evolution of the name of our profession.

VIEWS OF OTHERS: ENGINEERS AND CREATIVITY/INNOVATION

"Scientists define what is," according to aeronautical engineer von Karman, and "engineers create what never has been." Engineering professor Petroski (1985) refers to creativity this way: "It is the process of design, in which diverse parts of the given world of the scientist and the made-world of the engineer are reformed and assembled into something the likes of which nature had not dreamed, that divorces engineering from science and marries it to art." Engineering professor Cross (1952) said, "The glory of the adaption of science to human needs is that of engineering." According to professor Billington (1986), achieving an aesthetic result in design requires efficiency and economy plus "imagination—a talent for putting things together in unique ways that work, that are beautiful, personal, and permanent."

1.6 INTRODUCTION TO EXAMPLES OF CREATIVITY AND INNOVATION

To illustrate the creativity and innovation process and its benefits, this text contains ninety highly varied examples. The ones that I share are based primarily on my research and secondarily on my experience working on projects. In searching for and selecting examples, I sought variety in the following areas:

- **Contexts and circumstances:** For example, burrs stuck on coats and creation of Velcro; a snake bite and the invention of the Weed Eater; the Chicago stockyards and the first automobile assembly line; row crops and the creation of television; misinterpretation of two words and invention of the telephone; and the falling apple versus the "stationary" moon leading to discovery of universal gravitation.
- **Professions and specialties:** For example, creative/innovative work of individuals from various disciplines: scientists, constructors, architects, a dance instructor, biologists, a sand paper salesperson, and a road commissioner.

- **Technical and nontechnical developments and constraints:** For example, the low-tech but highly effective, like the Q-Drum; the high-tech and productive, like the moving automobile assembly line; and the useful but nontechnical, like the keystone habit—all being successful in spite of and/or fueled by various constraints.
- **Benefits:** For example, cost reduction, enhanced aesthetics, global impact, improved personal and organizational productivity, improved health and welfare, increased profit, less public impact during construction, quicker response, and reduced pollution (see Table 5.1 for many specific examples of the variety of benefits resulting from creativity and innovation).

This text draws widely from within and outside of engineering, for two reasons:

- **Many and varied process lessons to be learned:** Many of the creativity and innovation lessons learned from a variety of contexts and circumstances and widely varying professions and specialties are applicable to our work. For example, biomimicry (which is introduced in Section 7.2 and which prompted the commercial development of Velcro) can be a powerful stimulant within the engineering arena. Similarly, TRIZ, which is described in Section 7.9, is particularly powerful in technically oriented engineering work.
- **Many and varied potential applications:** Second, the potential for creativity and innovation lies within all professions and specialties and within all aspects of a given profession or specialty, including technical and nontechnical elements. When we as engineers think about being more creative and innovative, we include our technical challenges. Let's also consider being more creative and innovative within the other functions of our organizations, such as education and training, human resources, community involvement, finance, marketing, organizational structure, and simply finding ways to work smarter.

Failure to recognize possibilities
is the most dangerous and common mistake
anyone can make.

—*Mae Jamison, astronaut*

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EXERCISES

Note: These exercises are intended to gently jar you from conventional thinking.

1.1 USES OF PAPER CLIPS: This exercise (adapted from Bonasso 2013 and Buzan 1984) encourages interactive, imaginative thinking by members of a group.

- **a.** You have a small supply of paper clips. Give each member of your group a paper clip.
- **b.** For two minutes, write down all the uses your group can think of for one or more paper clips. Do this without searching the Internet.
- **c.** How many uses did you think of?
- **d.** Now do an Internet search and list additional uses. How many more did you find?

1.2 ALTERNATING GLASSES: The purpose of this exercise (adapted from Restak 2009) is to work as a team and carry out a task with a fresh perspective.

- **a.** As shown in Figure 1.7, six drinking glasses stand in a line. The left three are filled with water, and the right three are empty.
- **b.** Determine how you could get the full and empty glasses to alternate (full, empty, full, empty, full, empty) by moving only one glass.

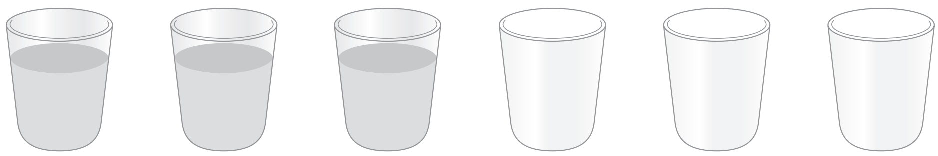


Figure 1.7
Six drinking glasses.

1.3 EQUATIONS: This exercise (adapted from Restak and Kim 2010 and Chrysikou 2012) will help you see in new ways—to see what you have not seen before.

a. The equations ahead, each of which uses Roman numerals, are incorrect.
b. Think of the straight elements as equal-length match sticks, Popsicle sticks, or toothpicks.
c. Correct each equation by moving just one stick. You may not discard a stick.
d. Review the following two examples:

Example 1
Incorrect: VI = VII + I
Correct: VII = VI + I
The single move: Remove one stick from the VII on the right of the equal sign and relocate it to the VI on the left of the equal sign.

Example 2
Incorrect: IV = III − I
Correct: IV − III = I
The single move: Remove one stick from the equal sign, forming a minus sign, and add it to the minus sign on the right to form an equal sign.

e. Ten incorrect equations follow. Make each one correct with a single move.

1. III = III + III
2. IV = III + III
3. V = III − II
4. VI = VI + VI
5. VIII = VI − II
6. IV = IV + IV
7. II = III + I
8. VII = II + III
9. VI = IV − II
10. IX = VI − III

1.4 EQUILATERAL TRIANGLES: The purpose of this exercise (adapted from Raviv 2004) is to suggest that repeated success in one mode should not stop us from considering other modes.

a. Think of equilateral triangles and how you might create them. You have a total of six Popsicle sticks to use and need to create equilateral triangles by having the sticks touch each other only near their ends.
b. Use three sticks to create one equilateral triangle.
c. Use five sticks to create two equilateral triangles.
d. Finally, use six sticks to create four equilateral triangles.

1.5 USES OF PAPER CLIPS WITH STIMULATION: This exercise (adapted from Bonasso 2013 and Buzan 1984) encourages interactive, imaginative thinking by members of a group stimulated by a list of objects.

a. You have a small supply of paper clips. Give each member of your group a paper clip.
b. For two minutes, write down all the uses your group can think of for one or more paper clips. Do this without searching the Internet.
c. While thinking about uses, visualize items from the following list of objects (the words "orange" through "cat" are from Buzan 1984):

orange; watch; window; leaf; table; radio; light bulb; handbag; pen; tire; ear; potato; kitchen; pigeon; bottle; shoe; book; cup;

cloud; pepper; glass; chair; garden; Germany; wood; rain; water; holiday; dinner; garage; tea; tree; house; wine; maid; newspaper; pub; banana; mirror; cat; Christmas tree; insect; TV; GPS; shopping; lottery ticket; car

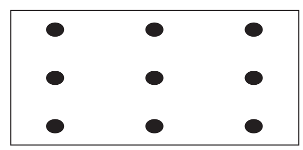
d. How many uses do you have?
e. Now do an Internet search and list additional uses. How many more did you find?

1.6 GEOMETRIC SHAPES AND EQUAL PARTITIONS OF THEM: This exercise (adapted from Raviv 2004) challenges you to visualize shapes within shapes. Think of some common geometric shapes and how we might operate on them to create smaller versions of them.

a. Draw an equilateral triangle. Partition it into four equilateral triangles.
b. Draw a symmetrical trapezoid. Partition it into four identical pieces.
c. Draw a hexagon. Partition it into eight identical pieces.
d. Draw a rectangle. Partition it into eight identical pieces.

1.7 CONNECT THE DOTS: Examine the nine dots in Figure 1.8 and then connect all of them with four straight lines. Cross each dot only once, don't lift your pen or pencil from the paper, and connect the lines only at their ends.. (adapted from Restak 2009).

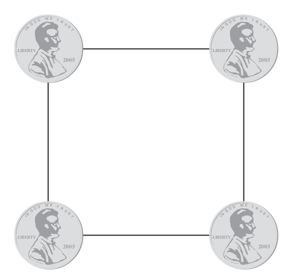
Figure 1.8
Connect these nine dots with four straight lines connected end-to-end.



1.8 SHRINKING SQUARE: Use four coins to define a square, as shown in Figure 1.9.

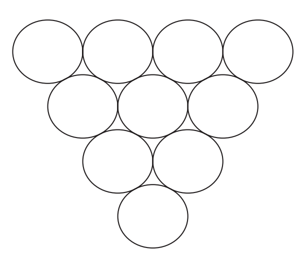
By moving only two coins, create a square that is smaller than the original square (adapted from Restak 2009).

Figure 1.9
By moving only two coins, create a square that is smaller than the original square.



1.9 CHANGING DIRECTION: Change locations of three of the ten billiard balls (Figure 1.10) to make a triangle that points up instead of down (adapted from Fogler, LeBlanc, and Rizzo 2014).

Figure 1.10
Make a triangle that points up by changing the location of three billiard balls.



1.10 CREATIVITY/INNOVATION, NATURE OR NUTURE: Engage five to ten people (fellow students or employees, faculty, administrators, others) in a brief conversation about creativity and innovation. Without getting bogged down in the definitions of the terms, ask each person if he or she thinks creativity and innovation are mostly inborn capabilities or mostly learned capabilities—that is, mostly nature or nurture. Regardless of the answer, ask for examples or other support. Summarize your findings in a brief report. If you do this assignment, try to refer back to it later when you read Section 5.3.

1.11 SUCCESS AND SIGNIFICANCE, YOURS: The intent of this exercise is to encourage you, the aspiring student engineer or young engineering practitioner, to creatively think about what you aspire to become or achieve in the future. Imagine how you see yourself five years down the line in terms of "Success" and "Significance". The results of this exercise should be confidential, unless you want to share them with your instructor or other trusted persons. In order to do the exercise, the student can make a table and use the following questions as row headers of the table:

- What skills (or talents) do you have?
- What activities do you like to do?
- What or how do you contribute to others?
- What are the underlying values?
- Whom do you admire and why? Think of this in terms of a) your personal life and b) your professional life
- Whom do you want to be like and why? Think of this in terms of a) your personal life and b) your professional life

Now try to mix and match the points and think creatively about your success and significance goals. Then identify five actions that you need to take to move towards your goals within the next year. Try to think in a creative and innovative manner. Whatever success you have with this exercise, by the time you finish reading this text, you will be well equipped to think creatively and innovatively and to use that knowledge and skill to more effectively chart and then navigate your future.

1.12 CAPABILITIES OF TOMORROW'S ENGINEER, YOU: Although this exercise does not relate directly to the overall theme of this text, it will introduce you to or remind you of the National Society of Professional Engineers (NSPE) and its *Engineering Body of Knowledge* (EBOK), published in 2013. Furthermore, you have made a tentative choice of engineering as a profession. This bonus exercise, by describing the capabilities of tomorrow's engineer, can help you confirm or refine your choice.

Suggested tasks are as follows:

a. Search for and download the EBOK report using its name and/or NSPE.
b. Read the two-page executive summary, and note in particular the definition of the EBOK—that is, what you should *know* and *be able to do* when you enter into professional engineering practice.
c. Read Chapter 4 with an emphasis on the second and third columns in Table 1, which summarize capabilities (the *know* and *be able to do* items) and their relevance to professional engineering practice.

d. Using a paper or electronic copy of Table 1, label each of the thirty capabilities with either *Y* (for yes, this capability fits my current view of engineering) or *N* (for no, this capability does not fit my current view of engineering).

e. For the capabilities that you labeled *Y*, write a paragraph describing how seeing these expected and/or familiar capabilities may affect your choice to study engineering—for example, strengthens, weakens, or no impact.

f. For the capabilities that you labeled *N*, write a paragraph describing how being exposed to these less familiar capabilities may affect your choice to study engineering—for example, strengthens, weakens, or no impact.

g. Summarize your overall conclusions and take appropriate action.