CHAPTER

6 Characteristics of Creative and Innovative Individuals

The role of the human is not to be dispassionate,
depersonalized, or neutral . . . emotive traits are rewarded:
the voracious lust for understanding, the enthusiasm for work,
the ability to grasp the gist, the empathetic sensitivity to
what will attract attention and linger in the mind.

—David Brooks, columnist

Objectives:

After studying this chapter, you will be able to:

- Illustrate seven characteristics often exhibited by creative/innovative individuals
- Analyze your profile relative to the seven characteristics and infer your readiness for creativity and innovation
- Explain your strengths and articulate your weaknesses relative to your creativity/innovation potential
- Show further insight into how to apply the Medici Effect
- Recognize at least ten creative/innovative individuals and describe their contributions

6.1 INTRODUCTION TO CHARACTERISTICS

Section 1.4 provided six reasons that you should study creativity and innovation starting now, as part of your formal education, and continuing through your career: meeting 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 enjoying the satisfaction of doing what has not been done before.

Being more creative and innovative—taking a more whole-brain approach—requires personal growth, including learning the basics of how the human brain functions (Chapter 2), obtaining whole-brain tools (Chapters 4 and 7), and overcoming obstacles (Chapter 5). Enhancing creativity and innovation also requires recognizing, strengthening, or acquiring certain personal characteristics conducive to creativity and innovation, as discussed in this chapter, and perhaps being further inspired by the Chapter 8 case studies and the implementation ideas offered in Chapter 9.

I trust that you welcome learning about these personal qualities because you want to be more creative and innovative and wonder if you have it in you. Furthermore, in keeping with the Section 4.6 discussion of the Medici Effect, when you are invited to join a team or have the opportunity to form one, I hope you want diversity. The seven personal characteristics discussed in this chapter are a set of diversity factors that are important to consider when forming a team or, more broadly, establishing an organization.

I've studied what research has revealed about the characteristics of creative and innovative individuals in various professions and specialties. I've also reflected on my experiences and observations. Some of the findings are to be expected and others may be surprising. At best, we are talking about favorable tendencies—not a definitive personality profile prescription. For example, as you will soon see, innovative individuals tend to be empathetic—but of course, not all empathetic people are innovative. Few of us will be strong in all of the characteristics that I describe. However, each of us can determine the extent to which we do exhibit some of the characteristics, consider the possibility of embracing more of them, and bring appropriate characteristics to bear as situations require.

6.2 EMPATHETIC

The creative and innovative person is *empathetic*—that is, he or she recognizes the wants and needs of others. More specifically, that person thinks about ideas that may help fulfill those wants and/or needs (Canales 2011). Innovation educator Wagner (2012) defines empathy as "the ability to imagine the world from multiple perspectives and having an attitude that puts others first." From an engineer's perspective, *others* might be existing or potential clients, customers, owners, or colleagues who may be down the hall or halfway around the globe.

PERSONAL: MAJOR DAILY EFFORT TO OBTAIN POTABLE WATER

My wife and I visited Tanzania a few years ago. We were immediately shocked and saddened to notice that many people, mostly women and children, spent a good part of their day carrying containers of potable water from streams and community wells to their homes, often leading to debilitating back and neck injuries resulting from carrying heavy loads, frequently on their heads. In general, the load for an individual is limited at best to about four gallons (or 33 pounds), which could mean many trips each day for a family (Innovative Concepts Group 2014).

Figure 6.1
In some developing countries, people—mostly women and children—spent a good part of their day carrying containers of water from sources to their homes.
(DiversityStudio/Fotolia)

6.2.1 Q Drum Meets a Major Need

How could the major load-carrying problem in Tanzania (Figure 6.1) be solved? How could the weight per trip be increased and the number of trips be reduced at minimal cost?

One answer is the Q Drum, shown in Figure 6.2, which addresses the problem of reducing the load while increasing the volume (by a factor of four) by rolling the

Figure 6.2
The Q Drum addresses the challenge of reducing the water-carrying load for individuals, increasing the volume they can transport, reducing the number of trips, and making their lives more tolerable.
(P J Hendrikse/MCT/Newscom; CB2/ZOB/WENN/Newscom)

water in a simple cylindrical vessel (GreenUpGrader 2014). The vessel is a wheel; the wheel is a vessel. The idea of the Q Drum is credited to Piet Hendrikse and his brother Hans, who empathetically watched South African natives use wheelbarrows and old water drums to transport drinking water (Murray 2011).

A Q Drum carries 13.2 gallons and weighs about 120 pounds when filled. The drums are manufactured in Johannesburg, South Africa, and cost about $70 US dollars. The challenge shifts from the design of the drum to raising funds to purchase and distribute them. "The people that need them can't afford them and must rely on people who can afford them but don't need them" (Innovative Concepts Group 2014).

6.2.2 Additional Examples of Empathy-Driven Creativity and Innovation

Recognizing wants and needs enables us to help others and maybe do it in a creative/innovative manner. Many instances of known or implied empathy in action appear in this book. For example, in addition to the Q Drum, the invention of the weed eater, masking tape, and a special baby incubator (all of which are discussed later in this chapter) were initially motivated by empathy.

Biologist Medina (2008) recalls a shoe store he visited when he was five years old that had a front door with three handles: low, middle, and high. He described it as "a door [he] could actually reach" and went on to observe that anyone, "regardless of the strength or age of the customer," could reach a handle. This anecdote suggests that when we plan or design a structure, facility, system, product, or process, we should empathetically put ourselves in the shoes of intended users and search for creative/innovative—and maybe simple—ways to meet their needs. It also illustrates a pattern: innovation is often simple, in retrospect, and often low tech.

Speaking of being aware of wants and needs of others, Schultz, CEO and chairman of Starbucks, said, "We're in the people business serving coffee, not the coffee business serving people" (Behar 2009). Let's paraphrase that for our profession: "We are in the people business serving engineering, not in the engineering business serving people."

6.3 STUDIOUS

As used here, *studious* is broadly defined to mean observant, curious, and desirous to learn. Being studious includes zealously digging deep for new knowledge. Former educator turned consultant Wagner (2012) refers to the "exponential growth of information" and says that "all successful innovators have mastered the ability to learn on their own in the moment" and then "apply the knowledge in new ways." Presumably, their education taught them how to learn. According to Samuel Johnson, English lexicographer and writer, "Curiosity is the permanent and certain characteristic of the vigorous mind"—and, might I add, the whole-brain mind.

6.3.1 Always a Student

Study is essential in our rapidly changing world. Individually and organizationally, we must avoid exhausting our intellectual capital (Sanborn 2006). The creator or innovator is a perpetual student of things and people who, while continuing to develop his or her area of expertise, also observes, reads widely, engages diverse individuals in conversation, asks questions, participates in seminars and webinars, travels, plans new experiences, and seeks varied assignments.

The capital letter *T* nicely captures the essence of being studious. The vertical line represents one's specialty, which results from focused study and provides expertise to help resolve challenges. The horizontal line reflects the studious person's range of interests, knowledge, and skills and enables him or her to recognize, value, and integrate the different and potentially supportive expertise of others.

Curiosity may have killed the cat, but curiosity stimulated by observation cultivates creativity and innovation. Recall electrical engineer de Mestral's curiosity about the burrs that were attached to his and his dog's coat, the miniature hooks he discovered with his microscope that could attach to a surface bearing hoops, and the resulting creation of Velcro, as discussed in Section 1.3.2. Think also about Joseph Priestley's interest in what happens when living things are sealed in glass jars and the resulting discovery of oxygen (Section 3.6.3).

Creative and innovative people frequently ask questions (Canales 2011) motivated by their observations and curiosity. Sometimes, the frequency and/or intensity of the questions borders on annoying, especially when they challenge the status quo. That may be a small price to pay for the resulting creative/innovative thinking. Consider some examples of such questions:

- We've developed a great system to quickly repair products that come off the assembly line with flaws. Shouldn't we invest as much effort in finding and fixing the causes of those flaws?
- Why do we always wait for our competitors to use new technology or offer new services before we do?
- This process requires major manual effort. Could we automate it or write software to do it? (If this software-oriented topic interests you, read *Automate This* by engineer Steiner [2012].)
- Why don't we give selected personnel bonuses at the beginning of the year conditioned on defined performance, with the provision that if those individuals do not perform during the year, the bonuses would be taken away at the year's end? This unusual idea is based on the loss aversion phenomenon, which means that we typically dislike losing what we have more than not getting what we want (Brooks 2014).
- Why are my major course assignments thrown together at the last minute so that they do not reflect my best effort?
- Most of what our consulting firm does is routine, algorithmic. Aren't we at risk? Shouldn't we be trying to provide higher-level services that other firms are not providing?
- If we announced tomorrow that we were closing our business, government agency, university, or professional society who would notice and why?
- Why do we make the same mistakes over and over and over? How can we break this pattern?

PERSONAL: ONE WAY TO BE A STUDENT

Especially after you enter engineering practice, you may feel that you do observe and are curious, but that you don't have time to study! A participant in one of my webinars said the following about the list of study materials I provided: "With everyone working fifty to sixty hours per week, this reading becomes another item at the bottom of an ever-expanding to-do list."

That's like being too busy driving across the country to stop and buy gas (Clarke and Crossland 2002). You need to refuel, especially if you want to be creative and innovative. Refueling means staying current, but it also means satisfying your observations and curiosity. You owe it first to yourself, then to your employer, and then to the clients and stakeholders you serve. Take and make the time to study what you have observed and what captures your curiosity!

Let me share a mechanism I've frequently used to "make the time" to study something I've observed that has stimulated my curiosity. Select a topic that interests you and about which you want to learn much more, and set up a forum at which you will share what you do not yet know. For example:

- As a student member of a senior project team, volunteer to design an intriguing laboratory apparatus for your project, even though the topic is new to you, and commit to doing it in one month.
- As a co-op student, sign up to give a lunchtime presentation at your temporary employer one month from now to speak about a newly developing technology you recently heard about but do not fully understand.
- As a practitioner, submit an abstract to present a paper at next year's state geotechnical conference about a subsurface exploration technique that is used in your firm and about which you want to learn more.
- Also as a practitioner, join a committee of a professional or business society and volunteer to take on a specific task or function related to a topic that piqued your curiosity.

When we make these kinds of commitments, we are relying on a basic human characteristic: We do not want to embarrass ourselves. Therefore, we will do the study necessary to follow up on what we have observed and are curious about and learn much in the process. It works for me!

6.3.2 Leonardo da Vinci: Exemplar of Studiousness

Based on my experience and research for this book, no one was more observant, curious, and desirous to learn than artist, scientist, and engineer Leonardo da Vinci (Figure 6.3). His breadth and depth of curiosity are evident in his writings, his drawings and paintings, and the testimonials of those who knew him. About seven thousand pages of his notes and drawings, which is estimated to be about half of what he produced, still exist, along with about fifteen of his paintings. He was born in 1452 out of wedlock, near the tiny village of Vinci, Italy, about one day's travel by horse from Florence. Poor and raised mostly by his mother, da Vinci had little formal education, partly because his illegitimacy prevented him from entering the cathedral schools connected with churches.

Fortunately, he was apprenticed at the age of fifteen to a master sculptor and painter, Andrea del Verrocchio, in Florence, which started his painting career. His early artistic success introduced him to a community of artists, scientists, poets, mathematicians, philosophers, and financiers, in addition to less well-known skilled craftsmen that the powerful Medicis had assembled in Florence, marking the beginning of the Renaissance. The stage was set for da Vinci to become the ultimate perpetual student. His search for knowledge was reflected in his belief that if someone had information he wanted, he went to them and asked for it and his view that knowledge of all things was within his reach (Gelb 2004; Shlain 2014; Wallace 1966).

Let's consider some examples of da Vinci's curiosity, boundless studiousness, and creative and innovative results, all of which are based on books by Gelb (2004), Shlain (2014), and Wallace (1966). His interest in music led him to

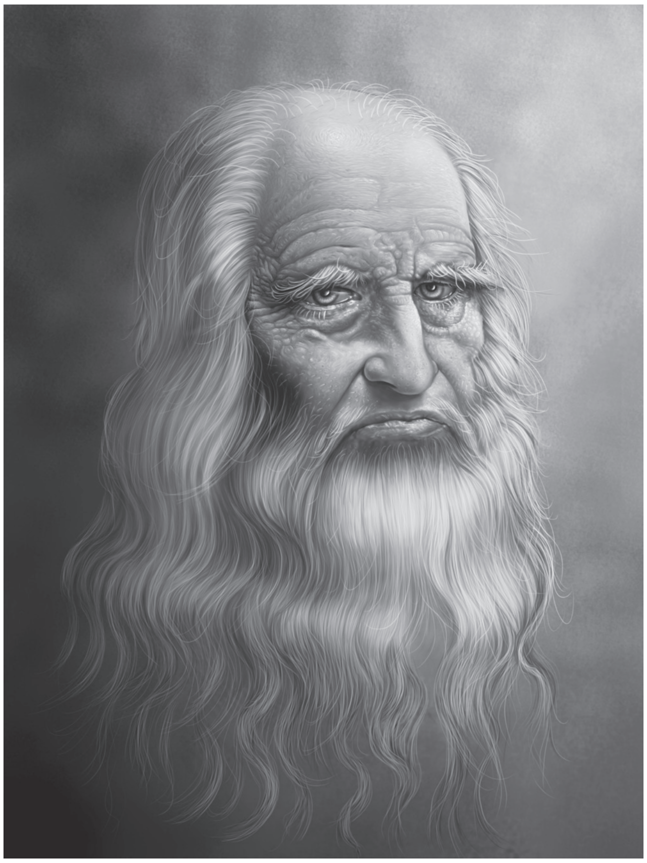


Figure 6.3
Artist, scientist, and engineer da Vinci exemplifies studiousness.
(Mates/Fotolia)

design, craft, and play musical instruments, and he enjoyed paradoxes and wrote books of riddles.

Da Vinci was a superb and trend-setting artist. He showed other artists how to beautifully portray three-dimensional effects with a two-dimensional medium. He championed strongly contrasting areas that were illuminated with those that were shadowed, and he introduced the idea of having the sky in the background be brightest on the horizon and gradually become darker with elevation. He worked in varied media, such as pen and ink, silverpoint (using a silver point on a surface prepared with a primer), frescoe, chalk, pencil, and paint, and sometimes used more than one on a project. However, his favorite medium was pen and ink because he could quickly alternate between drawing something and then annotating it, the result of which is evident in most of his drawings.

His fascination with human anatomy motivated him to dissect more than thirty human cadavers and many animal corpses. He conducted the first documented autopsy, was the first to diagnose arteriosclerosis, and can be considered pathology's founder. As a result of these investigations, da Vinci was the first artist to create highly detailed drawings of the inside of the human body. He used cross sections and exploded views, and he showed the same muscular structure from varying viewpoints on the same page (Figure 6.4), simulating what a moving viewer would see. His cross-sectional drawing of the human skull was the first in anatomy's history.

He became interested in what we now call *cartography*, as evidenced by his detailed maps of parts of Italy, which accurately depicted the landscape as would be

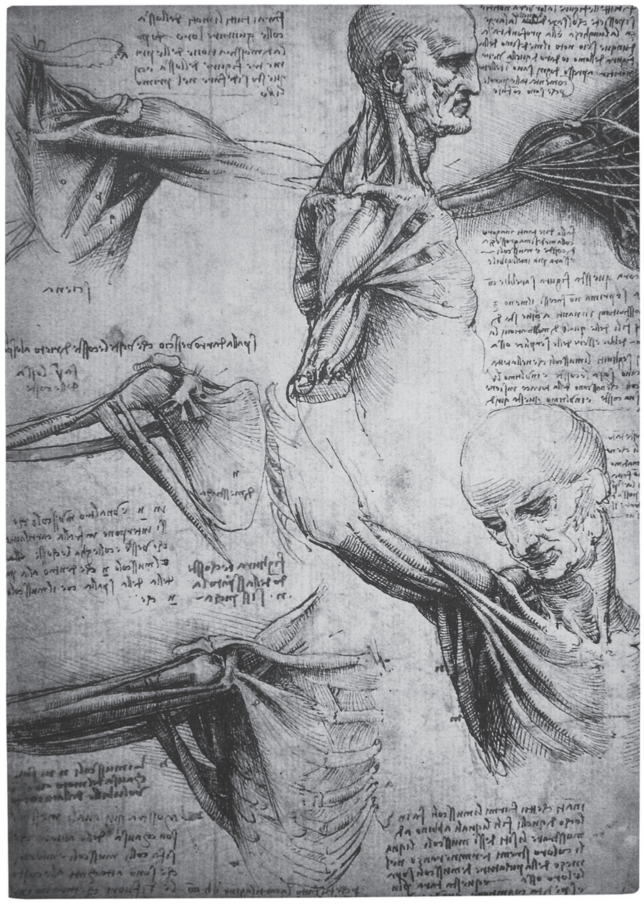


Figure 6.4
Based on his autopsies, da Vinci creatively depicted muscular structure from various viewpoints.
(Kmiragaya/Fotolia)

seen from a high altitude. Artistic zeal led da Vinci to develop a means of depicting distant objects when painting landscapes. His technique, called *sfumato* and widely used today, involves using less distinct borders—a misty and hazy effect—and more muted colors for distant landscape elements.

We engineers often use Newton's three laws of motion, which were described in the seventeenth century. Almost two centuries earlier, da Vinci described the essence of Newton's first law (an object tends to stay at rest or in motion) and third law (action and reaction). He also described the essence of the principle of conservation of mass, another foundation of engineering analysis and design. By observing water waves, da Vinci correctly postulated that when a wave moves through a medium, the molecules of the medium do not transfer with the wave. He established the basis for wave theory.

Leonardo da Vinci's observational powers, curiosity, and engineering-like desire to meet human needs resulted in many original ideas and ideas for inventions, some of which have come to fruition. For example, he suggested the possibility of contact lenses, conceived of windmills as power sources, provided a design for a double-hulled ship (an idea that eventually became the standard for oil tankers), and provided ideas for scissors and folding furniture. He also offered ideas for the machine gun, a huge crossbow, a bombshell, an army tank, a parachute, the helicopter (Figure 6.5), a bicycle, ball bearings, the universal joint, an anemometer, pontoon bridges, a fortress, swing bridges, life preservers, diving suits, a cathedral

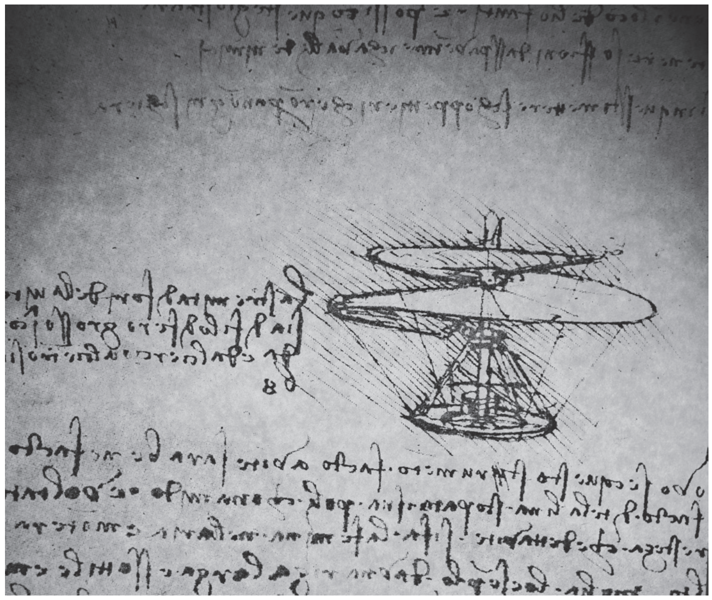


Figure 6.5
Da Vinci used freehand detailed drawings annotated with his unusual backward (right to left) writing to present his creative ideas, such as for the helicopter.
(Janaka Dharmasena/Fotolia)

dome, waterway locks, stone-cutting machines, shoes for walking on water, and metal-boring machines.

6.3.3 Philo Farnsworth: Crop Rows and Television

In 1920, an observant and curious fourteen-year-old farm boy, Philo Farnsworth, observed neat parallel rows of crops on his uncle's Idaho farm. This caused him to think of electronically capturing an image in line-by-line slices, transmitting the slices, and reassembling them into the original image. He shared the concept (illustrated in Figure 6.6) with his high school chemistry teacher, who Farnsworth later credited with providing key inspiration and knowledge.

Farnsworth persisted, continued his study and experimentation, and, at the age of twenty, demonstrated the first working television, which used electronic scanning of both the pickup and display devices. As you may have guessed, the father of television was just beginning his creative/innovative work: He eventually received over 130 patents for his many and varied inventions (Brigham Young University High School 2014; Michalko 2001). Dhillon (2006) mentions the invention of the mechanical television—a very different approach—in Great Britain at about the same time, in 1926.

As is often the case, one invention leads to another. Farnsworth's 1920s creation of television was built on Crooke's 1878 invention of the cathode-ray tube in Great Britain (Dhillon 2006) and possibly the invention of the mechanical TV. In turn, Farnsworth's television prompted another creation: Sarnoff, leader of the Radio Corporation of America (RCA), developed a television broadcasting system that brought black-and-white television to consumers beginning in 1939 (Carlson and Wilmot 2006).

6.3.4 Arthur Morgan: Twentieth-Century Renaissance Engineer

Engineer Arthur Morgan (1878–1975) was an unusually creative and innovative person. His accomplishments include the following (Leuba 1971):

- Authoring new drainage laws for Minnesota
- Founding an engineering firm

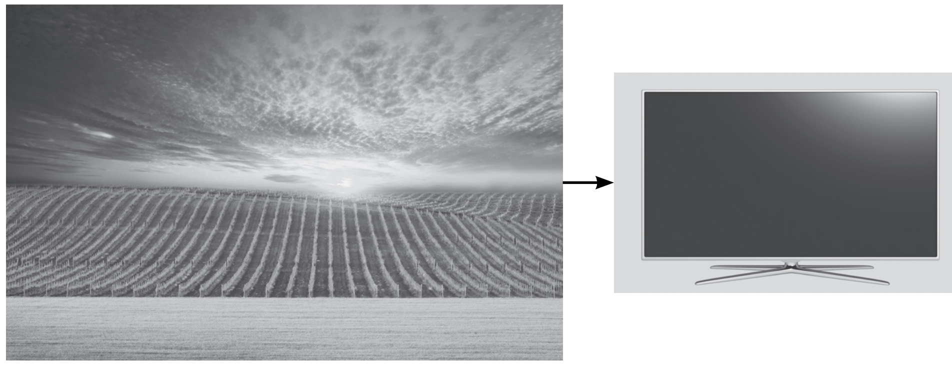


Figure 6.6
Studious and observant Farnsworth was inspired by a field of row crops to invent television.
(Andrii Salivon/Fotolia; Sebastian185/Fotolia)

- Establishing the Miami Conservancy District, "the first time [in the United States] that plans would be made for an entire river valley in a comprehensive and thorough fashion"
- Rescuing Antioch College
- Organizing the Tennessee Valley Authority

Note that he created and innovated in the private, public, and academic sectors and in technical and nontechnical spheres. His creativity and innovation were based in part on his widespread observations, intense curiosity, and thorough follow-up actions. In reflecting on his childhood, he said: "I was inordinately curious. When older people were talking, I had an irresistible urge to 'listen in,' and if I did not understand, to ask questions." He went on to say, "Much of my free time as a boy was spent in the woods and swamps about St. Cloud, Minnesota, where curiosity took the form of observation of earth and sky, streams, plants, and animals. As a result of this habit of curiosity and observation, my mind was stored with a vast miscellany of facts which served as the material for thinking" and, I might add, for lifelong creating and innovating.

Note that he says that his observation tendencies and curiosity were habitual. According to his biographer, Morgan was "observant of, and sensitive and open to, a wide variety of physical and social phenomena," and he read widely and was always "wanting to know" (Leuba 1971).

Are you curious as a result of your observations, maybe even "inordinately curious"? Good: Curiosity is a trait conducive to being creative and innovative. If not, you might consider developing the curiosity and observation habit, like Morgan, using the habit-changing process presented in Section 2.10.5; it could redirect your career and life.

6.3.5 Jack S. Kilby: Simplification and the Integrated Circuit

Useful but heat-producing, energy-hungry, fragile, unreliable, and bulky vacuum tubes dominated the electronic industry for the first half of the last century. Invention of the much smaller transistor—an efficient way to amplify and switch electronic signals—by Bell Telephone Laboratories in 1947 offset many of the vacuum tube disadvantages, but the assembly of complex circuits still required tedious hand-soldering to interconnect the transistors, diodes, rectifiers, and capacitors (Beakley, Evans, and Keats 1986; Johnson 2010; Texas Instruments 2014).

Jack S. Kilby, a newly hired and very observant electrical engineer at Texas Instruments (TI), spent two weeks in the company's shop in July 1958 while everyone else was away on the traditional two-week vacation; he had not yet earned vacation time. He became curious while working on circuits that had thirty parts, and asked himself, what if they only had one part? He later wrote: "Further thought led me to the

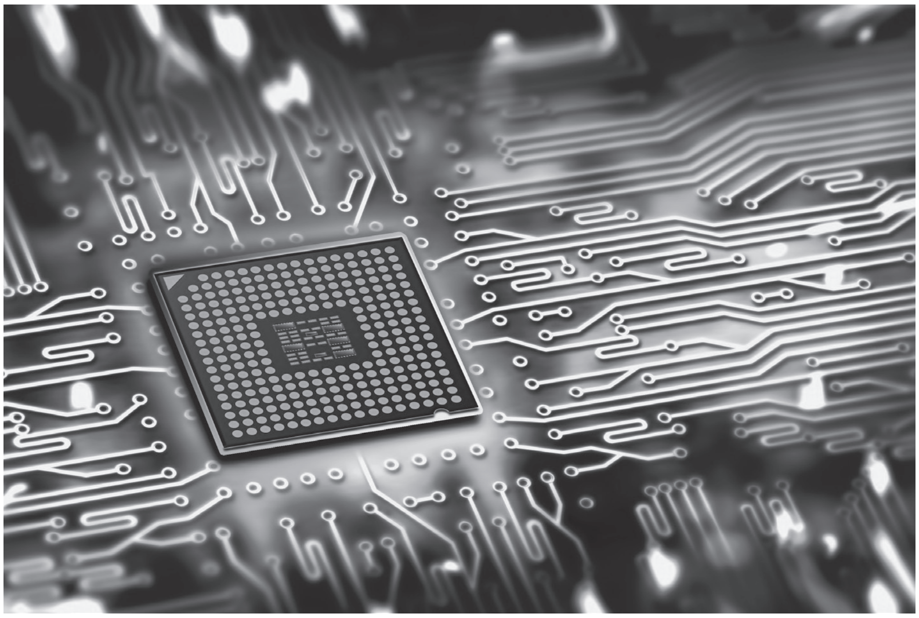


Figure 6.7
Electrical engineer Kilby's curiosity led him to invent the integrated circuit.
(Edelweiss/Fotolia)

conclusion that semiconductors were all that were really required—that resistors and capacitors [passive devices], in particular, could be made from the same material as the active devices [transistors]." He also recognized that all of the components could be made of one material and be interconnected to form a complete circuit. In September 1958, Kilby's curiosity and persistence enabled him to successfully demonstrate the first working integrated circuit, built on a piece of germanium (a semiconductor material); it eventually evolved to today's chip (Figure 6.7).

Of course, this creativity/innovation story continues. In order to stimulate commercialization of the integrated circuit, Kilby was challenged by TI to design a pocket-sized calculator based on the integrated circuit, one that could replace then-common desktop calculators: Kilby coinvented the TI pocket calculator. Mine was purchased in 1975 for $175 ($780 today accounting for inflation) and immediately replaced my slide rule, which I bought in 1959 for $29 ($240 today; see Figure 6.8). Today, the integrated circuit is everywhere. Engineer Kilby received the Nobel Prize in Physics in 2000 for his part in creating the integrated circuit in 2005 (Texas Instruments 2014).

6.4 PASSIONATE

Wagner (2012) argues that passion is essential to creativity and innovation. *Passion*, which may be defined as "a strong feeling of enthusiasm or excitement for something or about doing something" (Merriam-Webster 2014), can be a powerful aid when resolving issues, solving problems, or pursuing opportunities. Passion may also include an aversion to boredom and an accompanying deep-seated need to take on new challenges and eventually realize the thrill of making new things happen.

Pink (2009), author of *Drive: The Surprising Truth About What Motivates Us*, supports the importance of passion with this statement: "For artists, scientists, inventors, school children, and the rest of us, intrinsic motivation—the drive to do something because it is interesting, challenging, and absorbing—is essential for

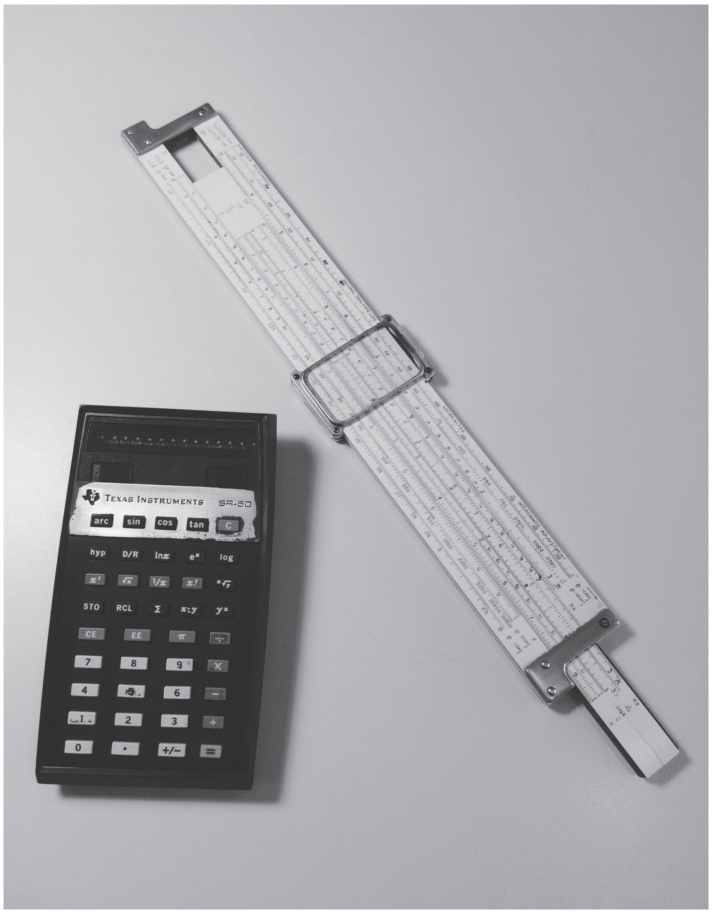


Figure 6.8
Creation of the integrated circuit led to the invention of many devices, including this pocket calculator, purchased by the author in 1975 to replace his slide rule, purchased in 1959.
(Stuart Walesh)

high levels of creativity." Pink does acknowledge that extrinsic motivation—carrots and sticks—"can work nicely for algorithmic tasks," but he goes on to suggest that although offering bonuses or threatening firing will usually increase productivity in more routine work, at least for some time, it will not stimulate creativity and innovation. The latter stimulation needs to come from within, and its driving forces include passion.

Without passion, creativity and innovation are likely to escape us. "A [person] without passion is only a latent force, only a possibility," according to the Swiss philosopher Amied, "like a stone waiting for the blow from iron to give forth sparks." Passion helps us to persist in spite of obstacles and setbacks. The passionate person is less likely to be deterred by failures, lack of support, negative criticism, and other setbacks. Passion will help you deal with the external obstacles described in Chapter 5. Passion revealed in your speaking and writing will also help you engage others, stimulate them to consider your ideas, and join you and others in exploring those ideas and implementing the best of them.

6.4.1 Joseph Strauss: Golden Gate Bridge

The story of engineer and poet Joseph Strauss demonstrates the power of creativity and innovation driven by passion. He dreamed of bridging San Francisco's Golden Gate (Figure 1.6) and knew how it could be done. For two decades, and in the face of widespread skepticism, Strauss lived his dream by leading the planning, design, finance, and construction of the now-famous bridge.

The intensity of his passion is suggested by these lines from his poem "The Mighty Task Is Done":

Launched midst a thousand hopes and fears,
Damned by a thousand hostile seers,
Yet ne'er its course was stayed,
But ask of those who met the foe
Who stood alone when faith was low,
Ask them the price they paid.

Strauss saw the 1937 opening of the bridge and then died approximately one year later. Strauss' passion is recognized with a statue at the south end of the bridge, dedicated to *The Man Who Built the Bridge* (Fredrich 1989; Walesh 2011).

As an example of how today's creative and innovative results, such as the Golden Gate Bridge, depend on earlier ones, consider the work of civil engineer Roebling in the mid-1800s. He was employed as a canal engineer when he observed horses pulling boats along canals. The hemp ropes connecting the horses to the boats often broke, so Roebling created a cable composed of twisted wire that moved the boats faster and safer.

This invention moved him towards a higher goal: the design and construction of suspension bridges. Eventually, he, his engineer son Washington Roebling, and Washington's wife Emily accomplished the design and construction of the Brooklyn Bridge in New York City, which opened in 1883 (Section 6.8.4). Its four twisted wire cables were the first to be used in a suspension bridge. Similar cables were then used on many other suspension bridges around the world, such as the previously discussed Golden Gate Bridge and the Menai Straits Bridge in Wales (Section 4.3.4), which was upgraded in 1941 (Fredrich 1989; Weingardt 2005).

6.4.2 Hermann von Helmholtz: Conservation of Energy Principle

Hermann von Helmholtz is the creative and prolific German scientist who made contributions in mathematics, biology, and physics. In 1847, he published his formulation of the conservation of energy, a principle that is widely used in engineering (Koenigsberger 1906).

Consider his description of passion in action—desire to reach a goal (Stuewer 2013): "I must compare myself to a mountain climber, who without knowing the way climbs up slowly and laboriously, must often turn around because he can go no farther, discovers new trails sometimes through reflection, sometimes through accident, which again lead him forward a little, and finally, if he reaches his goal, finds his shame on a Royal Road on which he could have traveled up, if he would have been clever enough to find the right starting point."

6.5 INTROVERTED

Creative and innovative individuals are often *introverts*—that is, people who are drawn to the "inner world of thought and feeling," contrasted with *extroverts*, who are drawn to their "external life of people and activities" (Cain 2012). By *introvert*, I do not necessarily mean *shy*.

One-third to one-half of Americans are introverts (Cain 2012; Culp and Smith 2001). In contrast, engineers tend to be significantly more introverted. For example, over 60 percent of engineering project team members are introverts (Culp and

Smith 2001); engineers as a group are more introverted than the population at large. However, don't make the mistake of denying the creativity and innovation potential of introverts (more on this shortly).

In her book *Quiet: The Power of Introverts in a World that Can't Stop Talking*, Cain (2012) says this about introverts: "Of course, there's another word for such people: thinkers." She goes on to state, "Introverts are not smarter than extroverts. According to IQ scores, the types are equally intelligent. . . . But introverts seem to think more carefully than extroverts." By the way, if you are an introvert and have been made to feel uncomfortable about it, read Susan Cain's book. Her message? Count your blessings!

Cain claims that "some of our greatest ideas, art, and inventions . . . came from the quiet and cerebral people who knew how to tune in to their inner worlds and the treasures to be found there. . . . Without introverts, the world would be devoid of these creations/innovations." Some of those introverts and their creations and innovations are featured in Table 6.1.

Cain (2012) describes the introvert approach to problem solving relative to the extrovert approach this way: "Extroverts are more likely to take a quick-and-dirty approach to problem-solving, trading accuracy for speed, making increasing numbers of mistakes as they go, and abandoning ship altogether when the problems seem too difficult or frustrating." In contrast, she says that "introverts think before they act, digest information thoroughly, stay on task longer, give up less easily, and work more accurately."

Table 6.1 Introverts contributed some of civilization's greatest creations and innovations.

Introvert	Example of creation/innovation
J. M. Barrie	*Peter Pan*
Lewis Carroll	*Alice in Wonderland*
Frederic Chopin	His nocturnes
Marie Curie	Pioneering radioactivity research
Charles Darwin	*On the Origin of Species*
Thomas Edison	Phonograph (Buelow 2015)
Albert Einstein	Theory of relativity
Bill Gates	Microsoft (Buelow 2015)
Theodore Geisel (Dr. Seuss)	*The Cat in the Hat*
George W. Goethals	Panama Canal (Fredrich 1989)
Sir Isaac Newton	Universal gravitation
George Orwell	*1984*
Larry Page	Google
J. K. Rowling	Harry Potter series
Steven Spielberg	*Schindler's List*
James Watt	Steam engine (Billington 1996)
Stephen Wozniak	Apple Inc.
Mark Zuckerberg	Facebook (Buelow 2015)

Source: All items provided by Cain 2012, except where other sources are indicated.

I'm not suggesting that I agree with Cain's views that introverts have a creativity/innovation edge. However, her ideas remind all of us—especially we introverts—that introverts have a fabulous creativity/innovation track record, as suggested by centuries of engineering creations/innovations. Furthermore, we tend to be very comfortable in the garden of the mind—the place where creative/innovative seeds are planted. Let's celebrate our introversion—not apologize for it—and create and innovate!

6.6 EXPERIMENTALIST

Creative/innovative persons are experimentalists. *Experimentalism* can be defined as "a process of trial and error that explores problems and possible solutions in new and creative ways" (Wagner 2012). In addition to thinking of new ways to do things, creative/innovative individuals act; they are willing to try ideas—that is, experiment, prototype, and pilot.

Although creative and innovative individuals appreciate and often engage in in-depth analysis, they also know when to avoid analysis paralysis and *just do it*. They conduct laboratory experiments, pilot new project management processes, build prototypes to see what their ideas might look like and how they could work, try different marketing tactics, or apply new design approaches. Sometimes, the experiments succeed; sometimes they fail. Although success is appreciated, the creative/innovative person never truly fails because what others may view as failure, he or she sees as a valuable lesson learned. As engineer Weingardt said, "It's only a mistake if you don't learn from it."

HISTORIC NOTE: LEONARDO DA VINCI KNEW HOW TO EXPERIMENT, SUCCEED OR FAIL, AND LEARN

Speaking of experimentation sometimes leading to insightful failure, consider the experimental philosophy and experiences of the genius da Vinci during the fifteenth and sixteenth centuries. He experimented in the very late 1400s with a new way of fixing the paint on a huge refectory wall in a Milan monastery as he created *The Last Supper*. Instead of painting fresco-style on wet plaster, he painted experimentally on a dry surface. The work soon started to fade and flake; the experiment failed, but useful lessons were learned. The painting has been restored many times and survived major bomb damage to the refectory in August of 1943.

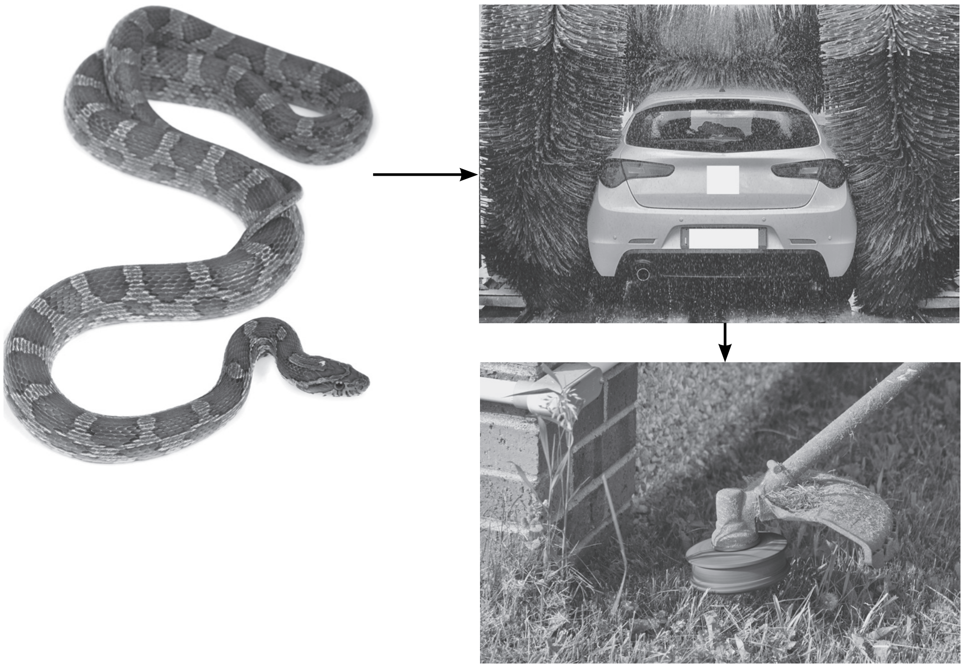
As noted earlier, da Vinci is credited with being the first to describe the essence of the principle of conservation of mass and is credited with laying the foundation for wave theory.

He confirmed his initial hypotheses about these phenomena with experiments. Perhaps in the spirit of encouraging experimentation and the resulting learning, da Vinci said, "The greatest deception men suffer is from their own opinions." (Gelb 2004; Shlain 2014; Wallace 1966). In other words, ideas that seem to have value warrant experimentation.

6.6.1 From Car Wash to Weed Eater

The story of the invention of the Weed Eater, as summarized in Figure 6.9, illustrates early experimentation or prototyping. George C. Ballas, who ran a dance stu-

Figure 6.9
The Weed Eater story illustrates experimentalism as well as empathy and Borrowing Brilliance.
(Volodymyr Khodaryev/Fotolia; Photoiron/Fotolia; Dave Willman/Fotolia)



dio in Houston, was concerned when a poisonous snake bit a worker who was using hand shears to trim the edges of Ballas's lawn.

Shortly thereafter, in 1971, while moving through an automatic car wash, Ballas observed large, rotating nylon bristles that cleaned but did not scratch cars. He took a popcorn can, attached wires radially, connected it to a rotating edger, and experimented. This prototyping evolved into the commercial Weed Eater device introduced in the early 1970s, and "by 1976 [he] was selling $40 million worth of them annually" (Miller 2011). Note that in addition to illustrating experimentation, the Weed Eater story also provides examples of empathy (Section 6.2) and Borrowing Brilliance (Section 4.3).

6.6.2 From Sandpaper to Masking Tape

About a century ago, Dick Drew was a sandpaper salesperson for what is now 3M, and he called on auto body shops to ask mechanics to buy his brand. He gradually noted a problem common to body shops when they performed two-tone paint jobs: Because the tape they used was too sticky, it removed some of the paint on previously painted sections of vehicles, which required wasteful and frustrating rework.

Committed to solving this problem, which was not directly related to sandpaper, Drew began to experiment in 1925. He started with what he knew best: sandpaper, which was manufactured by coating strong paper with glue and then rolling it in crushed minerals. He omitted the crushed minerals and experimented with progressively less sticky sheets of paper. As he moved toward an optimum stickiness, he was increasingly challenged by how to store and handle the sticky sheets of paper. He continued to experiment, and then hit on an idea: Apply the adhesive to a strip of paper and roll it up so that auto body experts could unwind it as needed.

He called his creation *masking tape*. It may seem commonplace now, given the plethora of specialty tapes on the market, but masking tape came into being because of Drew's persistent experimentation in spite of setbacks. In fact, Drew's boss ordered him to stop the project, but Drew simply continued to experiment on his own time until he produced a tape of "pressure-sensitive adhesive that could be applied to metal and then ripped off without damaging the paint." By 1928, 3M's masking tape sales exceeded its sandpaper sales (Lehrer 2012).

6.6.3 From Bird Beak to High-Speed Train

Japan's high-speed trains are known for their safety, efficiency, and comfort. However, until the late 1990s some lines were also criticized for the loud noise they made on exiting the country's many tunnels. "When a train entered a tunnel, its bullet-shaped nose compressed the air into something like a tidal wave; when the wave exited the tunnel, it expanded so rapidly it set off what is known as a tunnel boom" (Vanderbilt 2012).

Consider the long, tapering beak of the kingfisher, a bird that dives quickly and quietly into water to catch fish (Figure 6.10). The bird and its beak were known to Eiji Nakatsu, Chief Engineer of the West Japan Railway Corporation, because he was a birder. His engineers experimented by firing variously shaped bullets into a pipe until they found the shape that caused the least tunnel boom. The new kingfisher-beak-shaped trains entered service in 1997 (EarthSky 2012; Vanderbilt 2012).

PERSONAL: WORDS MATTER WHEN CONSIDERING CHANGE

I like to use the word *experiment* when offering a new idea or suggestion to an individual, team, or organization. Rather than say, "I suggest that you implement this new project management process across your company," I prefer to say, "I suggest that you experiment with this process for a specific period in one part of your company and then evaluate."

The word *experiment* and alternatives such as *prototype*, *trial*, and *pilot* seem less threatening. Such words suggest that the idea may work, while recognizing that it may not work. Although we prefer the former, the latter is OK, especially if we find failure early on so that we can learn from it and direct our creative/innovative efforts in a modified or new direction.

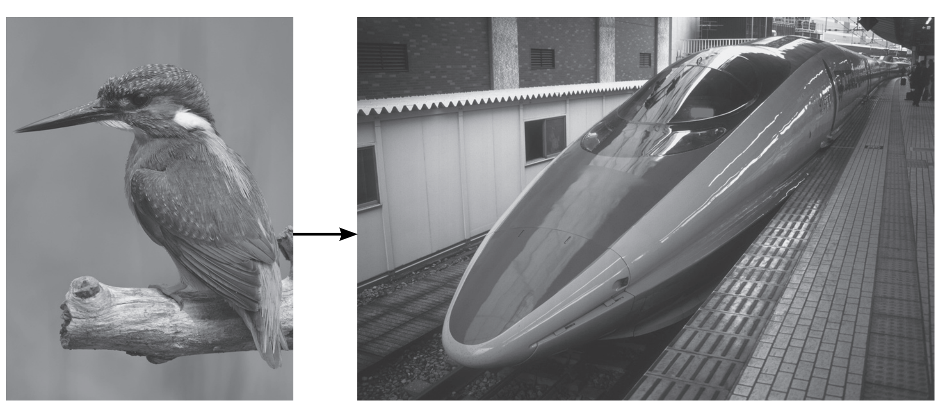


Figure 6.10
The kingfisher's beak inspired the new shape for the lead unit on a Japanese high-speed train and solved the problem of loud noise when exiting tunnels.
(Massimhokuto/Fotolia; SCPhotos/Alamy)

6.6.4 From No Theory for Flow Through Porous Media to a Widely Used One

Henry Darcy was a member of the French civil engineering corps. Born in Dijon, France, he returned there after his education in Paris in the early 1800s and was given responsibility for designing and constructing the municipal water supply system. To gain further insight into the behavior of sand filters, which were one component of the Dijon water supply system, Darcy conducted experiments on flow through porous media. His experiments demonstrated that energy loss is proportional to velocity, as stated in what is now called Darcy's Law—that is, $v = k\,(dh/dl)$, where

v = apparent velocity (volumetric discharge divided by total cross-sectional area),

k = coefficient of permeability with dimensions of velocity,

h = head with dimensions of length, and

l = distance in the direction of flow with dimensions of length.

In 1856, Darcy published the results of his experiments and the equation he developed, thus enabling others to benefit from his creative/innovative work as they design water treatment plants, analyze groundwater flow, and take on other flow through porous media challenges. Similar creative/innovative theoretical and experimental efforts driven by pragmatic needs gave us the Manning Equation for open channel flow, the Rational Formula for storm water system design, and the Darcy-Weisbach pipe flow equation (Walesh 1990).

6.7 COLLABORATIVE

Although creative/innovative individuals certainly value personal study and reflection and use them wisely, they also frequently reach out to and interact with others in many ways (Canales 2011; Wagner 2012). Their *collaboration* may be informal, like when individuals exchange ideas with various members of their networks, or more formal, like when they serve on teams or groups formed to address an IPO. Creative/innovative individuals highly value and proactively apply the Medici Effect discussed in Section 4.6 because they recognize that diversity of education, experiences, viewpoints, and other characteristics stimulate creativity and innovation. Some ways in which creative/innovative individuals collaborate informally are as follows:

- Seek to understand the wants and needs of prospective clients and customers.
- Ask questions of and offer ideas to members of their professional and personal networks using email or other electronic media.
- Arrange and participate in group sessions that use the kinds of whole-brain tools described in Chapters 4 and 7.
- Study new topics and share and test their preliminary findings by writing articles, papers, and blogs and speaking to various groups. By offering and testing new concepts, ideas, processes, and methods, these proactive collaborative communications benefit both the presenter and the audiences/readers.
- Find partners with whom to seek research and development funding.

6.7.1 Birth of the Personal Computer System

As an example of fruitful collaboration, consider the birth of the personal computer system. On December 9, 1968, electrical engineer Englebart, leader of a thirteen-person team at the innovative consulting organization SRI spoke at the San Francisco Fall Computer Conference. His topic: the team's development of basic computer functions that exist in computers today.

After describing and demonstrating the "computer mouse, multiple windows, on-screen editing, hypermedia, context-sensitive help, distributed collaboration, and shared-screen video teleconference," Englebart and his team received a standing ovation. Today, essentially every personal computer uses those interface features (Carlson and Wilmot 2006). This event was almost a decade before the 1977 San Francisco release of the Apple II, the first ready-to-run, out-of-the-box personal computer (Isaacson 2011). Because commercializing inventions was not part of SRI's mission, the company licensed the computer mouse to Xerox, Apple, and others.

Douglas Englebart's team exhibited highly productive collaboration. Their successful collaboration is attributed to factors such as selecting an important and challenging need; assembling a team of software and hardware personnel with complementary expertise; Englebart's passionate championing of his ideas; thinking of prospective customers; integrating ideas from around the globe; and leveraging what Engelhart referred to as the team's *collective intelligence* through frequent interaction (Carlson and Wilmot 2006).

6.7.2 Other Collaboration Examples

Many collaboration examples are noted in Chapter 4, including the cardiac pacemaker, Shakespeare's writing, Thomas Edison's devices, Steve Jobs' electronic inventions, breaking the German Enigma code, defining a pond problem, building a Taco Bell restaurant in forty-eight hours, temporarily storing storm water on streets, and the Panama Canal. Collaboration examples cited in this chapter include an adaption of the shape of the kingfisher beak to the high-speed train (Section 6.6.3) and development of a baby incubator for developing countries (Section 6.8.1).

PERSONAL: THREE ESSENTIAL FACTORS FOR SUCCESSFUL COLLABORATION

Having experienced many successes and a few failures in collaborative efforts in the business, government, academic, and volunteer sectors, I am convinced that three qualities lead to productive collaboration. These three qualities, which are consistent with the factors noted in the Douglas Englebart example, are as follows:

- **Vision:** The first quality is a strong and shared commitment to an ambitious vision—the bolder, the better. The vision should initially appear highly desirable and perhaps unachievable. Sometimes, groups take on less aspirational but nevertheless challenging tasks. In these situations, the word *vision* may not be appropriate. Instead, use an end-point term, such as *objective* or *goal*, and as with vision, seek a strong and shared commitment to it.
- **Diversity:** An optimum mix of participants is the second collaboration factor. Diversity characteristics to consider when forming a team are discussed in the Medici Effect portion of Section 4.6. When a group is care-

fully constituted, each member is important. This idea is explained in one of my favorite statements from former US Secretary of Health, Education, and Welfare Gardner, who said: "The society which scorns excellence in plumbing as a humble activity, and tolerates shoddiness in philosophy because it is an exalted activity, will have neither good plumbing nor good philosophy: Neither its pipes nor its theories will hold water."

- **Trusting, communicative structure:** Trust and open, ongoing, intrateam communication is the third collaboration success factor. With this factor, the emphasis moves from the characteristics of the team members to the relationships among them, which must be respectful and trusting.

All three qualities are necessary; none is sufficient alone. An aspirational vision without diverse players is a pipe dream. A talented team toiling without a shared vision or goal is poor stewardship. A superb organizational structure without talented players degenerates into bureaucracy.

6.7.3 Additional Thoughts about Trust

The previous personal note asserts that trust is one of three essentials in collaboration, which warrants elaboration. Each member of a team that is taking on a challenging IPO must be able to trust and be trusted by all other participants. Mutual trust is crucial in creative/innovative efforts because much is often at stake; the initiative could fail at great cost or succeed and provide great benefits. You may be tempted to hoard the essentials of your creative/innovative idea because you don't trust others; some of them may do the same because they don't trust you and others. A team's success is jeopardized when it does not have access to all of its intellectual and other resources. In keeping with the theme of this book, your desired success and significance are frustrated when you don't engage all of your intellectual resources—that is, your whole brain.

Trust can be difficult to define, but we know at the gut level when it is present. I try to keep it simple by defining *mutual trust* as meaning that you and I view each other as being honest and as practicing integrity. Honesty and integrity, which are essential for mutual trust, are different but complementary and may be described as follows:

- *Honesty* is telling the truth. It's retrospective; it's how we report the past. For example, if while in high school your dog ate your homework and you told your teacher that, then you are being honest.
- *Integrity* is keeping promises. It's prospective; it's how you keep your commitments. To continue the homework example, if you then promised your teacher that you would redo the homework and hand it in at the beginning of the next class and then did as you promised, that's integrity. People of integrity live by the DWYSYWD principle: "Do what you say you will do."

Let's not distinguish between little promises and big promises. They are viewed the same; more specifically, you are viewed the same way by team members who receive your promises, whether big or small. It's like when your doctor says he or she will be performing only "minor" surgery. You still want him or her to be just as careful as if it were "major" surgery (Sheth and Sobel 2000). Each promise you or I make, large or small, should be treated habitually with the same seriousness.

Motivational writer Anderson (2007) says this about trust: “Contrary to what most people believe, trust is not some soft, illusive quality that you either have or don’t have; rather trust is a pragmatic, tangible, actionable asset that you can create.” Think about it. We follow the trusted leader, we seek help from the trusted friend and advice from the trusted professor, clients retain the trusted firm, employers hire and promote the trusted engineer, and citizens support the trusted official (based, in part, on Horsager 2012). You can take trust to the bank—symbolically and literally. Once you earn the trust of others, doors will open, opportunities will arise, your recommendations are more likely to be accepted, sole-source consultant selection will occur more often, and so on.

Notice I said you must *earn* trust. You can’t buy it. You must build it piece by piece by your words and actions. If you discipline yourself to habitually tell the truth and keep your word, many good things will come your way, not the least of which is being an effective player on teams that seek to creatively and innovatively resolve issues, solve problems, or pursue opportunities.

6.8 PERSISTENT

The final characteristic of creative and innovative individuals is *persistence.*

This attribute follows from but is different than being passionate (Section 6.4). We hear about fabulous ideas that supposedly came out of the blue, but the accounts of actual creative/innovative contributions are very different. They are admirable human stories reflecting many qualities like those discussed in this chapter, with persistence perhaps being the most important.

VIEWS OF OTHERS: STICK WITH IT

The amazing scientist/artist/engineer da Vinci credited persistence for his creative and innovative successes, writing, “I do not depart from my furrow” next to a drawing of a plow in one of his notebooks and also stating, “Every obstacle is destroyed though rigor” (Gelb 2004). Einstein shared his faith in persistence by saying, “It’s not that I’m so smart; it’s just that I stay with problems longer.” Coolidge, the thirtieth US president, said this about the power of persistence: “Nothing in the world can take the place of persistence. Talent will not; nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education alone will not; the world is full of educated derelicts. Persistence and determination alone are omnipotent.” Michelangelo, Italian painter and sculptor and contemporary of da Vinci, stated, “If people knew how hard I work to gain my mastery, it would not seem so wonderful at all.”

Assume you are succeeding as an engineering student or have already earned one or more engineering degrees. You probably are persistent and have other admirable qualities discussed in this chapter, because the formal study of engineering and similar disciplines requires above-average effort. If that applies to you, then celebrate your demonstrated persistence and continue to use it in all that you do, including finding ways to work smarter and to be more creative and innovative.

6.8.1 Baby Incubator for Developing Countries

Infant incubators (heated cribs for newborns) were first created by French medical doctors in 1881 and were inspired by the use of an incubator for baby birds. Given the number of extra years of life they provide, baby incubators may be one of the greatest medical creations. However, today almost two million newly born babies die each year, mostly in developing countries, because the infants lack a consistent heat source. A standard modern incubator, as used in an American hospital, costs roughly $40,000 and requires careful maintenance.

Even if funds are available to purchase and send incubators to developing countries experiencing high infant mortality rates, the devices soon fail because of power fluctuations, high humidity, and other complications. They are rarely repaired due to lack of expertise, absence of instructions in native languages, and shortage of parts. Up to 98 percent of the medical technology donated to developing countries fails within five years of its first use. For example, eight incubators were sent to an Indonesian city following the 2004 Indian Ocean tsunami. By the end of 2008, none of the eight were working.

On learning about this dilemma in 2008, mechanical engineer Prestero committed to finding a solution. He and his team were inspired by an idea offered by Boston doctor Rosen, who observed that people in the developing world knew how to keep automobiles running. The team persisted until they designed and created an incubator that is readily assembled with many automobile or similar parts (Figure 6.11). For example, a sealed beam headlight supplies heat, a dashboard fan circulates heated air, and a motorcycle battery provides power during a power outage or when an incubator is being transported (Design that Matters 2014; Johnson 2010).

In summary, a critical medical device originally created in 1881 that gradually improved and naturally became very complex and widely used was, through persistence, successfully recreated in a vastly different and simpler form for a very special environment. Like the development of the cardiac pacemaker described in Section 3.6.1, the design of the special-purpose incubator is another example of the potential for collaboration between engineers and medical professionals.

6.8.2 Xerography

In the late 1940s, inventor Chester Carlson visited the laboratories of a major photography company. He met with a company researcher and demonstrated step by

Figure 6.11
Persistence-driven innovation led to the development of this life-saving baby incubator that can be maintained in developing countries using readily available automobile and motorcycle parts.
(Design that Matters, Inc.)

step the quick electrostatic photography process that he had created. Carlson envisioned his process as replacing the then-cumbersome copying method—that is, the film-developer-darkroom process.

He was shown the door because his imaging process did not fit the paradigm of the time—that is, exposing film using a developer solution and working in a darkroom. Being persistent, Carlson presented his ideas to forty-two other companies, including IBM and Kodak; unbelievably in retrospect, all rejected it. His persistence paid off, however, because his electrostatic photography process was finally accepted by what was then the Halloid Corporation, which eventually changed its name to the Xerox Corporation. Carlson's process became known as xerography, which is the basis for today's omnipresent copy machines (Barker 1989).

On hearing this story, you may be tempted to say, "I can see that some companies wouldn't get it, but forty-two?!" Keep that in mind when someone presents an idea to you, whether as a student or practitioner or member of any community, and your first inclination is to say, "That's not how we do things."

6.8.3 From Car Batteries to Home Batteries

Elon Musk, who was born in South Africa and completed his formal education in Canada and the United States, exemplifies the highest form of persistence, accompanied in good measure by other characteristics presented in this chapter. He takes on a creative/innovative challenge, carries it to completion or a major milestone, and then moves forward to a new challenge, sometimes in a very different area of technology. There seems to be no limit to his apparent desire to do what has not been done. Consider some of his creative/innovative accomplishments, portions of which were achieved in parallel (Biography.com 2015a):

- Launched the online payment system PayPal in 2000 as the result of a merger.
- Started Space Exploration Technologies (Space X) in 2002; in 2012, under contract to NASA, Space X launched a rocket that was the first to send a commercial vehicle to the International Space Station.
- Cofounded Tesla Motors in 2003, which designs and manufactures all-electric cars. Its first version, a sports car, went into production in 2008, and a four-door luxury sedan was introduced in 2012.

Described as "an earnest entrepreneur," Elon Musk explains his persistence this way: "If I am trying to solve a problem, and I think I've got some elements of it kind of close to being figured out, I'll pace for hours trying to think it through." One can only imagine the intense and productive interaction between Elon Musk's conscious and subconscious minds (Biography.com 2015a).

In 2015, Musk announced that Tesla Energy, the battery unit of the company, would offer batteries for residential, business, and utility use. Building innovatively on what the company learned about lithium-ion battery technology in its automobile business, Tesla began offering Powerwall batteries, which are wall mounted, inside or outside of a building, and connect to solar and/or grid power systems.

The Powerwall stores energy that can be used when other energy is temporarily not available or too expensive. Control devices direct the flow of energy among solar panels, the grid, and the Powerwall. Initial challenges included the high cost of the Powerwall, which was expected to decline; the cost of other parts of a system, such as solar panels; dealing with competitive products; and determining the roles of electric utilities (Shandrow 2015; Smith and Sweet 2015).

HISTORIC NOTE: NIKOLA TESLA

Tesla Motors' namesake is the creative and innovative electrical and mechanical engineer Nikola Tesla. Born in Croatia in the mid-1800s, Tesla was educated and worked in Germany, Austria, the Czech Republic, and Hungary. He came to the United States in 1884 and worked briefly with Edison. However, the two parted ways after several months and later became adversaries: Edison advocated direct current (DC) power systems, whereas Tesla promoted alternating current (AC) systems. Tesla won in the sense that AC became dominant worldwide beginning in the twentieth century.

The creative and innovative Tesla founded the Tesla Electric Company in 1885, and there he began to develop AC electrical systems. In 1895, Tesla designed an AC hydroelectric plant at Niagara Falls, which was one of the first such power facilities in the United States. It powered Buffalo, New York, and was viewed worldwide as an amazing feat. Tesla was also involved in the development of radar, X-ray, remote control, and wireless transmission of energy (Biography.com 2015b).

6.8.4 Brooklyn Bridge: It Took a Family

Returning to the Brooklyn Bridge (Section 6.4.1) after noting its innovative first use of twisted wire cable, now consider the persistent family effort that brought this iconic bridge to reality (Fredrich 1989, Weingardt 2005). For decades, the idea of the bridge, like many creative/innovative ideas, was widely dismissed as impossible. Challenges to crossing New York City's East River from Manhattan to Brooklyn included deep water and severe weather that moved up the river from the Atlantic Ocean. However, if anyone could get the job done, engineer Roebling could.

He completed overall plans in 1865. At about that time, Roebling sent Washington, his just-married son, and Emily, his new daughter-in-law, to Europe and around the world to study deep-water caisson foundations. The senior Roebling invested the next four years to getting support for the project from city, state, and federal officials.

Unfortunately, as construction began in 1869 and Washington and Emily Roebling returned home, the family experienced the first of a pair of disasters. John Roebling died as the result of an accident at one of the bridge's abutments. Exemplifying persistence, Washington Roebling took over as chief engineer, and his wife helped with labor, materials, political, and public relations challenges. Emily Roebling also began to study civil engineering topics, including mathematics, strength of materials, catenary curves, and cable and bridge construction. The seeds of these studies would soon bear great fruit.

In 1872, three years into what would be a thirteen-year project, Washington, who was a hands-on professional, suffered caisson disease, leaving him paralyzed, partly blind, deaf, and usually unable to speak. He and his wife were determined to persist and complete the bridge. Washington used binoculars to watch construction progress from his bedroom window on the Brooklyn side of the river, while Emily visited the site daily to observe details and deliver and receive messages. She gradually took on increased responsibilities, such as dealing with construction workers, material suppliers, assistant engineers, and public officials. Functionally,

Figure 6.12
New York City's iconic and innovative Brooklyn Bridge was constructed largely through a persistent and strong family effort.
(Mike Liu/Fotolia)

Emily became the chief engineer. The Brooklyn Bridge, shown in Figure 6.12, opened in 1883.

The Roeblings moved on, with the ailing Washington involved in the family's cable business and Emily, in addition to being a wife and a mother to their son, John, taking on many new endeavors and challenges. For example, she earned a law degree, was a much-in-demand speaker, wrote many articles, traveled worldwide, and championed various causes. She wrote her husband's biography, which barely describes her own role in building the bridge but lauds the contributions of her husband and the assistant engineers.

However, history reminds us of Emily Roebling's leadership role. The Brooklyn Bridge story reminds us that when we take on creative/innovative endeavors, our immediate families may be among our most important supporters; they can enable us to persist.

6.8.5 Other Persistence Examples

Consider some other examples of persistence leading to creative/innovative results:

- Engineer de Mestral worked ten years to bring Velcro to market (Section 1.3.2).
- Goodyear devoted ten years to experimentation and other efforts to obtain his vulcanization patent (Section 3.6.2).
- From concept to implementation, development of the now-omnipresent bar code required twenty-six years (Section 4.11.2).
- Starting at the age of fourteen, Farnsworth worked for six years to be the first to demonstrate a very simple version of what he is reported to have called *electronic television* and then worked many more years to commercialize it (Brigham Young University High School 2014; Section 6.3.3).
- In spite of many unsuccessful experiments and lack of support from his boss, sandpaper salesperson Drew continued with his experiments and eventually created masking tape (Section 6.6.2).
- Theodor Geisel, more popularly known as Dr. Seuss, is considered a premiere author of children's books. He was a pioneer in linking drawings to text, an approach that appeared in his first book. That innovative book was rejected by

twenty-nine publishers before being accepted thanks to the author's persistence (Walesh 2011).

- James Dyson, inventor of the dual-cyclone bagless vacuum cleaner, worked through more than five thousand designs before achieving success (Forbes 2014).

6.9 CHARACTERISTICS: CONCLUDING THOUGHTS

This chapter discusses recognizing, strengthening, or acquiring seven personal characteristics conducive to being creative and innovative:

- Empathetic
- Studious
- Passionate
- Introverted
- Experimentalist
- Collaborative
- Persistent

On seeing the list of characteristics after our review of each, and recognizing that the list reflects the thinking of many individuals, you may have had a number of reactions. Maybe you expected a silver bullet, or perhaps, like me at first, you thought that this is an interesting list, but you sort of expected at least some unusual characteristics that clearly set apart creative/innovative individuals. However, based on my studies and observations, that's not the case.

Or you may be saying to yourself that creative/innovative people have a set of normal human characteristics. There is nothing exotic or unusual about the components of their profiles. Creative/innovative individuals simply stand apart because they focus on a mix of appropriate characteristics in a given situation and apply them more intensely. Therefore, you and others possess most of these characteristics, and you can celebrate those that are strong and strengthen those that are weak. We have great potential!

Perhaps this is just another way of declaring, in keeping with the evolving theme of this and previous chapters, that anyone can be creative and innovative. The essentials: Take a more whole-brain approach by learning the basics of how the human brain functions; obtain whole-brain tools; overcome obstacles; and recognize, strengthen, or acquire certain personal characteristics, as noted in this chapter.

The real contest is always between what you've done
and what you are capable of doing.
You measure yourself against yourself and nobody else.

—Geoffrey Gaberino, Olympic swimmer

CITED SOURCES

Altshuller, G. 1996. *And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving.* Translated by Lev Shulyak from the original 1984 Russian version. Worcester, MA: Technical Innovation Center, Inc.

Anderson, M. 2007. *You Can't Send a Duck to Eagle School and Other Simple Truths of Leadership.* Naperville, IL: Simple Truths.

Barker, J. A. 1989. *Discovering the Future: The Business of Paradigms.* St. Paul, MN: ILI Press.

Beakley, G. C., D. L. Evans, and J. B. Keats. 1986. *Engineering: An Introduction to a Creative Profession.* New York: Macmillan Publishing Company.

Behar, H. 2009. *It's Not About the Coffee: Leadership Principles for a Life at Starbucks.* New York: Penguin Group.

Billington, D. P. 1996. *The Innovators: The Engineering Pioneers who Made America Modern.* New York: John Wiley & Sons.

Biography.com. 2015a. "Elon Musk: Engineer, Inventor, Explorer." Accessed May 6, 2015. http://www.biography.com/people/elon-musk-20837159.

Biography.com. 2015b. "Nikola Tesla: Engineer, Inventor." Accessed May 6, 2015. http://www.biography.com/people/nikola-tesla-9504443.

Brigham Young University High School. 2014. "Philo Taylor Farnsworth: Mathematician, Inventor, Father of Television." Accessed November 17, 2014. http://www.byhigh.org/History/Farnsworth/PhiloT1924.html.

Brooks, D. 2014. "In Praise of Small Miracles." *The New York Times,* December 14.

Buelow, B. 2015. "The Introvert Entrepreneur." Accessed April 12, 2015. http://theintrovertentrepreneur.com/resources/introvert-info/.

Cain, S. 2012. *Quiet: The Power of Introverts in a World That Can't Stop Talking.* New York: Crown Publishers.

Canales, K. 2011. "Finding Creative People Is Easy (and Here's How)." June 7. Accessed November 17, 2014. http://www.theatlantic.com/life/archive/2011/06/finding-creative-people-is-easy-and-heres-how/240069/.

Carlson, C. R., and W. W. Wilmot. 2006. *Innovation: The Five Disciplines for Creating What Customers Want.* New York: Crown Business.

Clarke, B., and R. Crossland. 2002. *The Leader's Voice.* New York: SelectBooks.

Culp, G., and A. Smith. 2001. "Understanding Psychological Type to Improve Project Team Performance." *Journal of Management in Engineering,* ASCE, January: 24–33.

Design that Matters. 2014. "Work and Vision." Accessed June 11. http://www.designthatmatters.org.

Dhillon, B. S. 2006. *Creativity for Engineers.* Hackensack, NJ: World Scientific.

EarthSky. 2012. "Sunni Robertson on How a Kingfisher Inspired a Bullet Train." June 21. Accessed November 17, 2014. http://earthsky.org/earth/sunni-robertson-on-how-a-kingfisher-inspired-a-bullet-train.

Forbes. 2014. "The World's Billionaires: #351 James Dyson." *Forbes.* Accessed August 3, 2015. http://www.forbes.com/profile/james-dyson/.

Fredrich, A. J., ed. 1989. *Sons of Martha: Civil Engineering Readings in Modern Literature.* New York: American Society of Civil Engineers.

Gelb, M. J. 2004. *How to Think like Leonardo da Vinci: Seven Steps to Genius Every Day.* New York: Bantam Dell.

GreenUpGrader. 2014. "Q Drum: Water Transportation Made Easier." Accessed November 17. http://greenupgrader.com/3934/q-drum-human-water-transportation-made-easier/.

Horsager, D. 2012. "Trust." Audio CD, *Success Magazine*, December.

Innovative Concepts Group. 2014. "Q Drum." Accessed November 17. http://www.qdrum.co.za.

Isaacson, W. 2011. *Steve Jobs.* New York: Simon & Schuster.

Johnson, S. 2010. *Where Good Ideas Come From: The Natural History of Innovation.* New York: Riverhead Books.

Koenigsberger, L. 1906. *Hermann von Helmholtz.* Translated by F. A. Welby. London: Claredon Press.

Lehrer, J. 2012. *Imagine: How Creativity Works.* New York: Houghton Mifflin Harcourt.

Leuba, C. J. 1971. *A Road to Creativity: Arthur Morgan—Engineer, Educator, Administrator.* North Quincy, MA: The Christopher Publishing House.

Lumsdaine, E., M. Lumsdaine, and J. W. Shelnutt. 1999. *Creative Problem Solving and Engineering Design.* New York: McGraw-Hill.

Medina, J. 2008. *Brain Rules: 12 Principles for Surviving and Thriving at Work, Home, and School.* Seattle: Pear Press.

Merriam-Webster. 2014. "Passion." Accessed November 17. http://www.merriam-webster.com/dictionary/passion.

Michalko, M. 2001. *Cracking Creativity: The Secrets of Creative Genius.* Berkeley, CA: Ten Speed Press.

Miller, S. 2011. "Dance Studio Owner Invented Weed Eater." *The Wall Street Journal,* June 30.

Murray, P. 2011. "The Wheel Reinvented: The Q-Drum is an Easy Way to Transport Water in Developing Countries." *Singularity HUB,* October 24. Accessed November 17, 2014. http://singularityhub.com/2011/10/24/the-wheel-reinvented-%E2%80%93-the-q-drum-is-an-easy-way-to-transport-water-in-developing-countries-video/.

Pink, D. H. 2009. *Drive: The Surprising Truth about What Motivates Us.* New York: Riverhead Books.

Sanborn, M. 2006. *You Don't Need a Title to Be A Leader.* New York: Currency Doubleday.

Shandrow, K. L. 2015. "Elon Musk Unveils Clean, Green Batteries to Power the World." *Entrepreneur.* Accessed May 6, 2015. http://www.entrepreneur.com/article/245713.

Sheth, J., and A. Sobel. 2000. *Clients for Life: Evolving from an Expert for Hire to an Extraordinary Advisor.* New York: Simon & Schuster.

Shlain, L. 2014. *Leonardo's Brain: Understanding da Vinci's Creative Genius.* Guilford, CT: Lyons Press.

Smith R., and C. Sweet. 2015. "Will Tesla's Newest Battery Pan Out?" *The Wall Street Journal,* May 2–3.

Steiner, C. 2012. *Automate This: How Algorithms Came to Rule the World.* New York: Penguin Group.

Stuewer, R. H. 2013. "The Joy of History." 2013 Pais Prize Lecture, American Physical Society, forum on the history of physics. Accessed April 12, 2015. http://www.aps.org/units/fhp/newsletters/fall2013/pais.cfm.

Texas Instruments. 2014. "The Chip that Jack Built." Accessed November 17, 2014. http://www.ti.com/corp/docs/kilbyctr/jackbuilt.shtml.

Vanderbilt, T. 2012. "Better Living through Imitation: Biomimicry Engineers Are Finding the Designs of the Future in the Greatest Field Laboratory of the Past: The Natural World." *Smithsonian,* September: 50–53.

Wagner, T. 2012. *Creating Innovators: The Making of Young People Who Will Change the World.* New York: Scribner.

Walesh, S. G. 1990. "Water Science and Technology: Global Origins." In *Urban Stormwater Quality Enhancement: Source Control, Retrofitting, and Combined Sewer Technology: Proceedings of an Engineering Conference,* Davos, Switzerland. New York: American Society of Civil Engineers.

Walesh, S. G. 2011. "Creativity Plus Persistence Equals Breakthroughs." *Leadership and Management in Engineering,* ASCE, April: 222.

Wallace, R. 1966. *The World of Leonardo 1452–1519.* Alexandria, VA: Time-Life Books.

Weingardt, R. G. 2005. *Engineering Legends: Great American Civil Engineers.* Reston, VA: ASCE Press.

EXERCISES

Notes:

1. The goal of the exercises is to provide students, sometimes working alone and sometimes as teams, with the opportunity to think about and use the ideas, principles, and information offered in this and earlier chapters.
2. However, many circumstances and corresponding teaching-learning opportunities may arise. For example, a stated situation may be altered to meet specific concerns or needs. Such variations are encouraged, subject to the concurrence or direction of the instructor.

6.1 RESEARCH PAPER (INDIVIDUAL STUDENT VERSION): Identify two-person creative teams: a. a professional; b. a student. These two person teams can be identified on the basis of your knowledge regarding their exemplary work in developing creative and innovative facilities, structures, systems, products, or processes. The intent of this exercise is to study what goes behind the scene of innovation. The following steps are suggested:

- Select the two person teams and get an approval from the instructor.
- Prepare an interview questionnaire with open-ended questions using the principles discussed in the chapters till now.
- Conduct the interview and make a recording of the session with permission.
- Go through these recordings again and again to identify keywords or phrases that describe creative/innovative results, operable personal characteristics and training, inspirations or methods used. Write each keyword/phrase on a sticky note.
- Now for each team, cluster the sticky notes on the basis of affinity. You can identify affinity as per your choice.
- Compare the professional against the student and identify similarities and differences.
- Write the paper. Provide a complete description of the creative/innovative result and identify operable personal characteristics. Assume your principal readers are engineering or other technical profession students who know very little about your topic.

6.2 INTERVIEW AN ENTREPRENEUR: Ask around and identify one or more widely recognized creative/innovative individuals in or near your community. I suggest that you use the term *entrepreneur* because people you talk to are more likely to relate to that word than to *creative/innovative person*. Be assured that most entrepreneurs are creative and innovative.

Select one of the identified individuals, contact him or her, and ask if you could have a half hour to an hour of his or her time for an interview. Then, prepare some questions, possibly drawing on Section 4.2 for some ideas. In addition to formulating questions about the interviewee, you might include some queries helpful to your career plans.

Conduct the interview and write a summary that stresses what you learned about the characteristics of the interviewee and how they compare to one of more of the seven characteristics discussed in this chapter. Thinking about your career, what might you do differently as a result of the interview? This interview exercise reflects my belief that we can learn a lot by conversing with accomplished people. Ask questions and listen carefully.

6.3 WIDENING YOUR CREATIVITY (WHAT IF): How can a man get a clean and smooth shave? As an individual or a team, explore possible ways you can provide a better shave for a man using What If (Section 4.12).

One can think about making sharper blades, increasing the number of blades, adding vibrations along with blade movement. But What If we put aside the word shave and replace it with remove facial hair or eliminate facial hair or groom facial hair. Does that trigger new ideas or ways for looking at the age-old problem of facial hair? For example, there are several ways to remove facial hair such as shaving, waxing, and threading. Laser treatment can be seen as eliminating facial hair permanently. Grooming facial hair can be interpreted as trimming it so that it is still visible. Summarize your initial ideas in writing and include a list of scenarios, supplemented with sketches as needed.

6.4 RASPBERRY SYRUP IN CHOCOLATE BOTTLES (MIND MAPPING): At a birthday party, each child received a piece of novelty candy consisting of a tiny chocolate bottle containing raspberry syrup. Being inquisitive, the children began discussing how the candy was made while enjoying it.

One idea was that someone made the tiny chocolate bottles and then filled them with the raspberry syrup. An adult who knew the candy-making process indicated it was not done that way; the bottles would be too fragile, and pouring the thick syrup would take too long. The children's discussion continued; they suggested warming the syrup to make it flow easier, but the adult said that was not what was done: The warm syrup would melt the chocolate bottle.

Eventually, the children described how it was done and they were correct. What was the process (adapted from Altshuller 1996)? How could that process be scaled up and used in engineering? Work as an individual or in a team; consider using Mind Mapping (Section 4.7) to find answers to both questions.

6.5 FINDING THE MISSING OIL (FISHBONE DIAGRAMMING): Each week, a manufacturing company receives numerous shipments of fuel oil delivered by a tanker truck driven by the same person. The tank's capacity is fifteen thousand gallons, and the tank is completely filled and sealed when it leaves the seller—that is, the oil company.

However, the buyer—that is, the manufacturing company—gradually realizes that when the truck arrives and is unsealed and unloaded, there is always a shortage of three hundred gallons, or 2 percent. The buyer's representative begins to ask questions and check measuring devices at the seller and at the manufacturing plant; all are in order. There is no leakage from the tank truck, and even a thin oil film left on the inside walls of the truck's tank would not explain the shortage. Temperature change effects are ruled out (adapted from Altshuller 1996).

What's going on? *Hint:* The tank truck driver is dishonest. You or your team might want to use Fishbone Diagramming (Section 4.5) to search for possible explanations to generate ideas.

6.6 YOUR LOGO: You just joined a company known for its creativity and innovative work. As part of the first-day orientation, you learn that you will be given a security card to enter certain project areas. You are asked to design a logo for your card that expresses one or more of your creativity/innovation strengths. Design your logo, perhaps using some of the seven creativity/innovation characteristics discussed in this chapter as the starting point (adapted from Lumsdaine, Lumsdaine, and Shelnutt 1999).

6.7 THE NEED FOR EMPATHY: Recall your last visit to a doctor's clinic. Reflect on the setting, the behavior of the medical staff, the doctor, and the tools and equipment used. Now imagine a ten-year old child who is unwell and has to come to see a doctor. Do you think the medical environment lacks empathy for the child? How can you fix the situation?

Think critically about a 10-year old child's behavior, wants, and needs, and ideate on an empathetic design solution.

6.8 LEARN ABOUT AND EXPLAIN THE USE OF CAISSONS: As noted in this chapter's discussion of building the Brooklyn Bridge (Section 6.8.4), part of the process included underwater construction using caissons, and Washington Roebling was seriously injured as a result of working within a caisson. Study caissons, and then describe them and how they are used via a series of simple, freehand drawings (Section 7.4).