PART I

THE NEED AND CONTEXT

CHAPTER 1

MEETING NEW CHALLENGES: TRANSFORMING ENGINEERING EDUCATION

GRÉTAR TRYGGVASON and DIRAN APELIAN

1.1 INTRODUCTION

Engineering education is embarking on a transformation as profound as the birth of engineering as a profession in the nineteenth century and the establishment of scientific knowledge as the foundations of engineering in the middle of the twentieth century. The change is driven by the emergence of a connected, competitive, and entrepreneurial global economy, where successful engineers will need a technical competency and a professional skill set that differs from what worked in the past. Technology has made globalization possible and globalization, in turn, is affecting technology in profound and often unexpected ways. While globalization has increased prosperity and opened new and larger markets, globalization and Internet connectivity has also made available labor, that is often both educated and cheap. It is impossible to predict the long-term impact of these changes on the socio-economic structure of developed and developing countries, but what is clear is that the prosperity of nations is intrinsically linked to a population with the knowledge and know-how to develop and produce goods and services that are competitive [1,2]. The education of innovative and entrepreneurial engineers is therefore of critical importance to every nation.

The modern professional identity of engineers emerged in the early nineteenth century with the establishment of the Ecole Polytechnique in France and the foundation of professional engineering societies in England. The current way of educating engineers was already established by the early

Shaping Our World: Engineering Education for the 21st Century, First Edition.
Edited by Grétar Tryggvason and Diran Apelian.

twentieth century, but the content has, of course, changed significantly since then. The last major shift in engineering education in the United States goes back over half a century when the role of science in the educational program increased significantly [3]. Although some evolution certainly has taken place, those changes are relatively modest and the basic structure and course content of a modern engineering program is very familiar to someone educated in the 1960s. The time for another major reexamination of engineering education is overdue. Countless committees, taskforces, panels, and commissions have already addressed the need and eloquently emphasized that the competitiveness of the country and therefore our standard of living hinges on our ability to educate a large number of sufficiently innovative engineers [4–8, for example].

That the world has changed in fundamental ways during the past few decades is self-evident. Computers have fundamentally altered the way we live and work. They have, in particular, transformed our ability to deal with information and data. We are now moving rapidly toward a world where—for all practical purposes—we can *process information infinitely fast, store infinite amount of data, and transmit data instantaneously*, to paraphrase a statement made by Henry B. Schacht, the first chairman and CEO of Lucent Technologies Inc. in his commencement speech at WPI in 2001. As a result of the emergence of the Internet, knowledge has been "communalized." Everybody has access to information about anything and—perhaps equally importantly—knowledge is no longer "owned" by the experts. High-school students can—and do—write articles on Wikipedia, just like the professors. This change has already transformed industries and raised fundamental questions about authorship and ownership of information and scholarly works. Computers have also empowered the average man and woman to create products that previously required large corporations with significant resources. In many aspects of digital media we have now reached the point that if we can imagine it, we can create it. As computer speed and software advances, this trend will continue and in next 20 years or so it is very likely—certain, actually—that a high-school student with a little bit of time will have the capability to create his or her full-length animated movie with virtual actors of the quality currently only produced by major movie makers. The same transformation is likely to happen to the creation of engineered artifacts, although the time frame may be somewhat longer: If you can imagine it, you can create it! Ordering components through the web and receiving them in the mail is now part of everyday life and e-manufacturing—where the customer sends an electronic description of a part to a manufacture who makes it and mails it back—is emerging [9]. While low cost manufacturing is currently made possible by outsourcing it to countries with low labor cost, cheap and flexible robotics is likely to be equally or more important in the future.

The movement of labor intensive but low-skill industries to countries with low labor costs is, of course, not new. Such transfer has been largely responsible for the low cost and abundance of most manufactured goods and the rising importance of service over "stuff." Today, however, the rise in education in nations where salaries are low and the connectivity that makes this cheap and educated talent available worldwide are gradually changing the nature of jobs that move oversees. Skill is rapidly becoming a commodity that can be bought from low-cost providers anywhere. It does not matter what you know how to do, someone else knows it too and is willing to do it for less. Thus, highly educated workers are no longer immune from the possible outsourcing of their job.

The mechanization of labor and advances in transportation, taking place during the past century, coupled with the more recent information revolution and globalization of the economy, has brought us unprecedented opportunities and challenges. On the positive side is that the increase in our material wealth makes it—for the first time in history—realistic to talk about eliminating extreme poverty [10,11]. On the negative side is the possibility—for the first time in history—that human consumption of materials and energy may irreversibly damage the entire global environment [12,13]. Just as engineering brought us to where we are, engineering will be central to shaping the world of the future. Doing so will be both a daunting and an exciting undertaking!

1.2 WHAT IS ENGINEERING?

A discussion of the future of engineering education is impossible without an attempt to define engineering. Such definitions are in abundance: "engineers solve problems," "engineering is applied science," "engineering is the use of science and mathematics to solve technical problems." These definitions are about as accurate as describing Columbus as a sailor—true but vastly incomplete. Engineering is perhaps best understood in its relation to other disciplines. In Figure 1.1, we project several disciplines onto a plane defined by the *physical* versus the *cultural* world as one axis and *study* versus *create* on the other. The sciences obviously involve studying the *physical* world and humanities study the *cultural* world. Engineering falls squarely in the lower right quadrant (as does architecture, for example), thus sitting next to the sciences (studying the physical world) and the arts (creating the cultural world). Thus, engineering is properly described as the discipline focused on the creation of our physical world. Some professions, such as law and medicine, do not fit particularly well in this particular projection, pointing out important differences with engineering. Engineering is, of course, a profession. However, the fact that it fits naturally in the projection in Figure 1.1

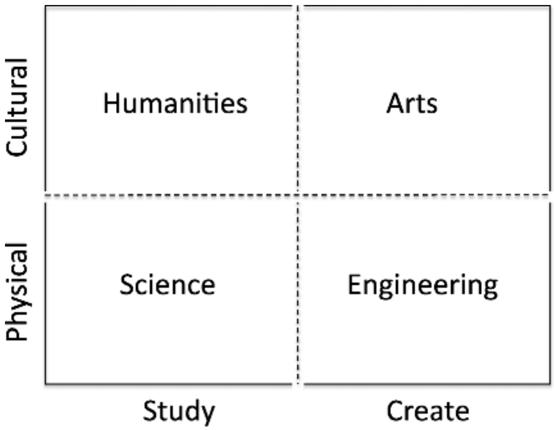

FIGURE 1.1 Projection of different disciplines onto a plane defined by cultural versus physical and study versus create. Engineering is the discipline focused on creating our physical world.

emphasizes an important distinction from many other professions—namely that engineering is also a discipline with well-defined intellectual foundations comparable but distinct from the sciences, arts, and the humanities. This difference is clear if one examines the roots of engineering and its evolution (see [14], for example). The importance of recognizing the discipline of engineering as distinct from the engineering profession has recently been emphasized by Duderstadt [15].

Engineering in the United States owes much to both French and British traditions. Louis XV established a civilian engineering corps to oversee the design and construction of bridges and roads in France. In 1716 he established the Corps des Ponts et Chaussées, which subsequently established a school to train its members; in 1747 Ecole des Ponts et Chaussées was founded in Paris—the very first engineering school ever. This led to the founding of other technical schools in France, the Grandes Ecoles. The famous Ecole Polytechnique of Paris was founded in 1794 by Napoleon. The French recognized engineering as a noble profession that prepared the future statesmen and leaders of their society. Laplace, who served as the head of a commission to reorganize the Ecole Polytechnique, wrote that the Ecole's goal is to produce young people "Destined to form the elite of the nation and to occupy high posts in the State." The graduates of these Grandes Ecoles have over the years proven their "power" by occupying posts in the highest economic strata of French society [16]. Engineering in Britain evolved along a very different path. The English upper class believed in a much more classical education wherein the bright young males sought careers in the church or in the army. There was no meaningful governmental funding of higher technical education during the industrial revolution and it was not until the early 1900s that Cambridge and Oxford Universities established chairs in Engineering Science. Much of the industrial revolution was driven by individual ingenuity and entrepreneurial initiative. Knowledge was gained pragmatically in workshops and on constructions sites. Apprenticeships became the way young men went into engineering. As Samuel Florman has characterized it—"In France engineering became associated with professional pride and public esteem, with leadership at the highest level. Whereas, in Britain, engineering was considered a navvy occupation—the original navvies being the laborers on canal construction jobs" [17]. Both of these cultures, the theoretical foundation emphasized by the French Ecoles and the practical hands-on attitude of the British, permeated across the Atlantic and impacted the development of engineering education in America. Although it is possible to argue that the marriage of theory and practice played no small part in the phenomenal successes of American engineering in the twentieth century, finding the right mix challenged engineering educators throughout the century.

As engineering education has changed in the past to adjust to the needs of society, the evolution must continue and change is needed to address the needs of the twenty-first century. With many approximations and generous error bars, we can summarize major trends in engineering education by the following classification (for a more fine-grained classification see Ref. [18]):

Nineteenth Century and First Half of the Twentieth Century: *The Professional Engineer.* As engineering became a distinct profession, early engineering programs focused on providing their graduates with considerable hands-on training. However, the role of science and mathematical modeling slowly increased and gained acceptance.

Second Half of the Twentieth Century: *The Scientific Engineer.* By mid-century, technological complexities required engineers to be well versed in science and mathematics and the engineering curriculum adjusted to the changed needs. This structure has, to a large degree, continued until the present time, although "design" content increased slowly. In the early 1990s, it was clear that more than science was needed and many schools started to emphasize nontechnical professional skills such as teamwork and communications.

The twenty-first Century: *The Entrepreneurial/Enterprising Engineer.* The rapid changes that the world is currently going through, as discussed above, coupled with changes in engineering education starting to take place in the 1990s, will result in an extensive reengineering of engineering education. While the new structure will, almost certainly, continue to be based on a solid preparation in mathematics and sciences, it is likely to emphasize the professional role of the engineer, and then demand new qualifications suited for the new world order.

These changes were driven by needs. The professionalization of engineering coincided with an explosion in the creation of new infrastructure and mechanization and the need for people with the appropriate skills to design and oversee such projects. Similarly, the "scientification" of engineering was a response to the realization that during the twentieth century, barriers to new engineering achievement were primarily our understanding of physical phenomenon. We could not build fast airplanes without understanding aerodynamics, we could not harness nuclear energy without understanding atomic physics, integrated circuits required understanding of solid-state physics, and so on. Engineers met the challenge learning what they needed to learn. There was a lot to learn and the learning consumed the profession for several decades. Indeed, for a while many engineers—academics in particular—became so enamored by what they were learning that they lost sight of why they were learning it. The distinction between engineering and science became blurred. The general public became confused too and could not distinguish the engineer from the scientist. A "rocket scientist" is, after all, usually an aerospace engineer! Engineering and science, however, make for a somewhat "strange bedfellows" in the words of E.E. Lewis [14]—a point reiterated by B.M. Gordon in his observation that the acronym STEM education (science, technology, engineering, and mathematics) lumps together very distinct topics [19]. The difference, as von Karman famously said, is that "scientists discover what is, engineers create what has not been." This observation is seconded in Figure 1.1.

1.3 THE ENGINEER OF THE TWENTY-FIRST CENTURY

Engineering students and their teachers are already scrambling to adjust to a world where all information is immediately available and tools to analyze and create new artifacts are in abundance. However, as skill becomes a commodity and routine engineering services are available from low-cost providers that can be located anywhere in the world, engineering education has to add value beyond just teaching skills. It seems reasonably safe to expect that the added value will include an extensive exposure to innovation and entrepreneurship [4–8], which in turn requires students to become superb communicators and to understand the context of their work. In Ref. [20] we suggested that the entrepreneurial engineer of the twenty-first century is someone who:

knows everything: can find information about anything quickly and knows how to evaluate and use the information. The entrepreneurial engineer has the ability to transform information into knowledge.

can do anything: understands the engineering basics to the degree that he or she can quickly assess what needs to be done, can acquire the tools needed, and can use these tools proficiently.

collaborates: has the communication skills, team skills, and understanding of global and current issues necessary to work effectively with anybody, anywhere.

innovates: has the imagination, the entrepreneurial spirit, and the managerial skills to identify needs, come up with new solutions, and take it into the world.

In some cases we are already making progress toward these attributes but in other cases we have a long way to go. The Internet has transformed our access to information in a way that is more like the invention of writing than the introduction of the printed book. Enormous amount of information is already available within a few clicks and everything ever written (and anything else that can be digitized) will be accessible within a few decades at most—probably not free, but certainly under a cost structure that will not impede access. We can now "google" any concept and the probability is that we will have an abundance of information in a matter of seconds. Thus, in some sense we already "know everything"—at least if we know how to ask. As search engines become more sophisticated, knowing how to ask is likely to become easier and the probability that the information we find is relevant will increase. The transformative effect of being able to access information instantaneously cannot be overemphasized. We all "know more than we know" because in addition to knowledge we possess, we also know where to find information about specific things. Most of us know how to fix our computers, not by knowing so ourselves, but by knowing whom to ask. The introduction of the Internet expanded this network of contacts to literally every piece of information that is out there. However, while finding information is already trivial, the communalization of knowledge will make it essential for the professional engineer to be able to judge the quality of the information that he or she has. Thus, teaching how to deal with an abundance of information and how to judge the relevance and the quality of the information at hand will be the educational challenge.

Traditionally, teaching engineering students how to do certain tasks took up a significant fraction of the time in the curriculum. The explosion in the availability of tools to do nearly everything does, however, suggest that engineering educators must rethink how students are prepared in the foundation of their disciplines. Computer programs to do virtually anything, from simple calculations to simulations of complex systems, to design a complete engineered artifact, and to create physical prototypes, empower the modern engineer to do more than his or her predecessors could ever imagine. These tools do, however, not only require the engineer to know how to use them but also require him or her to be able to first of all to assess what tool is appropriate for a given task and then to be able to evaluate the result in a critical way. Indeed, the importance of common sense will be even greater when design and analysis are done exclusively on the computer (as the saying goes: "to err is human, but to really screw up you need a computer"). While teaching engineering students how the physical world works will remain at the core of engineering education for the foreseeable future, reexamining how we teach the fundamentals of engineering science to students is needed.

In addition to what we teach, how we teach is starting to change. Internet tutorials and guides are already available on many subjects and in many cases complete courses, often specifically designed for Internet delivery [21,22] are available. This trend will accelerate and the material will grow in sophistication. The National Academy of Engineering has identified "advance personalized learning," where instructions "can be individualized based on learning styles, speeds, and interests," as one of the Grand Engineering Challenges" of the twenty-first century; Christensen [23] has discussed the impact of computerized learning on our educational system; and many investigators are engaged in developing and improving such systems [24,25, for example]. Since engineers need to know many things and be able to do much, engineering courses generally tend to have high content density and most of the class time is spent on information transfer (this is what you need to know and here is how to compute the answer). In other disciplines the emphasis is very different. A course in the humanities, for example, typically will include considerable time spent on reflection and discussion of the material. We obviously appreciate the value of "reflections" in engineering and many instructors have attempted to incorporate more of that into their courses [26]. In most cases, however, the need to "transfer information" is so great that everything else is crowded out. Computerized and personalized learning has the power to relieve us from much of the information transfer part. The engineering student of the future is likely to learn thermodynamics, for example, interacting with a computer program that adjusts to his or her learning styles and speed, provides constant feedback and assures mastery of every step, rather than from a faculty member droning on (and on) in the front of the class. Furthermore, once the foundations has been mastered, the rest of the studying will often be on a "just-in-time" basis, as the engineering student needs specific mastery for a specific task. With much (or at least some) information transfer moved out of the classroom, the time with a faculty member can focus on other aspects of engineering, such as developing communication skills, an understanding of the social context of engineering and fostering innovative and entrepreneurial mindset. The professor is now a facilitator and a coach of the learning environment, and the traditional lecture format of instruction is not the modus operandi.

Considerable progress has already been achieved in the United States to make communication in the broadest sense an integral part of the engineering curriculum [26,27]. Most programs now require their graduates to exhibit proficiency in oral and written communications and to be able to work on diverse teams. Engineering, possibly more than most professions, requires accurate and efficient communications—I have to understand what you are saying and vice versa for the design that we both are working on to function. Furthermore, in a world where highly networked organizations are increasingly replacing highly hierarchical ones, the ability to communication is key for professional success. The surprising thing about communications is not that engineering schools have recently started to emphasize it (motivated by ABET [27], in some cases), but that there ever was a need to remind educators that engineers need to communicate! However, in a global economy the ability to communicate takes on a much broader meaning. Not only are engineers frequently working on products that will be made in a different country and marketed to people of different cultures, but product engineering is increasingly done by teams consisting of people located in different countries and with diverse cultural background. Such interactions obviously have enormous potentials for misunderstanding and conflicts. Ron Zarella, CEO of Bausch and Lomb, said the following in a speech that he gave at WPI during a globalization workshop:

> We make a product called interplak. The electromechanical design for this home plaque-removal device is done in Germany and Japan. The batteries are supplied from Japan, the motors are built in the Peoples Republic of China, the charging base is made in Hong Kong, the precision molded plastic pieces are manufactured in Atlanta, GA, the brush head is made in Ohio, and the final assembly is done in Mexico.

Preparing young engineers to work in a global (or "flat" according to Ref. [28]) world is no longer something that engineering schools can treat as an extracurricular activity, available only to those who have the time and resources to spend an extra semester abroad. Every student must now develop the attitudes and skills necessary to function globally, right from the time they first enter the workforce.

As important it is for the engineer to understand the physical sciences, the "show stoppers" of the new century are likely to have as much to do with human behavior than with the laws of Physics. We have technical solutions that allow us (at least in principle) to provide unlimited power and we could probably curb (or at least reduce significantly) greenhouse gas emission with nothing more than current technologies. The question will increasingly move from "can we" to "do we want to." The engineer is going to have to adjust to this environment. In addition to learning how the physical world works (and that will remain as important as ever) the engineer of the new century has to understand how humans behave. Attempts to understand human behavior go back to the beginning of the species. Historians have attempted to understand us, sociologists and economists have sought to predict our behavior, marketers have attempted to sway us, and politicians and religious leaders have dreamed about controlling us. For the most part we defy simple models, but in the last few decades our understanding of ourselves has moved forward significantly. We now know scientifically that we can be exasperatingly irrational (to the dismay of economists), have a strong sense of fairness, yet can be unspeakably cruel in the "right" circumstances (the Stanford experiment), make snap decisions, and depend intimately on each other. Some of our understanding comes from progress in medical imaging—where researchers are now literally able to see what we are thinking—and from a large number of careful behavioral studies. This progress is not just manifested by a flood of pop social science books [29–31] but also by increasingly sophisticated use of this knowledge in politics [32]. The importance of understanding how humans think, make decisions, and act is already evident in product design (the iPod contained no technological breakthrough, the Segway is a technological marvel), and we now know that failure to account for human behavior is often the main reason for catastrophic accidents (airplane crashes, Chernobyl). Understanding how to create systems, structures and products that work in harmony with how humans act will be central to the engineer of the twenty-first century. For him and her, social science may well become what physics was for the engineer of the twentieth century!

1.4 THE NEXT FEW YEARS AND THE WPI EDUCATIONAL PROGRAM

Although the details of engineering programs of the future are difficult to predict (and they may look very different from each other), the following developments seem relatively safe bets:

- Development of competencies (knowing everything and being able to do everything) will increasingly take place outside the classroom through personalized computer-based learning, with time with faculty members devoted to the development of other professional skills (collaborating and innovating).

- The emphasis on innovation and entrepreneurship in societal context will increase. All engineering students will be required to understand the role of engineering entrepreneurship in taking technologies to society, including through the creation of commercial enterprises.
- The need to be able to collaborate effectively will take on an increased urgency. All engineering students will, in particular, need to develop the experience and attitude needed to work globally, in collaborations with people with different cultural perspectives.
- Graduate education will become increasingly important and all students planning a career in engineering will complete a MS professional degree. The BS degree will allow an "early escape" for those using undergraduate engineering education as a springboard for other professions. The PhD degree will become more professionally focused, possibly along with alternative advanced professional degrees.
- The demand for more customization of engineering education will grow, to suit the diverse career plans of a new generation of students who have increased expectations of institutions that serve them [33]. This will increase the number of electives within disciplines and the offering of interdisciplinary degrees.

Fundamental to the WPI Plan, introduced in the early 1970s, is the acknowledgment that education consists of providing the student with the technical competency needed to accomplish certain tasks and the professional maturity to decide what tasks to take on. In the original incarnation of the Plan a student could acquire technical skills anyway he or she chose, but had to pass a test to prove his or her competency. The competency exam proved to be too far ahead of its time (they were tedious to administer and unpopular with the students) and soon gave way to more conventional "distribution requirements" for courses. The professional maturity part of the plan, on the other hand, focused on project work and has been an unqualified success. WPI currently requires student to do two major projects, usually done in the junior and the senior year. The senior project is a capstone experience that demonstrates application of the skills, methods, and knowledge in the student's chosen discipline to the solution of a problem representative of the type to be encountered in their career. In the junior project, on the other hand, the students "address a problem that lies at the intersection of technology and society." Many junior projects are done at global projects centers, often located in the developing world, and currently over half of all students at WPI do at least one project abroad. The WPI Projects Program, including the junior and senior projects, as well as the Global Perspectives Program, is discussed in more detail in Chapters 6, 8 and 14.

The WPI project experiences are focused on developing the student's professional mindset and prepare them to work collaboratively in an innovative, entrepreneurial, and global world. While WPI currently teaches the technical competencies necessary for the practice of engineering in a relatively conventional way, the emergence of "advance personalized learning" systems, where competencies can be acquired and assessed outside of the classroom, will allow the original philosophy of the plan to be revisited.

Although the WPI Plan is now 40 years old, the faculty has continued to introduce educational innovations. The Global Perspectives Program was, for example, not part of the original plan. The WPI curriculum is designed to be relatively flexible and this flexibility has profound implications for how changes can be introduced. The flexibility does, in particular, encourage faculty entrepreneurship and experimentation. New ideas can be introduced and examined outside of the mainstream, and allowed to gradually gain their place in the curriculum, in a way somewhat reminiscent of Christensen's theory of disruptive innovations [23]. Recent innovations include a Great Problem Seminar series designed to introduce first year students to project-based learning and ignite their passion for tackling tough and important problems, and the first undergraduate Robotics Engineering Program in the United States. The Great Problem Seminars series is described in Chapter 5 and the Robotics Engineering Program in Chapter 10.

1.5 CONCLUSION

It is unthinkable that our society can remain competitive and that we can sustain the present standard of living without a large number of people with the knowledge and know-how to innovate [1,2]. In the early days of our nation's birth, Noah Webster claimed that democracy succeeds and prevails only if the people have *economic* and *educational hope*, and that these two are closely interlinked. To educate engineers ready to face the challenges of tomorrow, we must appreciate how profoundly the world has changed from just a few decades ago. With skill becoming a commodity, the engineer of the future must be able to do more than just perform technical tasks. There have always been extraordinary engineers who have had the imagination, vision, dedication, and endurance to change the way we live. Those who did not, however, were in the past able to make a living performing routine engineering tasks. The young engineers of the future must, on the other hand, all be extraordinary. They will not be able to enjoy the comfort of well-paid jobs where routine tasks are performed more or less unchanged year after year. More and more the engineer of the future will be responsible for creating new ideas and solutions and seeing them through. Innovation has already been identified as one of the most important factors in the future prosperity of both nations and individuals [1,2,7,8,34]. The engineering challenges are, however, even greater. Not only must the engineer innovate, he or she must also be able to help the innovation become a reality. Thus, the education of the engineers of the future must prepare them to see new opportunities as well as to give them the skills needed to marshal the resources to realize their ideas. We believe that engineering education needs to be transformed, and that such a transformation must include reengineering the curriculum to focus on and nurture the creative aspect of engineering.

ACKNOWLEDGMENT

The discussion here borrows heavily from an earlier article, originally published in JOM [20].

REFERENCES

1. J. Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress*. New York: Oxford University Press, 1990.
2. D.S. Landes, *The Wealth and Poverty of Nations, Why Some Are so Rich and Some so Poor*. New York, NY: W.W. Norton & Company, 1998.
3. L.E. Grinter, "Report of the Committee on Evaluation of Engineering Education," *Journal of Engineering Education*, pp. 25–60, Sept. 1955. Reprinted in *Journal of Engineering Education*, pp. 74–95, June 2009. Available: http://www.asee.org/resources/beyond/grinter.cfm.
4. Committee on Prospering in the Global Economy of the 21st Century, (U.S.). *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Washington, DC: National Academies Press, 2007. Available: http://www.nap.edu/books/0309100399/html/index.html.
5. Tapping America's, Potential. *The Education for Innovation Initiative*. Washington, DC: Business Roundtable, 2005. Available: http://www.businessroundtable.org/pdf/20050803001TAPfinalnb.pdf.
6. National Science Foundation. *The Engineering Workforce: Current State, Issues, and Recommendations. Final Report to the Assistant Director of Engineering*, 2005. Available: www.nsf.gov/attachments/104206/public/Final_Workforce.doc
7. The Engineer of 2020: *Visions of Engineering in the New Century*. Washington, DC: National Academies Press, 2004. Available: http://www.nap.edu/catalog/10999.html.

8. Educating the Engineer of 2020: *Adapting Engineering Education to the New Century.* Washington, DC: National Academies Press, 2004.
9. See, for example, eMachineShop.com. "eMachineShop.com: Machine Custom Parts Online." 2010. Available: http://www.emachineshop.com.
10. J. Sachs, *The End of Poverty: Economic Possibilities for Our Time*, New York: Penguin, 2005.
11. M. Yunus, *A World Without Poverty: Social Business and the Future of Capitalism*, New York: Public Affairs, 2007.
12. A. Gore, *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*. New York: Rodale Press, 2006.
13. L.R. Brown, *Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble*. New York: Norton, 2006.
14. E.E. Lewis, *Masterworks of Technology: The Story of Creative Engineering, Architecture and Design*. Amherst, NY: Prometheus, 2004.
15. J.J. Duderstadt, *Engineering for a Changing World. A Roadmap to the Future of Engineering Practice, Research, and Education.* Ann Arbor, MI: The Millennium Project, University of Michigan, 2008. Available: http://milproj.dc.umich.edu/pdfs/2009/Engineering%20for%20a%20Changing%20World.pdf.
16. D. Apelian, "Re-engineering of Engineering Education—Paradigms and Paradoxes," Alpha Sigma Mu invited lecture, presented at the ASM Fall meeting, Pittsburgh, PA, October 18, 1993; Advanced Materials & Processes, vol. 145, no. 6, pp. 110–114, June 1994.
17. S.C. Florman, The Existential Pleasures of Engineering. New York: St. Martin's Press, 1996.
18. L.E. Grayson, The Making of an Engineer: An Illustrated History of Engineering Education in the United States and Canada. New York: Wiley, 1993.
19. B.M. Gordon, "Engineering Education Must Get Real," *New England Journal of Higher Education*, pp. 28–29, Summer 2007.
20. G. Tryggvason and D. Apelian, "Re-Engineering Engineering Education for the Challenges of the 21st Century." *Commentary in JOM: The Member Journal of TMS*, October 2006. Reprinted in IEEE Engineering Management Review, vol. 37, pp. 38–43, 2009. Also translated into Chinese (China University Teaching, vol. 12, pp. 84–86, 2008).
21. See, for example, Apple, Inc. "Mac Basic Tutorials: Find Out How." 2010. Available: http://www.apple.com/findouthow/mac/.
22. The Mathworks website has several tutorials and interactive sessions. See, for example, Mathworks, Inc. "MATLAB Tutorial." 2010. Available: http://www.mathworks.com/academia/student_center/tutorials/launchpad.html.
23. C.M. Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press, 1997.
24. See, for example, JEDM—Journal of Educational Data Mining. Available: http://www.educationaldatamining.org/JEDM/.

25. See, for example, Journal of Computer Assisted Learning. Available: http://jcal.info/.
26. P.C. Wankat and F.S. Oreovicz, *Teaching Engineering*. New York: Knovel, 1993. Available: http://www.knovel.com/web/portal/basic_search/display?_EXT_KNOVEL_DISPLAY_bookid=1287.
27. ABET Board of Directors, "Criteria for Accrediting Engineering Programs." 2008. Available: http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2009-10%20EAC%20Criteria%2012-01-08.pdf.
28. T.L. Friedman, The World Is Flat: A Brief History of the Twenty-First Century. New York: Farrar, Straus and Giroux, 2005.
29. R.H. Thaler and C.R. Sunstein, *Nudge: Improving Decisions About Health, Wealth, and Happiness*. New Haven, CT: Yale University Press, 2008.
30. D. Ariely, *Predictably Irrational: The Hidden Forces that Shape Our Decisions*. New York: HarperCollins, 2008.
31. J. Lehrer, *How we Decide*. New York: Houghton Mifflin Co, 2009.
32. M. Grunwald, "How Obama is Using the Science of Change." *Time Magazine*, vol. 173, no. 14, pp. 28–32, April 23, 2009.
33. N. Howe, W. Strauss, and R.J. Matson, *Millennials Rising: The Next Great Generation*. New York: Vintage, 2000.
34. C.R. Carlson and W.W. Wilmot, *Innovation: The Five Disciplines for Creating What Customers Want*. New York: Crown Business, 2006.