The Case for STEM Education

Challenges and Opportunities

Rodger W. Bybee

NSTApress
National Science Teachers Association

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PREFACE

All those who provide leadership in STEM education will find this book useful. No doubt you are beyond worrying about a precise definition of STEM because you use the acronym within the context of your work. So, you ask, what is the value of this book? The value can be found in two of the book's features. First, the early chapters explore the history and lessons of reform and explain contemporary STEM in an attempt to make its complexity clear. In this case, the book provides clarity about STEM and lessons for individuals at the state, district, and school levels.

Second, the book proposes ideas and a helpful process of strategic and even factual plans for those engaged in improving STEM education at various levels. The value of this book goes beyond clarifying discussions—it should be used to develop action plans for STEM education.

Those familiar with some of my earlier works—for example, *Reforming Science Education: Social Perspectives and Personal Reflections* (1993), *Achieving Scientific Literacy: From Purposes to Practices* (1997a), and *The Teaching of Science: 21st-Century Perspectives* (2010)—will recognize ideas, themes, and models from those publications. In many respects, the application of earlier ideas, themes, and models to the challenges and opportunities of STEM education represents the central theme of the book.

This book should be of interest to national and state policy makers interested in STEM education, state-level educators responsible for STEM initiatives, college and university faculty who educate future STEM teachers, local administrators who make decisions about district and school programs, and teachers who represent STEM disciplines.

Acknowledgments

I could not have developed the ideas in this book without the ideas and suggestions of many colleagues and friends. I express a deep and sincere appreciation to Harold Pratt, Mark St. John, and David Heil for our extended discussions during annual NSTA meetings. For their recommendations about technology and engineering education, I thank Greg Pearson, Kendall Starkweather, Mark Saunders, Karl Pister, and Cary Sneider. Celeste Pea provided background on the origins of the acronym STEM. Working on the Next Generation Science Standards has provided numerous opportunities to explore my ideas about STEM with Brett Moulding, Peter McClaren, Nicole Paulson, Rick Duschl, and Stephen Pruitt.

Robert Pletka, superintendent of Fullerton Unified School District, gave freely of his time and insights about a school administrator's role in STEM education. Jennifer Jeffries, associate vice president at California State University, San Marcos, and I had a long discussion about supplemental instruction and STEM education. I must thank and acknowledge Mike Lindstrom, past executive director of SciMathMN, for several extended conversations and permission to use his models for STEM. These conversations occurred during a 2011 policy-maker briefing in Minnesota.

Being an advisor to the Hands-On Science Partnership has resulted in several opportunities to discuss my ideas about STEM education with publishers interested in seeing that teachers and students have materials and equipment central to learning science, technology, engineering, and mathematics. For these opportunities, I thank Chris Chopyak, Steve Alexander, and Kathy Workman.

Kimberly Jensen from the San Diego County Office of Education did an excellent job drafting several chapters and established a foundation for the book. The final drafts were completed by Byllee Simon, who continues to be my assistant for numerous projects and to whom I am deeply thankful for all she does to make any project the best it can be.

NSTA had the proposal for this book reviewed by very competent and experienced individuals. When the manuscript was near completion, NSTA had the draft reviewed. I took all the reviewers' suggestions seriously and the book is better for their recommendations. Here, I thank those reviewers: Greg Pearson, Kendall Starkweather, and Francis Cardo.

I express my appreciation to NSTA's Claire Reinburg, for her continued support of my work, and Wendy Rubin, for her careful editing of the final manuscript.

Finally, Kathryn Bess has been an inspiration for this work, a source of numerous ideas, and consistently a critical friend.

Rodger W. Bybee
Golden, Colorado
2013

INTRODUCTION

How I Became Interested in STEM Education

The problems I address in this book were initially encountered through a variety of education workshops, presentations, and endeavors. Educators commonly use the acronym for science, technology, engineering, and mathematics—STEM—in diverse ways. I was struck by the contrast of authoritative statements that lacked specificity concerning the meaning of STEM. For example, individuals would proclaim, "We have a STEM center," "Our state has a STEM advisory committee," or "The district has a STEM program." Although I understood the disciplines to which the acronym referred, there seemed to be a lack of clarity about the meaning of STEM in the different educational contexts. With time, use of the acronym *STEM* spread within the education community, and the need for a clarifying exploration of the term *STEM* increased.

My initial interest in use of the acronym STEM was reinforced on numerous occasions for more than a year. The problem regarding clarity and meaning seemed to grow worse as STEM went from an acronym communicating four disciplines to the use of *STEM* to describe K–12 education groups, initiatives, programs, or practices. At one level, for example, one hears policy makers proclaim the need to retain individuals in STEM-related careers. In the K–12 context, I heard science coordinators proclaim the need to improve STEM courses. For the latter, it was not clear what might be taught and learned in the STEM course. I began to look for and ask second and third questions: What is the STEM program in your district? What does your STEM advisory committee discuss? What is the work of your STEM center? It should come as no surprise that the answers were sincere but quite varied. *STEM* referred to whatever the individual or group was doing. Most often, *STEM* referred to either science or mathematics. Much less often did STEM address technology and engineering. When reference was made to technology, the term usually meant computers and a means of delivering instruction. Technology is greater than computers and more than a means of teaching.

During the period of engagement and observations about the acronym *STEM*, I worked on the science component of the Program for International Student Assessment (PISA). My work on PISA reinforced a long-standing conviction that K–12 education should contribute to individuals' life and work as citizens. Education in the STEM disciplines also should include the application of these knowledge, skills, and abilities to life situations in STEM-related categories such as health choices, environmental quality, and resource use. While understanding the concepts and processes of traditional disciplines certainly contributes to citizens' intellectual growth, I argue that future citizens need educational experiences that transcend the traditional boundaries of science, technology, engineering, and mathematics disciplines. It is not enough to assume that if students know enough biology, for example, they will make healthy choices. One argument in this book is simple and straightforward: If we want students to learn how to apply knowledge, their education experiences must involve them in both learning the knowledge of STEM disciplines and reacting to situations that require them to apply that knowledge in contexts appropriate to their age and stage of development. It really is not complicated. STEM initiatives have the potential to provide these educational opportunities.

To be clear, I fully realize that discipline-based knowledge is essential. However, so are opportunities to learn how to apply knowledge and skills to situations one confronts in life.

With time, these experiences led me to believe that the widespread and varied use of STEM, current discussions of reform, and long-standing aims of education deserved to be explored and, I hope, clarified in a book-length discussion of the challenges and opportunities of STEM education.

A Few Words About Definitions and STEM Education

As STEM education continues to expand and develop, use of the acronym has been applied to advertisements, classrooms, competitions, conferences, curriculum, resources, presentations, workshops, summer experiences, and videos, to name only a few examples. All of these examples present significant variations in what STEM education might mean and how it might be defined.

There is an interesting paradox I have observed concerning definitions in education: Many request a definition, and few agree with one when it is presented. So it is with STEM education. The meaning or significance of STEM is not clear and distinct. There is reference to four disciplines, but sometimes the meaning and emphasis only include one discipline. In some cases, the four disciplines are presumed to be separate but equal. Other definitions identify STEM education as an integration of the four disciplines.

In time, I have found it most useful to read or listen for the context within which STEM is being used. In a sense, the context clarifies the meaning of STEM. It may be four separate disciplines, as in "We need more individuals entering STEM careers," or a general category, such as "The teachers had STEM experiences in industries this past summer."

For the purposes of this book, I begin with these separate but related goals. Education should contribute to

- a STEM-literate society,
- a general workforce with 21st-century competencies, and
- an advanced research and development workforce focused on innovation.

The broader category, which applies to everyone, is STEM literacy, which refers to an individual's

- knowledge, attitudes, and skills to identify questions and problems in life

situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues;
- understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design;
- awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and
- willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen.

This defines STEM literacy, a goal of STEM education. This goal has to be translated into policies, education programs, and, finally, the concrete practices of teaching. The contexts will vary as appropriate for formal and informal education; states, districts, and schools; K–12 and postsecondary education; and different grade levels, among other variables.

I hope the chapters in this book give direction to STEM education, if not a definition. That direction will be played out through leadership at the state, district, and school levels through policies, programs, and practices. To the degree this occurs, the education community will progress beyond Humpty Dumpty's view expressed to Alice in Lewis Carroll's *Through the Looking Glass*: "When I use a word,' Humpty Dumpty said in rather a scornful tone, 'it means just what I choose it to mean neither more or less'" (Carroll [1872] 1999, p. 57).

My Aims for This Book

My goals for those who read the book are to (1) develop an understanding of the historical and contemporary contexts of STEM reform and (2) provide some practical guidance and suggestions for STEM reforms that are appropriate to varied contexts—states, districts, schools, or classrooms. In addressing these aims, the book can be viewed in two parts. The first chapters present historical and contemporary contexts of STEM education. The latter chapters provide some practical suggestions as individuals become engaged in the reform of STEM education.

The first chapter discusses contemporary challenges of STEM education. The chapter describes several challenges and presents a model I introduced in earlier publications—the 4Ps of purpose, policy, programs, and practice—as a way to understand the various dimensions of STEM education. I return to this model in Chapter 10 and use it as a practical way to develop a plan of action for STEM education.

The second chapter reviews the Sputnik era and reforms of the STEM disciplines. The chapter includes the national mission and insights specific to educational reform. I include this historical discussion because Sputnik has been presented as a metaphor for the current era of education reform. This chapter is based on earlier work completed in 1998 while I was at the National Academies.

The third chapter sets the stage for the later chapters by describing several unique features for the STEM reform. The chapter addresses the themes of globalization and current STEM-related issues, 21st-century workforce skills, and the continuing pipeline of needs for scientists, engineers, computer scientists, health care workers, and other professionals.

Chapter 4 answers the question, How is STEM education reform different from other education reforms? The chapter discusses four themes as an answer to the question:

1. Addressing global challenges that citizens must understand
2. Changing perceptions of environmental and associated problems
3. Recognizing 21st-century workforce skills and
4. Continuing issues of national security

Chapter 5 provides an overview of 35 reports and articles that discuss STEM education. I have tried to move beyond the obvious point that STEM is used in many contexts with a variety of meanings and identify underlying and recurring themes that may be important.

Chapter 6 presents five policy recommendations for the federal government. This chapter is a response to a federal mandate to review STEM initiatives across federal agencies and coordinate, if not consolidate, various programs. This chapter provides an opportunity for me to make recommendations at the national level, as the remainder of the book addresses the state, district, and school levels.

Chapter 7 presents a framework and concrete way to begin thinking about STEM programs and practices.

Chapter 8 presents different perspectives of STEM education. I have heard or seen all of these perspectives, and it is highly likely there are more. These perspectives have been helpful to me, as they identify the meaning of STEM for those in leadership positions and certainly clarify discussions of policy and programs. My point is not to criticize or suggest one perspective. The idea is to help others recognize their perspective as they toil in the STEM fields.

Chapter 9 addresses a critical point that I have often heard. When taking a programmatic curricular view, does STEM imply an integrated perspective? Beginning with a view of separate STEM disciplines, the chapter progresses to a variety of ways that the STEM disciplines might be integrated. If you are thinking about an integrated approach to STEM, this chapter should help with the next steps and program design.

The final chapter will help you develop an action plan by considering critical factors such as the unit of change, resources, components, and support for STEM education. The plan should address the way you initiate, implement, bring to scale, and sustain STEM education, as well as how to evaluate the results. Finally, I return to the 4Ps and ask you to answer questions that help formulate specifics of an action plan for STEM education. Each chapter ends with several discussion questions for those conducting seminars, classes, or professional development workshops.

CHAPTER 4

How Is STEM Education Reform Different From Other Education Reforms?

"How is this education reform different from any other reform?" In the context of this chapter, the answer to this question is what differentiates STEM reform from other reforms, such as the Sputnik era. The answer gives some clarity to the meaning of STEM education. What makes a STEM reform different resides in four themes:

- Addressing global challenges that citizens must understand
- Changing perceptions of environmental and associated problems
- Recognizing 21st-century workforce skills
- Continuing issues of national security

Globalization has steadily increased in relevance in discussions about STEM education. Although abstract, the term *globalization* has captured our imagination and emerged as a theme with the potential for significant innovations. Because globalization is somewhat ambiguous, the term does not in and of itself suggest what those innovations might be. Indeed, most contemporary discussions of globalization variously describe processes, conditions, systems, forces, and historical eras and center on social relations, communications, economics, and politics. A discussion of the possible connections between globalization and STEM education and the identification of subsequent innovations for STEM education seem timely and appropriate.

This chapter has three parts. The first part uses global challenges to present themes that connect globalization and STEM education. Several of these themes, such as environmental problems, are understandable and easily connect to STEM education. The second section will cover other themes, such as economics, that will be unique to many in the STEM education community. The third part presents 21st-century skills and innovations implied by global challenges. The discussions in the chapter answer the question, How is the STEM reform different from other education reforms?

GLOBAL CHALLENGES FOR CITIZENS AND SOCIETIES

In considering the connections between globalization, STEM education, and the connective tissue of global challenges, one can rightfully ask an initial question: What constitutes a global challenge? A second reasonable question follows: Which problems are clearly appropriate for STEM education? Finally, what are the appropriate responses for the STEM education community?

Connecting Global Challenges and STEM Education

Answering the first question—What constitutes a global challenge?—centers on cross-border effects and issues related to the "global commons." These issues have to do with sharing the planet with others and recognizing use (and overuse) of common resources such as the atmosphere, biodiversity and ecosystem losses, deforestation, water deficits, and fisheries depletion. The consequences are problems such as global climate change, ecological scarcity, and emerging and re-emerging infectious diseases. These global challenges clearly have connections to the STEM disciplines and, subsequently, to international economics, politics, and national security (Rischard 2002).

Responding to the second question—Which problems are clearly appropriate for STEM education?—centers on the global problems for which the STEM disciplines provide insights, explanations, and potential solutions. Finally, the responses from the STEM education community require clarification of STEM literacy as an aim and the identification of new learning outcomes, curriculum programs, and teaching practices.

In education, the STEM disciplines have a long history of responding to societal issues, and we are now being called to address new challenges that extend beyond the personal and societal realms to global dimensions. Even a cursory review of daily news reports, National Research Council (NRC) reports (see, e.g., NRC 2009), or presidential addresses at the American Association for the Advancement of Science (AAAS) provides indicators for the theme of global challenges: "Reflections on Our Planet and Its Life, Origin, and Futures" (McCarthy 2009); "Science and Technology for Sustainable Well-Being" (Holdren 2008); "Grand Challenges and Great Opportunities in Science, Technology, and Public Policy" (Omenn 2006); "The Nexus: Where Science Meets Society" (Jackson 2005); and "The Grand Challenges of Engineering" (see *www.engineeringchallenges.org*) could also be added to this list. To be more specific, global challenges include topics such as climate change, health, energy efficiency, environmental quality, resources use, natural hazards, national security, and general themes of sustainable development (Sachs 2004).

Challenges for the STEM Education Community

Globally, there are myriad and unique challenges. In coming decades, nations must begin addressing STEM-related challenges that have general implications for education and the literacy of citizens. Our globe needs citizens who understand and are ready to address STEM-related challenges such as the following:

- Economic stability and the development of a 21st-century workforce
- Energy efficiency and adequate responses for a carbon-constrained world
- Environmental quality and the need for evidence-based responses to global climate change
- Resource use and the need to address continuing conflicts over limited natural resources

- Mitigation of natural hazards by preparing for severe weather, earthquakes, and fires
- Health maintenance and the need to reduce the spread of preventable diseases
- Public understanding of the role of scientific advances and technological innovations in health and human welfare

The global challenges citizens face are clearly significant and will require more than an education solution, but STEM education must be part of any response. The education response requires more than tinkering at the margins of current policies, programs, and research priorities and updating life, Earth, and physical science disciplines. The reform requires significant innovations for STEM education in general and, in my view, the curriculum in particular. The next sections explore themes that extend beyond the traditional school disciplines of science and math. Educators must rethink the fundamental content for school programs and address the 21st-century challenges.

CHANGING PERCEPTIONS OF ENVIRONMENTAL PROBLEMS

The perspective here centers on the observations that debates about, for example, global climate change have altered public perceptions about environmental problems; the role of science, technology, engineering, and mathematics in understanding and solving problems; and the connections between environmental problems and economics, politics, and societal values. Heightened environmental awareness and changed perceptions did not emerge from major reforms in traditional school science programs. Rather, the public's education likely occurred through the media, informal education, and various supplemental and ancillary programs in formal education.

Linking the Environment and Economics

Although perceptions and some attitudes about the environment have changed in recent times, major policy changes have been driven by economics, politics, and, most recently, national security. Since the 1960s, there has been a steady development of knowledge and understanding about the global environment and related problems. At first, this understanding centered on science and technology and was popularized by individuals such as Rachel Carson (1962), Paul Ehrlich (1968), and Garrett Hardin (1968) and publications such as *The Global 2000 Report to the President* (Barney 1980). These individuals and publications began introducing the social, economic, and political aspects of environmental problems. Groups such as the Natural Resources Defense Council (NRDC) and Worldwatch Institute began sending clear and consistent signals about increasing environmental problems and the counterpoint of sustainable development. My point here is this: In time, discussions of the environment have increasingly addressed global problems and incorporated aspects of all the STEM disciplines as well as social sciences, in particular economics and politics. Discourse has, for example, gone from scientific understanding of ecosystems to an understanding of ecosystem services and the implications of balancing resource conservation and use based on societies' values concerning consumptive (e.g., food and fuel) and nonconsumptive (e.g., health and aesthetics) services provided by ecosystems (Perrings et al. 2010).

Few have made more compelling cases for the link between global economics and the environment than Lester Brown in *Eco-Economy: Building an Economy for the Earth* (Brown 2001), *The Earth Policy Reader* (Brown, Larsen, and Fischlowitz-Roberts 2002), and *Plan B 3.0: Mobilizing to Save Civilization* (Brown 2008). While making the point that the relationship between the global economy and the Earth's ecosystems is increasingly stressed, Brown and his colleagues succinctly review the strengths and weaknesses of our present economic perceptions:

> The market economy has brought a wealth to the world that our ancestors could not even have imagined. It allocates resources among competing uses, it balances supply and demand, and it facilitates the specialization that underpins the productivity of modern economics. But as the economy expands, the market's weaknesses are beginning to surface. Three stand out: its lack of respect for the sustainable-yield thresholds of natural systems, its inability to value nature's services properly, and its failure to incorporate the indirect costs of providing goods and services into their prices. (Brown, Larsen, and Fischlowitz-Roberts 2002, p. 31)

Although Brown and his colleagues did not mention national security in this part, any contemporary review of either the economy or the environment mandates consideration of the causes and consequences for national security and the causes and consequences of conflicts.

Adding Sustainability to Ecology and Economics

The 20th century witnessed the rise of science and technology and an increasing awareness of environmental and resource problems. The contemporary environmental movement has relied on knowledge from scientific research and implemented many technologies designed to ameliorate the diversity and scale of environmental problems. As environmental problems have developed at all levels, from local to global, we have seen science and technology addressed as both the possible causes and the potential solutions. Relative to this discussion, the STEM disciplines also have become factors in political and economic decision making. More than any other time in history, science, technology, engineering, mathematics, and the environment now have direct links to human health and the goods and services that contribute to personal and social welfare.

Out of necessity, many in the scientific and engineering communities have turned their attention to the environment, increased our understanding of environmental issues, and broadened our perspectives by, for example, making clear which services are provided by ecosystems. Unfortunately, some insights only emerge when the ecological services become disrupted and diminished.

One role of science and technology is to help us understand the physical world and the consequences of human intervention in natural systems. But science can only tell us what did or will happen, not what *should* happen. Human decisions influence the direction, rate, and scale of change. As mentioned in the previous section, many of the decisions are directed by economic motives that have detrimental environmental consequences. The concept of sustainability serves as a counterpoint to current economic perspectives (Brown 1981) and connections to STEM education (Holbrook 2009).

In *Eco-Economy: Building an Economy for the Earth* (2001), Lester Brown states the case and challenge:

> Transforming our environmentally destructive economy into one that can sustain progress depends on a Copernican shift in our economic mindset, recognition that the economy is part of Earth's ecosystem and can sustain progress only if it is restructured so that it is compatible with it. The preeminent challenge for our generation is to design an eco-economy, one that respects the principles of ecology. A redesigned economy can be integrated into the ecosystem in a way that will stabilize the relationship between the two, enabling economic progress to continue. (p. 21)

This extract that provides important insights about the enormity of the challenge and the central place of ecology. Brown continues by identifying ecological principles that would be among those considered fundamental to an education in science and the environment with a global perspective:

> Unfortunately, present-day economics does not provide the conceptual framework needed to build such an economy. It will have to be designed with an understanding of basic ecological concepts such as sustainable yield, carrying capacity, nutrient cycles, the hydrological cycle, and the climate system. Designers must also know that natural systems provide not only goods, but also services—services that are often more valuable than the goods. (Brown 2001, p. 22)

In the early years of the 21st century, the United Nations Educational, Scientific and Cultural Organization (UNESCO) designated the years 2005–2015 as a decade of education for sustainable development. This UNESCO initiative has resulted in some countries, such as Germany, teaching students about issues related to sustainable development. This discussion set the stage for STEM education and innovations inspired by a global perspective.

RECOGNIZING 21ST-CENTURY WORKFORCE SKILLS

A quote from Dr. Alan Greenspan's testimony to the U.S. Congressional Committee on Education and the Workforce in September 2000 sets several themes for this section:

> [I]n today's economy, it is becoming evident that a significant upgrading or activation of underutilized intellectual skills will be necessary to effectively engage the newer technologies. (Greenspan 2000, p. 2)

Greenspan identifies several important points. He provides an economic justification for reform of STEM education and highlights "intellectual skills," which are later discussed as 21st-century workforce skills aligned with scientific inquiry and engineering design (Bybee 2010). He clearly emphasizes technology—an implicit goal of education that should be explicit and a priority in the theme of globalization and STEM education.

Changing Demands for Intellectual Skills

Just more than a century ago, many nations faced a period of substantial social change. The industrial revolution presented new demands on the intellectual skills of workers; they had to develop the cognitive skills to operate equipment in factories, manage production lines, and direct emerging transportation and communications systems. In that era, the equivalent of a high school education became a requirement for workers in many countries.

The 20th century was a period of significant scientific advances and technological innovations, both of which contributed to dramatic social progress. As a nation's economy advanced, the requirements for skilled workers increased, especially the need for intellectual skills, including those often associated with science, technology, engineering, and mathematics.

By 21st-century standards, the intellectual skills required in the early 20th century were low. With time, nations realized the economic value of creative ideas and efficient means for the production and delivery of goods and services. As the 20th century progressed, the number of individuals in jobs requiring manual labor and routine cognitive skills steadily decreased, while the number of jobs that required intellectual abilities and the ability to solve nonroutine problems increased. In short, work became more analytical and technical. During the past century, entry-level requirements for the workforce increased to levels beyond a high school education. Taking this general observation to the more specific, one would have to note the combined role of science, technology, engineering, and mathematics as a driving force of economic change and the steady shift in requirements for entry into the workforce, especially in developed countries. The changes just described suggest a fundamental place for science, technology, engineering, and mathematics in our economy and, by extension, in our education programs. The next section addresses the connections between 21st-century skills and STEM education.

21st-Century Workforce Skills

In 2007, the National Academies held workshops that identified five broad skills that accommodated a range of jobs, from low-skill, low-wage service to high-wage, high-skill professional work. Individuals can develop these broad skills in STEM classrooms and programs, as well as in other settings (NRC 2008; 2010; Levy and Murnane 2004).

Research indicates that individuals learn and apply broad 21st-century skills within the context of specific bodies of knowledge (NRC 2008; 2010; Levy and Murnane 2004). At work, development of these skills is intertwined with development of technical content knowledge. Similarly, in STEM education, students may develop cognitive skills while engaged in the study of specific STEM-related social or global situations. The following discussion presents five skill sets important for the 21st century. Those skill sets include adaptability, complex communications, nonroutine problem solving, self-management, and systems thinking. These skills are summarized from the NRC report *Exploring the Intersection of Science Education and 21st-Century Skills* (2010).

Adaptability includes the ability and willingness to cope with uncertain, new, and rapidly changing conditions on the job, including responding effectively to emergencies or crisis situations and learning new tasks, technologies, and procedures. Adaptability also includes handling work stress; adapting to different personalities, communication styles, and cultures; and adapting physically to various indoor or outdoor work environments (Houston 2007; Pulakos, Arad, Donnovan, and Plamondon 2000).

Complex communications and social skills include skills in processing and interpreting both verbal and nonverbal information from others in order to respond appropriately. A skilled communicator selects key pieces of a complex idea to express in words, sounds, and images as a way to build shared understanding (Levy and Murnane 2004). Skilled communicators negotiate positive outcomes with customers, subordinates, and superiors through social perceptiveness, persuasion, negotiation, instructing, and service orientation (Peterson et al. 1999).

Nonroutine problem-solving skills include a skilled individual using expert thinking to examine a broad span of information, recognizing patterns, and narrowing the information to diagnose a problem. Moving beyond diagnosis to a solution requires knowledge of how the information is linked conceptually and involves metacognition—the ability to reflect on whether a problem-solving strategy is working and to switch to another strategy if the current strategy is not working (Levy and Murnane 2004). Nonroutine problem solving includes creating new and innovative solutions, integrating seemingly unrelated information, and entertaining possibilities (Houston 2007).

Self-management and self-development include personal skills needed to work remotely, in virtual teams; to work autonomously; and to be self-motivating and self-monitoring. One aspect of self-management is the willingness and ability to acquire new information and skills related to work (Houston 2007).

Systems thinking includes understanding how an entire system works; recognizing how an action, change, or malfunction in one part of the system affects other components of the system; and adopting a "big picture" perspective on work (Houston 2007). It includes decision making, systems analysis, and systems evaluation, as well as abstract reasoning about how the different elements of a work process interact (Peterson et al. 1999; Meadows 2008).

The NRC recently published another more detailed report, *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century* (NRC 2012). These 21st-century skills reveal a mixture of cognitive abilities, social skills, personal motivation, conceptual knowledge, and problem-solving competencies. Although a diverse group of skills, this knowledge and many of these skills and abilities can be developed in STEM programs that include scientific inquiry, technological innovation, and mathematical computation. That said, it should be made clear that STEM education cannot, and probably should not, assume sole and exclusive responsibility for developing 21st-century skills.

THE ISSUE OF NATIONAL SECURITY

Until September 11, 2001, an economic perspective would have been justification enough for education reform with a much greater recognition of STEM education. The tragic events on that date added national security to the rationale for education reform. A major point from *Road Map for National Security: Imperative for Change* (United States Commission on National Security/21st Century 2001) is worth noting. After terrorism, the greatest threat to national security (according to this report) resides in our research and education. The Commission's report stated the following:

> In this Commission's view, the inadequacies of our systems of research and education pose a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine. American national leadership must understand these deficiencies as threats to national security. If we do not invest heavily and wisely in rebuilding these two core strengths, America will be incapable of maintaining its global position long into the 21st century. (p. IX)

In the period immediately following September 11, several of the recommendations from this report were implemented. Now is the time to address the importance of education, because the current inadequacies—such as low levels of achievement on international assessments—certainly leave the nation in a vulnerable position.

CONCLUSION

STEM reform differs from other education reforms in four major ways. There is a need to address global challenges citizens face, recognize changing perceptions of problems related to the environment, and address the requirements for a 21st-century workforce. Finally, the issue of national security has emerged as a new and unique concern.

DISCUSSION QUESTIONS

1. How is contemporary reform of STEM education different from other education reforms?
2. Are 21st-century skills different from traditional skills and abilities developed by education in the STEM disciplines?
3. Would you add a theme to those discussed in this chapter? If so, what is the theme, and how do you justify its addition?

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If you are interested in STEM education, policies, programs, or practices, or you work on STEM in some capacity at any level, *The Case for STEM Education* will prove to be valuable reading.

Author Rodger W. Bybee has written this book to inspire individuals in leadership roles to better understand and take action on STEM initiatives. The book's 10 chapters accomplish several tasks:

- Put STEM in context by outlining the challenges facing STEM education, drawing lessons from the Sputnik moment of the 1950s and 1960s, and contrasting contemporary STEM with other education reforms
- Explore appropriate roles for the federal government, as well as states, districts, and individual schools
- Offer several ideas and recommendations you can use to develop action plans for STEM

With an emphasis on both thinking and acting, *The Case for STEM Education* is a must-read for leaders at all levels: national and state policy makers, state-level educators responsible for STEM initiatives, college and university faculty who educate future STEM teachers, local administrators who make decisions about district and school programs, and teachers who represent STEM disciplines.

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