The Case for STEM Education

Challenges and Opportunities

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EDUCATION

TABLE OF CONTENTS

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.

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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

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

CHAPTER 1

What Are the Challenges for STEM Education?

If you are reading this sentence, you probably have an interest in STEM education. So, suppose you had to answer this question: What is STEM education? How would you answer? As you formulated the answer, what was the context of your viewpoint? Was it national policies, state standards and assessments, school programs, classroom practices, or something else?

As you answered the question, how did you think about STEM? Did you primarily think about a school discipline such as science or mathematics? Or did you consider four separate disciplines: science, technology, engineering, and mathematics? Or did you consider integrating two, three, or all four STEM disciplines?

Your point of view on STEM education quite likely was influenced by where you work, what you do, and your obligations. To state the obvious, the views individuals have of STEM education vary and are a function of their roles in the education system.

A FIRST LOOK AT STEM EDUCATION

Origins of STEM

Contemporary STEM originated in the 1990s at the National Science Foundation (NSF) as an acronym for science, technology, engineering, and mathematics. Here is a discussion I can imagine occurred. The first acronym proposed was SMET, representing the same disciplines but with an inescapable negative association with the word *smut*. So, the discussion continued with the question, "What acronym can we use for mathematics, engineering, technology, and science?" The answer was METS. Would this work? Then an insightful baseball fan responded, "No, that is a National League baseball team in New York." "Okay, how about STEM?" "Yes, that works." We will only have to worry about confusion with stem cell research. The acronym was subsequently used to describe various NSF initiatives and programs. STEM thus had quite a simple yet functional origin.

When STEM first appeared in education contexts, it caught the attention of several groups. Botanical scientists were elated, as they thought educators had finally realized the importance of a main part of plants. Technologists and engineers were excited because they thought it referred to a part of the watch. Wine connoisseurs also were enthusiastic, as they thought it referred to the slender support of a wine glass. Finally, political conservatives were

CHAPTER 2

What Can We Learn From the Original Sputnik Moment?

The term *Sputnik* has come to symbolize reform of STEM education and a response to a perceived national crisis. For example, some call for a Sputnik Summit to address the potential decline of U.S. competitiveness. Others simply proclaim the need for another Sputnik to initiate the improvement of STEM education.

The use of Sputnik as a metaphor reached its apogee in the 2011 State of the Union address to Congress, when President Barack Obama said to the nation, "This is our generation's Sputnik moment." Elements of this discussion are based on an earlier discussion during the symposium Reflecting on Sputnik: Linking the Past, Present, and Future of Educational Reform (Bybee 1997b). Because of the continuous reference to Sputnik, I provide some reflections on that historically important era in STEM education.

The thesis of this chapter is that Sputnik provides some insights and lessons not often discussed in the zeal to improve STEM education. The central discussion explores several dimensions and dynamics that influence present-day initiatives.

Those interested in detailed and thorough discussions of the Sputnik era would benefit from the following resources: John Rudolph's *Scientists in the Classroom: The Cold War Reconstruction of American Science Education* (2002), George DeBoer's *A History of Ideas in Science Education: Implementation or Practice* (1991), and J. Myron Atkin and Paul Black's *Inside Science Education Reform: A History of Curricular and Policy Change* (2003).

THE BEGINNINGS OF REFORM

The education reform of the 1950s and the 1960s was already in progress when the Soviet Union placed Sputnik in orbit. In 1951, with the leadership of Max Beberman (1958), the University of Illinois Committee of School Mathematics (UICSM) initiated a reform of the secondary school mathematics curriculum. In science, the stage had been set by Jerrold Zacharias, who in 1956 began the Physical Science Study Committee (PSSC) a year before the launch of Sputnik. However, Sputnik still played a significant role in the educational reform of this era.

A Turning Point in the History of Education

The Sputnik era was a significant turning point for the STEM disciplines. It brought the sciences and mathematics to the foreground of education reform, but unfortunately it also moved

Innovations in Instructional Activities

Among the significant influences from the Sputnik era are the many classroom activities and lessons that have been infused into science and mathematics education. For example, the ESS program produced activities such as "Batteries and Bulbs" and "Mystery Powders." To this day, these activities and many others are used in classrooms, undergraduate teacher education programs, and professional development workshops. Though these activities are not as nationally prominent as student achievement scores, we did effect some changes in the teaching and learning of science and mathematics.

Collaboration on Curriculum Development

I think it is quite significant that senior scientists, mathematicians, and engineers worked along with teachers and other educators on this reform. They set a precedent for current and future reforms of education. It also is significant that many educators—for example, those responsible for teacher education—were not directly involved in the reform and were slow to support it, doing so through revision of programs for certification and licensure, professional workshops for teachers, and undergraduate courses for future teachers.

The End of an Era

The Sputnik era continued into the early 1970s; if I had to indicate an end of the era, it would be 1976. *Man-A Course of Study* (MACOS), an anthropology program developed with NSF funds, came under scrutiny and widespread attack from conservative critics who objected to the subject matter (Dow 1991). The combined forces of House subcommittee hearings, NSF internal review, and the Government Accountability Office (GAO) investigation of the financial relationships between NSF and the developers signaled the end of the MACOS program and symbolized the end of an era of curriculum reform.

REFLECTIONS FROM THE SPUTNIK ERA

Although the task of education reform is complicated by the scale of the problem and complexity of the education system, the work is essential. Those interested in reform may benefit from a brief reflection on this one period in our history. Although I have stated variations of these lessons in other contexts (Bybee 1993; 1997b; 2010), I state them again not because they are new, but because the generation of STEM reform and reformers is new.

I used the noun *reflection* because it presents an interesting metaphor for an examination of the Sputnik era. Reflection suggests two things: It implies seeing something from a different angle, as in light reflected from a mirror, and also means concentration or careful consideration, as in personal reflection on past events. Reflecting on education reform, then, may mean pausing and considering an era such as Sputnik from a different angle. Most reflect on the Sputnik era and extol the zeitgeist that permeated the period and ask questions about the characteristics of different programs and whether we were successful or not. In this reflection, I am taking another approach and asking different questions. This discussion reports more than a series of observations; it is a synthesis of ideas from authors who have examined the recent history of American education, especially in science and mathematics. The discussion centers

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?

Could STEM Education Provide Pathways to Prosperity?

Pathways to Prosperity, a report from the Harvard Graduate School of Education, was released in early 2011. The report builds a case from a more demanding labor market to the need for broader and deeper skills and insights from a global perspective on education reform. *Pathways to Prosperity* places considerable emphasis on the need to close the continually widening gap between demands of a 21st-century labor market and the interests and aspirations of 21st-century youth, especially minorities.

Several of the proposals in this report rest on the case that students cannot see connections between school programs and opportunities in the labor market. While avoiding explicit tracking, the report recommends developing connections between learning and work beginning in high school. Insights for these recommendations come from vocational education programs in northern and central Europe and especially from *Learning for Jobs* and *Jobs for Youth*, two reports from the Organisation for Economic Cooperation and Development (OECD 2009a; 2009b).

Work-based learning and career and technical education (CTE) programs are the pathways to prosperity that schools, especially high schools, should implement. Such programs would help adolescents and their families identify the patterns of course-taking and other experiences that would best position them for future careers.

There are direct implications for STEM, such as the engineering program Project Lead the Way and technology education programs, and indirect implications for science and mathematics education programs.

What Are Teachers' and Administrators' Perceptions of STEM Education?

The STEM education and leadership program at Illinois State University conducted a survey of 200 teachers and administrators (Brown, Brown, Reardon, and Merrill 2011). The survey was conducted to answer two questions: (1) Do administrators and STEM teachers have a basic understanding of STEM education? (2) What do administrators and STEM teachers believe about STEM education?

With regard to the first question, the authors concluded that STEM education is not well understood. Less than half of administrators understood STEM education—even though they had teachers in their building participating in a STEM-focused graduate program. Even teachers in STEM disciplines indicated varied levels of understanding of STEM education. In answering the second question, the team concluded that there is not a clear vision of STEM education even among those who support and teach STEM (Brown, Brown, Reardon, and Merrill 2011).

Although limited in scope, the implications of this research amplify the continuing need to clarify the form and function of STEM in education contexts and how STEM may be implemented in states, schools, and classrooms. The latter need is one purpose of this book.

Is STEM Education Slow Off the Mark?

Yes, according to a 2011 report from the Center for American Progress. The report is titled *Slow Off the Mark: Elementary School Teachers and the Crisis in Science, Technology, Engineering, and Math Education* (CAP 2011). The report makes a case for STEM education and the fact that elementary teachers are not prepared in STEM disciplines, especially science and mathematics. The background and rationale for the recommendations rest on the need to improve prospects for the future of U.S. global competitiveness.

Table 7.1. Contexts for STEM Education

Global, national, and local issues	Health maintenance and disease prevention Energy efficiency Environmental quality Natural hazards Natural resource use Understanding of STEM disciplines
Educational theme	A STEM-literate society
Advancing the goals of STEM education	Address 21st-century grand challenges in appropriate programs, courses, and classes Provide opportunities for the applications of knowledge and skills to STEM-related issues Include scientific, engineering, design, and mathematical Practices

A Definition of STEM Literacy

We can begin the discussion with a definition. My work on the Program for International Student Assessment (PISA) has influenced this formulation of STEM literacy (see OECD 2006; OECD 2009; Bybee and McCrae 2009). Figure 7.1 presents a proposed definition of STEM literacy.

This discussion of STEM literacy begins with the assertion that the primary purpose of STEM education is not solely and exclusively mastery of subject matter in respective STEM disciplines. Of course, STEM literacy includes the basic science, technology, engineering, and mathematics concepts and processes, but it must go beyond this traditional discipline-bound view. Rather, it should center on education that consists of the general learning of all citizens. In general, this is the Greek idea of *paideia*. Although understanding foundational subject matter in the sciences, technology, engineering, and mathematics is essential, one must consider the use and application of that knowledge, not just the acquisition of knowledge as a primary purpose of STEM education.

Future Scientists, Technologists, Engineers, and Mathematicians

There should be a clear distinction between an education in science that prepares for future study of science, for example, and an education that contributes to students' growth into literate adults. As literate adults, individuals should be competent to understand STEM-related global issues; recognize scientific from other nonscientific explanations; make reasonable arguments based on evidence; and, very important, fulfill their civic duties at the local, national, and global levels.

The idea that the purpose of education should center on full development of students as future citizens is quite old. In contemporary discussions of *Global Crises, Global Solutions* (Lomborg 2004), one can identify the purpose of STEM education with the following quote:

> Defining scope of the problem of "lack of education" must begin with the *objectives* of education—which is to equip people with a range of competencies