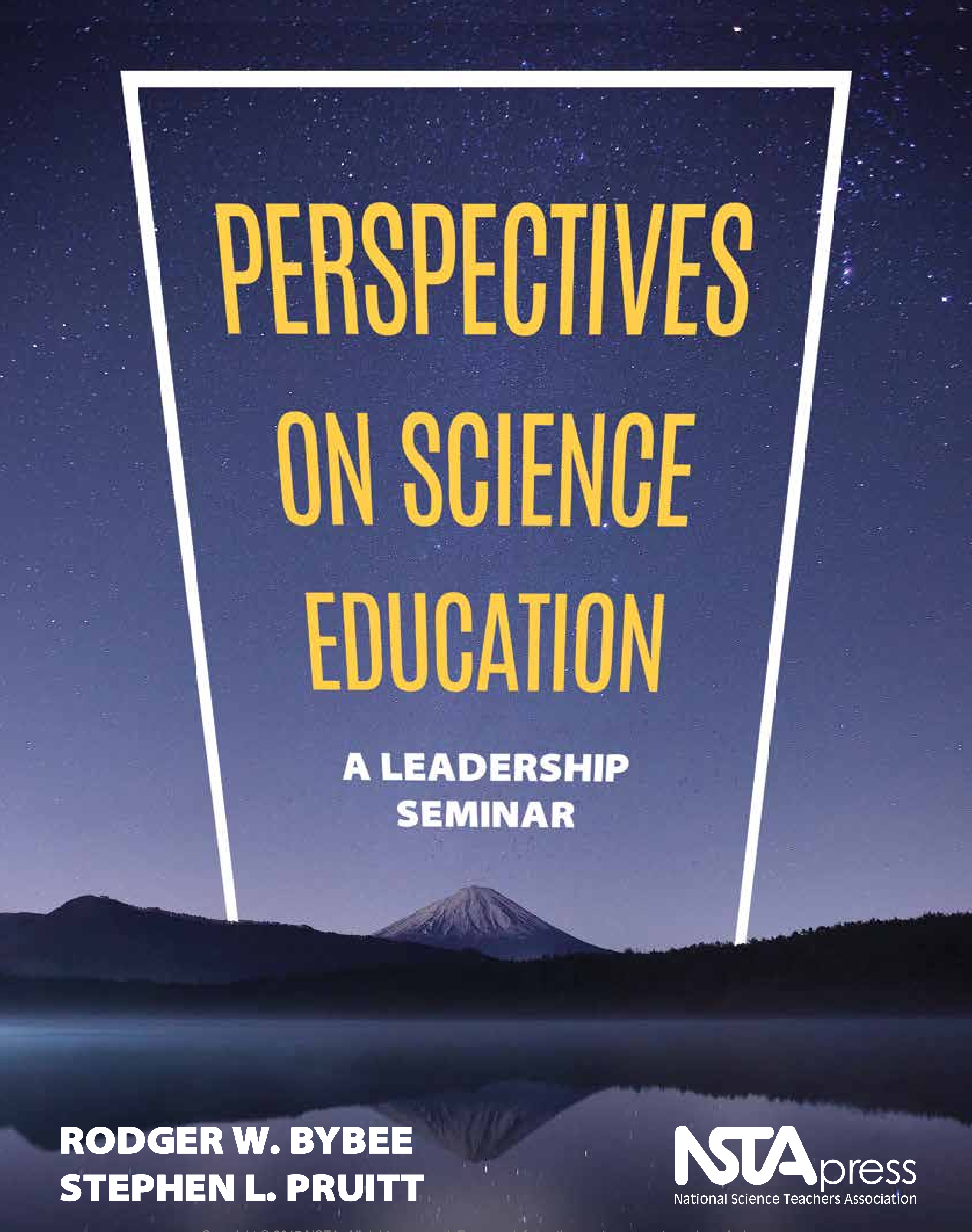

PERSPECTIVES ON SCIENCE EDUCATION

A LEADERSHIP SEMINAR

RODGER W. BYBEE
STEPHEN L. PRUITT

NSTA press
National Science Teachers Association

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ACKNOWLEDGMENTS

Our gratitude extends to the many individuals with whom we have interacted and from whom we have learned about the various realms of science education. To our teachers, college faculty in both science and education, and professional colleagues, we extend our appreciation for your many and varied contributions to our perspectives on science education. We also have held positions of leadership, and in all of these situations, numerous individuals have made decisions and supported our opportunities to lead. Finally, we have had thousands of conversations in classes and meetings and at conferences that have informed our professional knowledge and abilities. We thank all of the individuals who shared their views with us.

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Stephen: My first acknowledgement has to be to my co-author and very good friend, Rodger Bybee. He has probably forgotten more than I will ever learn, and he has been a great friend and mentor throughout the development of the *Next Generation Science Standards* (*NGSS*) and this book. I have had an opportunity to meet so many great people through my work with *NGSS* and am thankful for them all. However, it was Rodger who kept me sane, reminded me of history, allowed me to vent, and pushed me intellectually at every turn to do something special for the students of our country. I am honored to be his friend.

My second acknowledgement is to my two children, Samuel and Abby. It is for you I work hard to made education better for future generations. You both inspire me.

Finally, and most important, my greatest acknowledgment is to my wife, Cecelia. She has made my life a dream. She has believed in me far more than I believed in myself. She pushed me to do great things for our kids, the kids of the country, and now the kids of Kentucky. I am not being sentimental when I say I owe all my success to her. She saw abilities in me I never did. She pushed me to use them, and as a result I have had a special career. Thank you for your love, support, and encouragement.

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Rodger W. Bybee
Stephen L. Pruitt

PREFACE

Depending on the policy, report, or event, one can claim that science education reform has been on the national agenda for days, months, years, decades, or even centuries. Today's media regularly report on the poor achievement of American students on national and international assessments. From January 2001 until December 2015, educators heard about issues associated with the No Child Left Behind Act (NCLB); now there are new challenges posed by the Every Student Succeeds Act (ESSA). Business leaders look to science education to prepare a 21st-century workforce. Finally, there are continuous references throughout this book to health, environment, climate, and other issues that require significant levels of scientific literacy for all citizens.

Whether the means for improvement resides with curriculum materials, teachers' professional education, assessments, or assorted other initiatives, responsibility for improvement ultimately rests with the science education community. This community includes classroom teachers, science coordinators, district administrators, state science supervisors, college and university researchers, curriculum developers, science assessment specialists, administrators of national organizations, and federal agencies.

Looking at the science education community, there is a clear and—we think—compelling need to develop a new generation of leaders who understand science education and are willing to confront the challenges of reform. This book is our response to those ready to face the challenges and provide leadership for education reform.

The general idea for this book originated about a decade ago. F. James Rutherford and Rodger Bybee had a series of discussions about the need for a new generation of leaders in science education. The discussions included many of the themes in this book, such as the goals of science education, standards, and assessments. These conversations were rich in content, drew on professional experiences, and capitalized on different perspectives. However, like many such discussions, they were not fully developed and the ideas never evolved into a book.

The notion of a book on contemporary perspectives and leadership re-emerged with an invitation to both of us to make a presentation at the 2014 National Science Teachers Association (NSTA) national conference. We decided to engage in a dialogue about science education standards through the years.

PREFACE

While the *Next Generation Science Standards* (*NGSS*) were the primary focus of that presentation, we thought it important to identify earlier reforms of science education. Such a discussion naturally centered on aims and goals, standards and benchmarks, curriculum and instruction, assessment and accountability, and teacher education and professional development. These, after all, are topics at the core of science education and central concerns of the science education community in general and science teachers in particular.

This book is not about the need to reform science education. Others have made that argument and undoubtedly will continue making it in the future. This book is about science education and what one needs to know, value, and be able to do as a leader initiating and sustaining reform. The book serves as an introduction to purposes, policies, programs, and practices that science education leaders should understand and be able to apply. Beyond an introduction to science education, we have presented some of the contemporary challenges and controversies that leaders will face: Is the purpose of science education to prepare scientists and engineers, a 21st-century workforce, or scientifically literate citizens? What is the role of federal, state, and local governments in setting standards for science education? To what degree should the curriculum include science-related social issues? What are the roles of politics and policies in science education?

We conceived the book as a seminar, one that begins with an introduction to themes that unify the presentations—perspectives, challenges, standards, and leadership. This introduction is followed by personal introductions. These brief autobiographies present our backgrounds and experiences in science education.

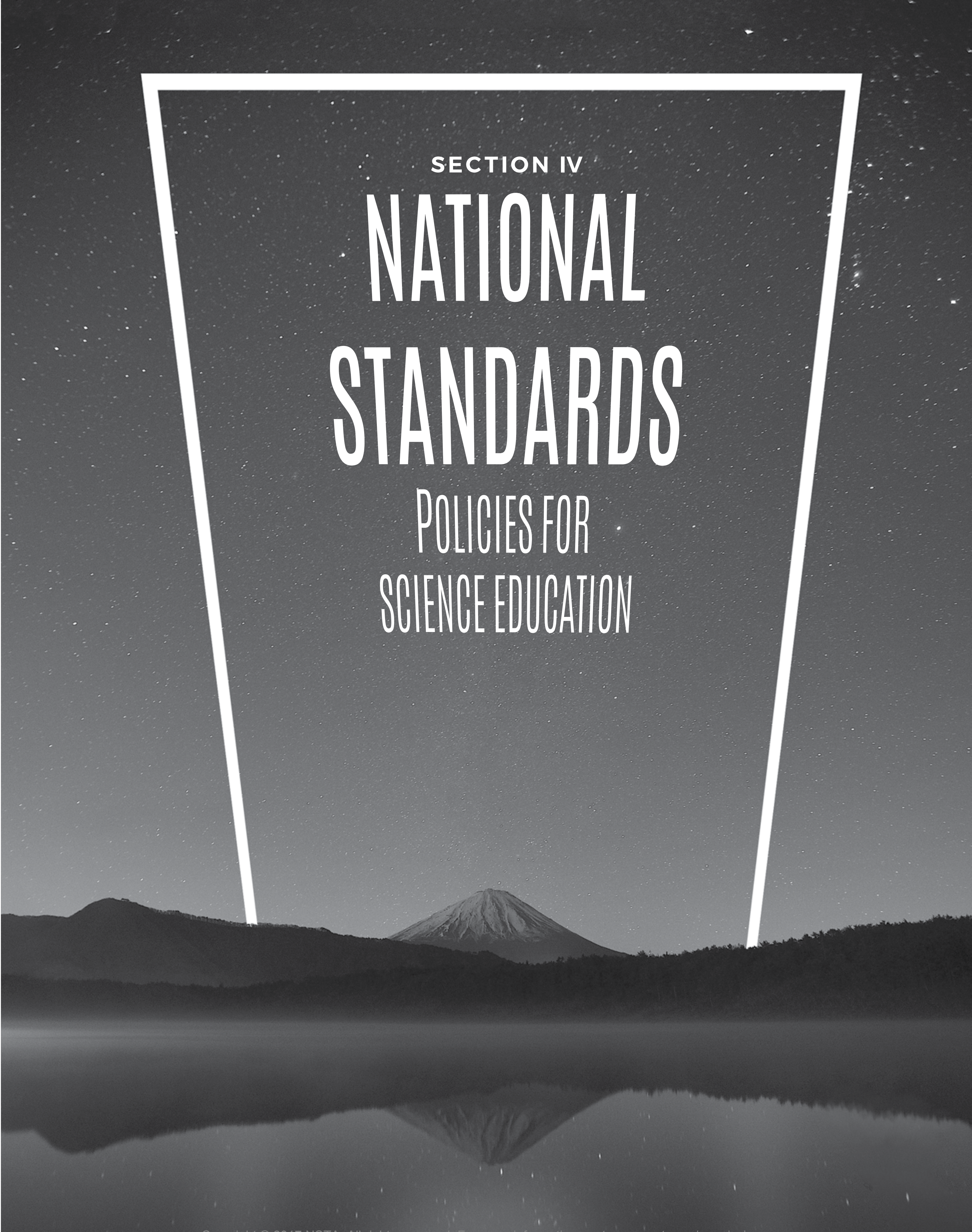
The book (and seminar) continues with a brief history of science education and a close look at the Sputnik era. These two sections of the book set the stage for the central topics of the purposes and goals of science education, national standards, state standards and district leadership, curriculum programs, classroom practices, professional development, and assessment and accountability. These are followed by reform, policies, politics, and two concluding sections on leadership.

Throughout the book, we use an informal, conversational style, as we would in an actual seminar. Most sections of the book include suggested readings that have historical or contemporary significance, personal perspectives, our common perspectives and leadership opportunities, and issues and questions for discussion.

Who is the audience for this book? This book is for those individuals already in leadership positions at national, state, district, and school levels; those enrolled in courses on curriculum and instruction; those participating in professional development; and those teachers of science who want to broaden and deepen their understanding of the foundations and dynamics of science education. Some individuals know much of what we present in the following chapters. They also are probably the ones who are teaching courses or arranging continued professional development. We hope our insights and discussions serve as the basis for continuing discussions. There are others who just want to understand more about their profession. This book is for all of you.

As mentioned, we conceptualized and developed this book as though we were presenting a seminar. Both of us have a broad set of experiences that range from teaching in science classrooms to formulating and implementing national and international policies and programs. We have careers that include the successes and failures of leadership. In a seminar, we would have the place to present our own scholarly work and that of others, the chance to express our perspectives on issues, and opportunities to challenge the participants with questions, situations, and issues.

Ultimately, science education leaders have to make decisions and set directions based on their positions and opportunities. In our careers, we have done just that. This book is not so much about answers; it is more about questions. It is not about persuading you of the need to reform; it is more about developing your understanding of science education and recognizing the challenges and opportunities of leadership. We present some of the perennial issues to structure the conversations so ideas are exchanged and individuals develop the understanding and abilities to lead. To the best of our knowledge, values, skills, and experiences, we try to begin professional conversations that will contribute to a deeper understanding of science education in general and your leadership in particular.



SECTION IV

NATIONAL STANDARDS

POLICIES FOR SCIENCE EDUCATION

Standards are specific policy statements and action plans based on the purposes of science education. Policies are concrete translations of the purpose and apply to specific components such as teacher education, K–12 curricula, and assessments.

National standards have become useful maps that provide purpose and direction in American education by answering questions about what students should know and be able to do after 13 years of school. At the same time, discussions of national standards and the implied reforms have raised questions about the purposes of education, the standards' impact on equity and excellence, who decides the content students should learn, and how society knows if students have learned the content and abilities the standards describe.

National standards identify the purposes and goals for education and—based on those aims—describe clear, consistent, and challenging learning outcomes. Who could be critical of this? After all, common sense and reasonable judgment suggest that educational quality and teaching are better if goals are clear and teachers' knowledge and skills, instructional materials, and assessments are all coherent.

The first generation of standards, the *National Science Education Standards* (*NSES*; NRC 1996), influenced state and district standards until the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013) were released. Table IV.1 summarizes the states that have adopted *NGSS* and those that have been influenced by *A Framework for K–12 Science Education* (NRC 2012) and the *NGSS* (NGSS Lead States 2013) in the development of their standards.

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SUGGESTED READINGS

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* New York: Oxford Press. A product of Project 2061, these were the initial standards for American science education.

Ravitch, R. 1995. *National standards in American education.* Washington, DC: Brookings Institution. An excellent introduction to and history of education standards.

Rutherford, F. J., and A. Ahlgren. 1990. *Science for all Americans.* New York: Oxford University Press. This volume set the stage for an era of national standards in science education.

Table IV.1. States That Have Adopted and Adapted the *NGSS*

States That Have Adopted the *NGSS*	States That Have Adapted the *Framework* and *NGSS*
• Arkansas • California • Connecticut • Delaware • District of Columbia • Hawaii • Illinois • Iowa • Kansas • Kentucky • Maryland • Michigan • Nevada • New Jersey • Oregon • Rhode Island • Vermont • Washington	• Alabama • Georgia • Idaho • Indiana • Massachusetts • Missouri • Montana • Oklahoma • South Carolina • South Dakota • Utah • West Virginia • Wyoming
States With Standards in Development or Not Formally Adopted	**States That Have Not Revised Their Science Standards**
• Colorado • Louisiana • Minnesota • Nebraska • New Hampshire • New Mexico • New York • North Dakota • Pennsylvania • Tennessee • Virginia	• Alaska • Arizona • Florida • Maine • Mississippi • North Carolina • Ohio • Texas • Wisconsin

Note: Updated September 23, 2016.

CHAPTER 7

NATIONAL STANDARDS AND SCIENCE EDUCATION

HISTORICAL PERSPECTIVES

This chapter provides background on the idea of standards, the context for contemporary national standards, and perspectives on the *National Science Education Standards* (*NSES*). Chapter 8 is an introduction to the *Next Generation Science Standards* (NGSS).

NATIONAL STANDARDS ARE A NEW IDEA—RIGHT?

National standards may seem like something new in American education, but they are not.

As you have seen, American education has a long history of committees, reports, and groups defining content and required courses that amount to standards. If the basic idea of standards is to provide clear and consistent statements of what students should know and be able to do, then standards, even if they were not called standards, have been a part of American education since Harvard established admission requirements in 1643, followed by Yale (1745) and Columbia (1778). With time, the admission requirements broadened from, for example, reading classical Latin (Harvard) to include the rules of arithmetic (Columbia; Ravitch 1995).

In 1892, the National Education Association (NEA) established the Committee of Ten, a panel of experts charged with making recommendations to improve the nation's high school curricula. As a national panel, the Committee of Ten had no precedent to make recommendations to thousands of school districts. The report was relatively effective, primarily due to the stature of the panel members as national leaders. The report recommended physical science (physics, astronomy, and chemistry), "natural history" (biology, which included botany, zoology, and physiology), and geography (physical geography, geology, and meteorology).

The standards described in these reports were clearly directed toward college preparation. Because of this orientation, many educators objected to the standards. As a result, the NEA established a Commission on the Reorganization of Secondary Education (CRSE), whose 1918 report (standards) was distinctly different from prior college preparatory standards. The committee included academic subjects and industrial arts, household arts, vocational guidance, agriculture, and other areas not generally considered academic. This committee report identified seven cardinal principles as the main objectives of education. Those principles included health, citizenship, worthy use of leisure, and ethical character. The individual academic subjects needed to be shown as making contributions to achieving these objectives. The emphasis was clearly on utility (What was useful for the student?) and social efficiency (How could school programs serve the needs of society?). In this justification of courses, in terms of educational objectives, geography was part of social studies (Ravitch 1995).

With the CRSE example, we point out the two different purposes of education, one with knowledge of academic disciplines and the second with a liberal arts orientation. The Committee of Ten example stressed an education primarily for college-bound students. In contrast, the CRSE underscored the purpose of social efficiency, an education for non-college-bound students. The CRSE report resulted in vocational and general tracks for some students and academic and college tracks for others. The contemporary perspective of college and career preparation is a possible resolution of the conflicting purposes expressed by the two committees and their respective national "standards."

Tests and Textbooks as Standards

We cannot leave this discussion of implied or suggested national standards without mentioning tests and texts. To be specific, we are referring to standardized tests and commercial textbooks. In the early decades of the 20th century, standardized achievement tests were introduced, as were college entrance examinations (Ravitch 1995). Both types of tests served as implicit academic standards for states and school districts. The American College Testing (ACT) and Scholastic Aptitude Test (SAT) examinations serve similar purposes today.

Textbooks, such as those used in science, also serve as de facto national standards in education. An estimated 75% (or more) of instructional time in classrooms is structured by textbook programs (Woodward, Elliott, and Nagel 1988). Although the report on this is several decades old, we have little reason to suggest significantly different percentages; however, this could change as states set new frameworks and adoption requirements based on contemporary national standards.

So, the term *national standards* may be a new addition to American education, but the idea of clarifying purposes and describing the content for curricula and assessments is by no means new. We continue with contemporary national standards for science education, beginning with their origins.

The Origins of Contemporary National Standards

In 1983, the landmark report *A Nation at Risk* (NCEE 1983) stimulated concerns and reforms among states. The report warned that the American education system was far behind its international competitors and that there were eminent threats to the country's economic future. The report recommended high expectations in academic subjects including science and a nationwide system of assessments. In time, it became clear that 50 states and thousands of school districts working independently could not meet the challenges and reduce the risks America faced. There was a need for national leadership.

On September 27 and 28, 1989, President George H. W. Bush gathered the country's governors in Charlottesville, Virginia, to discuss a single issue—education. This historic meeting resulted in the proposed America 2000 legislation (1991), which called for voluntary national standards. Congress did not pass the legislation. However, the idea of national goals and standards had risen to prominence. In 1989, the National Council of Teachers of Mathematics (NCTM) published *Curriculum and Evaluation Standards for School Mathematics*.

Given the increasing corporate attention to total quality management based on raising performance to meet higher standards of quality, it is not surprising that the National Educational Goals Panel (NEGP) found the idea of standards in different subjects and performance-based assessments attractive. When the National Council on Education Standards and Testing (NCEST) reported on the merits and feasibility of national standards and assessments, the NCTM standards had already provided the proof that NCEST needed—the mathematics standards. The standards set focus and direction, not a national curriculum; they were national, not federal; they were voluntary, not mandatory; and they were dynamic, not static.

NATIONAL SCIENCE EDUCATION STANDARDS: THE FIRST GENERATION

As you can see, support for national standards in science formalized in 1989, when the nation's governors and President George H. W. Bush established six national education goals, which were adopted by Congress and later expanded to a total of eight goals. In 1994, Congress enacted Goals 2000: Educate America Act and formed the National Education Goals Panel (NEGP) to support and monitor progress toward the goals. (See Table 7.1 [p. 94] for historical highlights of the *NSES*.)

Developing National Standards for Science

In science, two important publications preceded initial work on national standards. In 1989, the American Association for the Advancement of Science (AAAS), through its Project 2061 led by F. James Rutherford, published *Science for All Americans* (Rutherford and Ahlgren 1989). This publication defined science literacy for all high school graduates and provided the foundation for *Benchmarks for Science Literacy (*AAAS 1993), which had a significant influence on the development of national standards for science. Three years later, the National Science Teachers Association (NSTA), through its Scope, Sequence, and Coordination Project, published *The Content Core* (1992).

In 1991, the National Research Council (NRC) was formally asked by Dr. Bonnie Brunkhorst, then president of NSTA, to assume a leading role in developing national standards for science education. The NRC was encouraged by leaders of several other science and science education associations, the U.S. Department of Education, the National Science Foundation (NSF), and the NEGP. The effort—funded by the U.S. Department of Education, NSF, and the National Aeronautics and Space Administration (NASA)—was led by the National Committee on Science Education Standards and Assessment (NCSESA), advised by the chair's advisory committee that consisted of representatives from major science education organizations, and carried out by three working groups (i.e., content, teaching, and assessment) composed of science teachers, educators, scientists, and others involved in science education.

Preparations for work on the intellectual substance of the standards began in the fall of 1991. NRC staff were assigned to produce summaries of the proposed standards, based on the work of NSTA's Scope, Sequence, and Coordination; AAAS Project 2061; and other projects, as well as state science frameworks and science standards from other countries.

One early decision was to develop standards for content, teaching, and assessment all displayed in mutually re-enforcing ways. Another decision committed the working group chairs to function as a team throughout the project. A third decision was to take the critique and consensus process seriously, issuing frequent updates on the project and materials suitable for intense critique by teachers, subject matter experts, and others. Discussion and working papers were released in October 1992, December 1992, and February 1993. The first draft of content, teaching, assessment, professional development of teachers of science programs, and system standards appeared late in 1993.

Early drafts of the NRC standards were subsequently reviewed by groups of experts and large numbers of educators across the country. More than 40,000 copies of a complete draft were distributed in December 1994 to approximately 18,000 individuals and 250 groups for review. The comments and recommendations received from these reviewers were used to prepare the final document, which was formally released in December 1995 as the *National Science Education Standards* (NRC 1996).

National Science Education Standards: An Overview

In early 1996, the NRC consolidated its education activities into the Center for Science, Mathematics, and Engineering Education (CSMEE). CSMEE took on support for the new *National Science Education Standards* as an important priority, and Rodger Bybee was hired as the executive director. The first initiative of CSMEE was the preparation of an introduction to *NSES* (NRC 1997).

The *NSES* defined the science content that all students should know and the practices they should be able to do and provided guidelines for assessing the degree to which students have learned that content. The *NSES* detailed the teaching strategies, professional development, and support necessary to deliver high-quality science education to all students. The *NSES* also described policies needed to bring coordination, consistency, and coherence to science education programs. You can see from this summary that the *NSES* were a comprehensive set of standards for science education. Specifically, the *NSES* included standards for science content, teaching, assessment, professional development, school science programs, and the education system's support of *NSES*.

In *NSES*, the content standards included the following:

- Unifying concepts and processes

- Science as inquiry
- Physical science
- Life science
- Earth and space science
- Science and technology
- Science in personal and social perspectives
- History and nature of science

The first category of the content standards, unifying concepts and processes, identified powerful ideas that are basic to science disciplines. These standards included both conceptual and procedural content (e.g., systems, order, and organization; evidence, models, and explanation). The other content categories included knowledge and abilities in inquiry, which ground students' learning of subject matter in physical, life, and Earth and space sciences. Science and technology standards introduced the similarities and differences between the natural and designed worlds and questions and problems. The personal and social perspectives standards introduced students to science in life situations and helped them develop decision-making skills. The history and nature of science standards helped students see science as a human experience that is both ongoing and ever-changing (NRC 1996).

Benchmarks and Standards

The *Benchmarks for Science Literacy* (AAAS 1993) were also statements of standards and caused some confusion within the science education community. Which should be used, the *Benchmarks* or *NSES*? There were differences. For example, the *Benchmarks* included components for different grade levels and included more content in social and behavioral sciences and mathematics. The *NSES* gave greater emphasis to inquiry both as science content and as a teaching strategy. Finally, as mentioned above, the *NSES* addressed a broader range of standards. There was, however, an estimated 90% consistency of content between the *Benchmarks* and *NSES*. Use of either document by states or local school districts would improve science education.

Finally, the *NSES* content clarified scientific literacy. Here is an answer to the question, "What is scientific literacy?" Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. People who are scientifically literate can ask, find, or determine answers to questions about everyday experiences. They are able to describe, explain, and predict natural phenomena.

Scientific literacy has different degrees and forms; it expands and deepens over a lifetime, not just during the years in school. The *NSES* outline a broad base of knowledge and skills for a lifetime of continued development in scientific literacy for every citizen and provide a foundation for those aspiring to scientific careers (NRC 1996).

Table 7.1. ***National Science Education Standards:*** **Historical Highlights**

Year	Highlights
1983	*A Nation at Risk* is released by NCEE.
1989	*Curriculum and Evaluation Standards for School Mathematics* is released by NCTM. National Governors Association releases national educations goals. President George H. W. Bush forms the NEGP. *Science for All Americans* is released by AAAS.
1991 **1992**	NSTA's president and executive director request the NRC coordinate development of national standards for science education.
1993	The NRC establishes the National Committee on Science Education Standards and Assessment (NCSESA). The first meeting of NCSESA takes place.
1994	*Benchmarks for Science Literacy* are released by AAAS-Project 2061. The first complete draft of standards for science education are developed and released.
1996 **1996–2013**	Professional organizations, focus groups, and the NRC report review teams evaluate the first draft of standards. The second draft of the standards is released, and 40,000 copies are distributed for review
	The *National Science Education Standards* are released (NRC 1996). The *NSES* continue to influence components of the science education system until 2013, when the *Next Generation Science Standards* are released.

A PERSONAL PERSPECTIVE

THE *NATIONAL SCIENCE EDUCATION STANDARDS:* REFLECTIONS AFTER A DECADE

Rodger Bybee

"Nationwide Standards Eyed Anew." This headline appeared in the December 7, 2005, issue of *Education Week.* The story highlighted the diversity of demands by states and the resurgence of national standards. The article (Bybee 2006) quoted Diane Ravitch: "Americans must recognize that we need national standards, national tests, and a national curriculum" (p. 1). This article appeared 10 years, almost to the day, after the release of the *National Science Education Standards (NSES*). The article and quote expressed views generally consistent with my own. The United States needs national standards for science education and for technology and mathematics as well. National standards provide the means for improving student achievement while maintaining the authority for states and local school districts to determine their science programs. In principle, this is possible. In practice, it is far from reality. But that is not a reason to reject national standards. Indeed, quite the opposite is the case. We should embrace the national standards for science education. Although originally written in 2006, I think these ideas still hold in 2016.

It is worth noting several things about standards at the beginning of this essay. National, state, and local standards are primarily a reflection of values and priorities of those individuals, organizations, and agencies responsible for developing the standards. They are not research reviews or based on research. Questions about the influence of the *NSES* on education are important for research, albeit they are very complex issues to investigate. Second, the *NSES* provide policies for curriculum, instruction, assessment, and professional development. They must be interpreted by those responsible for designing and implementing programs, facilitating changes in instructional practices, and instituting new assessments and accountability measures. Finally, any significant influences of national standards on the education system will take time, likely more than a decade; a reasonable estimate would be two decades. The time it takes for national standards to influence the system is the reason the headline captured my attention and influenced my comments about the standards for science education.

This essay describes my reflections and opinions based on more than a decade's experience with the *NSES.* My work on the *NSES* began in 1992 as a member (and later chair) of the Content Working Group. In 1995, I became executive director of the Center for Science, Mathematics, and Engineering Education (CSMEE) at the National Academies, where my work completing and disseminating the *Standards* continued until 1999, when I returned to Biological Sciences Curriculum Study (BSCS). At BSCS, we used the *NSES* as the content and pedagogical foundation for curriculum materials and professional development. So, my experiences with the *NSES* have been quite varied and include the perspectives of policy, program, and practice. This essay does not include a discussion of the project that produced the *NSES*, but Angelo Collins has provided an excellent history (Collins 1995). Also worth noting is the October 1997 issue of *School Science and Mathematics,* a theme issue for which my colleague Joan Ferrini-Mundy and I served as guest editors. With this as context, I continue with my reflections on the 1996 *National Science Education Standards.*

WHY ARE NATIONAL STANDARDS IMPORTANT?

The power of national standards lies in their potential capacity to change the fundamental components of the education system at a scale that makes a difference. Very few things have the capacity to change curriculum, instruction, assessment, and the professional education of science teachers. National standards must be on the short list of things with such power. The changes also are systemwide and thus at a significant scale. To the degree that various agencies, organizations, institutions, and districts embrace the standards, there is potential to bring increased coherence and national unity among state frameworks, criteria for adoption of instructional materials, and other resources for science education.

How Do the Standards Change Components of the Education System?

Early in my work on the standards, I realized there were several ways they may affect the system. The importance of teaching biological evolution provides excellent examples for this discussion. First, including content such as biological evolution in standards in turn affects the content in state and local standards. A review by *Education Week* (November 9, 2005) found that a majority of states (39) included some description of biological evolution and 35 states described natural selection. In short, national standards influence the priorities for content in state and local standards.

My second point centers on feedback within the systems. Using the *NSES* as the basis for their review, *Education Week* provided insights about which states did *not* mention evolution—Florida, Illinois, Kentucky, and Oklahoma. It also indicated the significant variation in the presentation of evolution among other states. The latter was a major finding in the review.

The *NSES* also can be used to define the limits of acceptable content. This is my third point. When Kansas again planned to adopt state standards that would promote non-scientific alternatives to evolution and liberally borrowed from the *NSES* and the National Science Teachers Association's (NSTA) *Pathways to Science Standards* (2005), both organizations denied Kansas the right to incorporate any of their material into its new standards (*Science* 2005).

Briefly, the *NSES* indicate what should be included in state standards, school science programs, textbooks, and assessments. The standards provide the basis for feedback about content of other standards and programs. Finally, they can be used as defense against efforts to include non-scientific content. These are three important ways the *NSES* influence the science education system. This was true for the 1996 standards and is still true today.

Contrast the potential influence of standards on the instructional core and education system with the possibility of improving student achievement at national levels using other contemporary education ideas and priorities, such as vouchers, charter schools, and site-based management. To be very clear, I am not opposed to such ideas; they may embrace important goals and result in some improvement of student achievement. But they do not necessarily result in fundamental changes at the place where students and teachers meet. Furthermore, the changes are usually local and thus at a scale that lacks significance. They may represent high political priorities, but they have low value when viewed nationally.

What About Equity?

There is a second feature of the standards that demonstrates their importance: They present policies for all students. By their very nature, national standards are policies that embrace equity. When the *NSES* answered the question, "What should all students know and be able to do?" the standards became clear statements of equity. In the decade since the release of the *NSES,* I have had many individuals ask if we really meant *all.* The answer is yes. Of course, there are exceptions that prove the rule; severely developmentally disabled students would be an example. But the standards are still clear statements of equity. While developing the NSES, we were quite clear about the fact that many aspects of the education system would need to change to accommodate the changes the standards implied. The need for changes such as the reallocation of resources to increase achievement of those students most in need was clearly understood by those most closely associated with the *NSES.*

Have the *NSES* changed the fundamental components system-wide and achieved equity? No. But you will notice that I indicated they had the *potential* to do so, not that they actually *did* do so. I would note for readers that this nation has not achieved equal justice for all, but we hold this as an important goal, one that we do not plan to change simply because it has not been achieved.

How Have National Standards Influenced Science Education?

Using national standards places emphasis on outputs of the education system. The *NSES* clearly define the goals for 13 years of science education and assume the various inputs to the system will change to accommodate the goals. For example, textbooks, tests, teaching, and technologies would change to achieve the stated goals. Ultimately, we could assume that national standards would influence student achievement. Of course, educational change does not work as planned. The rubber of education innovation always meets the road of reality.

While directing the Center for Science, Mathematics, and Engineering Education at the National Academies, I initiated a report intended for researchers interested in answering questions about national standards, *Investigating the Influence of Standards: A Framework for Research in Mathematics, Science, and Technology Education* (NRC 2002), directed by Dr. Iris Weiss. Although the goal of standards is student achievement, the influence of national standards is proximate and often compromised by countervailing forces and conditions in the education system. The NRC committee identified three primary channels of influence: curriculum, teacher development, and assessment and accountability. This said, the channels of influence are complex and interactive; significant time is needed for national standards to influence components of the system. The standards may be altered or ignored at the interface of system components such as the design of instructional materials, development of state standards, requirements for teacher certification, and national, state, and local assessments. Several questions from the NRC report (2002) present the basis for the following discussion.

How Have the *NSES* Been Received and Interpreted?

The answer should not surprise any reader—it depends. Release of the *NSES* signaled change, and this by its nature resulted in resistance from some individuals and groups. Interestingly, the resistance primarily was about the *idea* of standards, not the actual content of the standards. On the other hand, I think it is safe to say that the standards have been positively received within the science education community. Science educators recognized the importance and potential value of the standards on the education system. Unfortunately, at the national level, policy makers did not embrace the *NSES*. I attribute this to politics and the need for a Republican Congress to set new policies and reject many aspects of the prior Democratic administrations. The *NSES* and *Before It's Too Late: A Report to the Nation from the National Commission on Mathematics and Science Teaching for the 21st Century* (U.S. Department of Education 2000) suffered this fate.

Textbook publishers did not receive the *NSES* well. We held a meeting for publishers at the National Academy to introduce and review the standards and help publishers interpret the various features for their textbooks and programs. The reception of the *NSES* by the representatives of major publishing houses was cold and largely dismissive. When I asked several individuals about their responses, I was told they were very upset because they had an excellent gauge of the current market for school science programs. Their "gauge" was well calibrated because they had influenced the market using a variety of strategies. The *NSES*, however, would cause the school district priorities to change, and publishers would need to change marketing strategies and publish new programs. Depending on whether you have economic or educational priorities, the publishers' views were seen as good or bad. Of course, I had a positive view of changes based on the *NSES*. I still do.

Interpretations of the *NSES* have varied. Initially, individuals had to make sense of the *NSES* in terms of background, potential use, and priorities. For example, some interpreted national standards in terms of the *Benchmarks for Science Literacy* (AAAS 1993), which had been released earlier. Other interpretations included equating standards on scientific inquiry with the traditional processes of science, equating the *NSES* with a curriculum framework, and confusing the statements of the *NSES* with other aspects of the narrative. Although the *NSES* included discussions of their use and function, it seemed that many individuals did not read the discussions. For example, the *NSES* state:

> *The content standards are not a science curriculum. Curriculum is the way content is delivered: It includes the structure, organization, balance, and presentation of the content in the classroom.*

> *The content standards are not science lessons, classes, courses of study, or school science programs. The components of the science content described can be organized with a variety of emphases and perspectives into many different curricula. The organizational schemes of the content standards are not intended to be used as curricula; instead, the scope, sequence, and coordination of concepts, processes, and topics are left to those who design and implement curricula in science programs. (NRC 1996, pp. 22–23)*

Still, the *NSES* were interpreted as a curriculum framework. Even now, a decade later, one hears that the *NSES,* for example, recommend an integrated approach to science curriculum or a particular scope and sequence for curricula. I will state again that the *NSES* do not represent a science curriculum. They present science content and abilities that all students should learn or develop, respectively. How curriculum developers, states, and local school districts organize the content can and should vary.

What Actions Have Been Taken in Response to the *NSES*?

The first point is that numerous and varied actions have been taken. States have used *NSES* as a basis for science standards, so the influences and actions are wide, but the variations in state standards are significant. *The State of State Science Standards,* a report from the Thomas B. Fordham Institute (Finn and Gross 2005), bears witness to the variation. I suspect the variation is even greater among the standards developed at the district level. Requests for proposals (RFPs) from federal agencies such as the National Science Foundation (NSF), the National Institutes of Health (NIH), and the National Aeronautics and Space Administration (NASA) have required alignment of proposed projects with the *NSES.* A review of journal citations reveals recognition of the *NSES* in articles that range from policy to practice.

BSCS, for example, paid very close attention to the *NSES* when designing new NSF-supported programs, such as *BSCS Biology: A Human Approach* and *BSCS Science: An Inquiry Approach,* and the revision of the elementary program *TRACKS.* Content from the *NSES* has been central to our professional development programs and research. Other developers—such as Lawrence Hall of Science (LHS), Education Development Center (EDC), and Technical Education Research Center (TERC)—used the *NSES* in the development of new programs.

A close review of national and international assessment frameworks for NAEP (2009), PISA (2006), and TIMSS (2003) also reveals the influence of the *NSES.* The actions have been national and even international and have bridged policies to practices.

ISSUES, INSIGHTS, AND IDEAS CONCERNING THE STANDARDS

During more than a decade of involvement with the *NSES,* I have read, heard, and seen many things, some of which are worthy of comment. Following are some of those issues.

Why Do We Have Both *NSES* and *Benchmarks*?

From the beginning of the work on *NSES*, we heard this question and associated questions, such as, "What are the differences between *NSES* and *Benchmarks?*" and "Which document should be used?" To the lead question, I have to answer that it is probably a function of timing and politics. Certainly, *Science for All Americans* (AAAS 1989) set the stage for national standards. The publication of *Benchmarks for Science Literacy* (AAAS 1993) presented the major ideas from *Science for All Americans* as practical outcomes for the science education community. From the beginning of my work on the *NSES*, I paid very close attention to the *Benchmarks.* Although many had questions and complained about the two documents, for some time I thought that this situation had the positive benefit of facilitating review, thought, and discussion about the fundamentals of science education and the importance, role, and function of pivotal documents such as *Science for All Americans*, the *Benchmarks*, and the *NSES.* I still believe this.

The *NSES* and *Benchmarks* are comparable sets of policies. In 1995, Project 2061 completed an analysis of the two documents and concluded there was a "consensus on content." There is an estimated 90% agreement on content associated with the traditional disciplines of life, Earth, and physical sciences. The congruence should not surprise anyone (Rutherford 1996). Indeed, we acknowledged the *Benchmarks* in the introduction to the *NSES* (NRC 1996, p. 15). When asked which document I recommend, my response has been "either": Pick either the *NSES* or *Benchmarks* and use it consistently. *Consistency* is the operational term here. I, for obvious reasons, prefer the *NSES* but have supported use of the *Benchmarks* (Bybee 1997).

There Is a Persistent Confusion of Policy, Program, and Practice

The *NSES* is a policy document. It is not a school science program or instructional materials. It is not a document to be used in actual classroom practice or science teaching. Confusion about the purpose and function of the *NSES* centers on a fundamental lack of understanding and misconceptions about standards in general. Primary audiences for the *NSES* included state coordinators, curriculum developers, preservice and in-service teacher educators, and those responsible for assessments and accountability. These individuals, by nature of their jobs, have the responsibility of translating the policies of *NSES* to programs of curriculum, instruction, assessment, and teacher education and facilitating the effective implementation of those programs in classrooms. One challenge associated with the translation of policies to programs and eventually to classroom practices is understanding the time involved in developing and implementing new instructional materials and assessments (i.e., programs) and then providing professional development that results in changes in classroom teaching practices. One has to ask how long it takes to develop and implement standards-based curricula, instructional strategies, teacher professional development, and assessments. Furthermore, one might wonder how soon after those changes have been implemented we can reasonably expect changes in teacher practices and student achievement. Based on my experience at BSCS with curriculum development, my answer to questions such as these is that one can expect achievement changes between three and six years after funding for new curriculum programs and between seven and ten years after new instructional practices have been adopted (Bybee 1997). A 2002 headline in *Education Week*—"Science Standards Have Yet to Seep Into Class"—should not have surprised anyone. Yet, the media characterized the situation as a failure of the *NSES*. This is the kind of report to which I have become quite sensitive. The *NSES* should not be deemed a failure to change instructional practice because they must be translated into materials, assessments, and professional development. These processes take time and money. Indeed, the report on which this article was based did have a more positive, albeit preliminary, evaluation. This *Education Week* article was based on the release of an NRC report (2003) called *What Is the Influence of the* National Science Education Standards*?* This report commissioned authors to review more than 200 studies related to the *NSES*. The authors reported on the following areas: curriculum, teacher professional development, assessment and accountability, and student learning. Although most authors reported that research was inconclusive, it did tend to support the positive influence of the *NSES*. Given the short time between release of the *Standards* and the report, I would consider the results somewhere between very good and excellent.

Shouldn't the *NSES* Include Contemporary Issues and Specific Courses?

Personally, my position on contemporary issues, particularly those related to the environment, is that science education programs should address such issues. But standards are not and should not reflect personal biases that conflict with federal policy, such as the Constitution's Tenth Amendment (that is, states' rights). Through all of our work on the *NSES*, we had to avoid anything that would suggest, or even hint at, a national curriculum or set of policies that would reduce the states' rights to select content. Why, for example, did we not provide grade-level-specific standards instead of standards for the grade-level ranges of K–4, 5–8, and 9–12? Why didn't we indicate that Earth and space science should be a ninth-grade course, thus assuring a place in school programs? Why didn't we include specific problems such as global warming or other contemporary issues? The answer centers on the potential for any of these to reduce the potential influence of the *NSES* due to the politically controversial nature of these positions. The potential controversy has two components: the issue of an organization such as the National Academies suggesting a national curriculum and the social-political acceptance of topics such as global warming and stem-cell research, among others.

We did respond appropriately to some issues by including standards for science in personal and social perspectives. We included concepts in the *NSES* that lend themselves to understanding environmental issues, the nature of science, and the relationships among science, technology, and society. However, these standards have, for the most part, been ignored. In these standards, for example, we introduced fundamental conceptual understandings of population growth, natural resources, and environmental quality. Educationally, these can be defended on the basis that they are fundamental to many contemporary environmental issues; they present the conceptual basis for understanding topics such as climate change. Students should understand scientific concepts fundamental to an array of science-related issues they may confront now and in the future.

Scientific Inquiry Includes Both Content and Teaching Strategies.

A decade later, confusion continues about what is meant by *scientific inquiry*. For some, scientific inquiry is the same as skills, and for others, scientific inquiry is associated with a variety of teaching strategies. In efforts to criticize the theme of scientific inquiry as expressed in the *NSES,* Chester E. Finn Jr., recently stated, "Science education in America is under assault with 'discovery learning' attacking on one flank and the Discovery Institute on the other. That's the core finding of the first comprehensive review of state science standards since 2000" (Finn and Gross 2005). This statement is in a report from the Thomas B. Fordham Institute, a conservative Washington, DC, think tank. Finn later stated that "'discovery learning' is getting more weight than it can support in science. This is largely due to states' over-eager, over-simplified, and misguided application of some pedagogical advice enshrined in the so-called 'national standards'" (p. 10). To show what it is like to take a reasonable idea and reduce it to the ridiculous, I cite the final conclusion of Finn's discussion. He stated, "American students run a grave risk of being expected to replicate for themselves the work of Newton, Einstein, Watson, and Crick. That's both absurd and dysfunctional" (p. 10). Inflated rhetoric such as this from one person may appeal to colleagues with similar views, but it does not diminish the potential of national standards, either the *Benchmarks* or *NSES,* especially since it is politically motivated, is not grounded in an accurate view of the presentation of science as inquiry in the content standards, and fails to recognize that the majority of instructional materials and teaching strategies currently in schools can only be characterized as old-fashioned traditional instruction for which we have evidence of their lack of effectiveness. The evidence for my statements can be found in reports on the status of science education including curriculum, textbooks, and teaching strategies by Horizon Research, Inc., on the one hand, and the results from NAEP, TIMSS, and PISA on the other hand. I do not think America is under assault with discovery learning attacking on one flank; there is little or no evidence for this. It well may be under attack by the Discovery Institute. There is ample evidence for this!

The *NSES* Can Resolve the Paradox of International Comparisons and States' Rights.

For some time, I have been intrigued by the paradox of our education system and the role of national standards. International assessments such as TIMSS and PISA present a situation where we view results as one nation. We ask, "How does the United States compare to other countries?" Yet, we maintain the right of each state to set its own standards and assessments. To magnify the situation, each of 14,000 school districts makes decisions on what science to teach, when to teach it, and how to teach it. This is a situation designed for incoherence. What is the role of national standards in the paradox of results for one nation versus 15,000 school districts? The *NSES* can facilitate increased coherence by establishing agreement on fundamental concepts that all students should learn while maintaining the freedom of states and school districts to select instructional materials, implement assessments, and provide professional development. It is not a perfect system, but one that may resolve the paradox.

I concluded the 2006 editorial on national standards with an answer to these questions: "Should the standards be revised? If so, how?" My answer was yes, and I described changes that should be made to the 1996 standards.

Note: In late 2005, Dr. Norman Lederman, then editor of *School Science and Mathematics*, asked me to prepare a guest editorial in which I reviewed my experiences developing and implementing the *National Science Education Standards* (1996) and reflected on the importance of standards for science education. That editorial was published in February 2006, a decade after the standards were released. The editorial is included here with minor editorial changes to describe my reflections after two decades and experience working on *A Framework for K–12 Science Education* (NRC 2012) and the *Next Generation Science Standards* (NGSS Lead States 2013).

CONCLUDING REFLECTIONS ON THE 1996 AND 2013 NATIONAL STANDARDS

For almost two decades, the 1996 standards had a positive influence on fundamental components of the science education system. The same can be said for the 2013 standards, even after the brief period since their release. Yes, both standards have caused debates, agitated critics, and resulted in political issues for states and districts. That said, both sets of national standards have maintained the integrity of science, the aims of science education, and the highest aspirations of the United States. Given the complexity of our education system, one could hardly ask for, or expect, more from national standards for science education.

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CHAPTER 8

NEXT GENERATION SCIENCE STANDARDS

CONTEMPORARY PERSPECTIVE

This chapter introduces contemporary standards that are having an effect on science education at the national, state, and local levels.

The Foundation for the *NGSS*

The *Next Generation Science Standards* (NGSS; NGSS Lead States 2013) began with the development of *A Framework for K–12 Science Education* (NRC 2012). However, we must go back even further. In 2009, the Carnegie Corporation of New York and the Institute for Advanced Study established a commission that released a report, *The Opportunity Equation*, that recommended development of a common set of standards for science education (Carnegie Corporation 2009). The following introduction is adapted from the *Framework.*

The *Framework* is based on a body of research on teaching and learning in science, as well as on nearly two decades of efforts to define foundational knowledge and skills for K–12 science and engineering education. From this work, the *Framework* committee concluded that K–12 science and engineering education should focus on a limited number of disciplinary core ideas and crosscutting concepts, be designed so that students continually build on and revise their knowledge and abilities over multiple years, and support the integration of their knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design (NRC 2012).

The committee recommends that science education in grades K–12 be built around three major dimensions (see Figure 8.1, p. 107):

- Scientific and engineering practices
- Crosscutting concepts that unify the study of science and engineering through their common application across fields

- Core ideas in four disciplinary areas: physical sciences; life sciences; Earth and space sciences; and engineering, technology, and the applications of science

All three dimensions must be integrated into standards, curriculum, instruction, and assessment. Engineering and technology are featured alongside the natural sciences (physical sciences, life sciences, and Earth and space sciences) for two critical reasons: to reflect the importance of understanding the human-built world and to recognize the value of better integrating the teaching and learning of science, engineering, and technology.

The broad set of content in the *Framework* guided development of new standards that, in turn, will guide reforms of curriculum, instruction, assessment, and professional development for educators. A coherent and consistent approach throughout grades K–12 is key to realizing the vision for science and engineering education embodied in the *Framework*—that students, over multiple years of school, actively engage in science and engineering practices and apply crosscutting concepts to deepen their understanding of each field's disciplinary core ideas.

Before publication, a draft of the *Framework* was sent out for review. The Council of State Science Supervisors (CSSS) played an important role in this review by organizing focus groups and providing feedback to the National Research Council (NRC).

The *Framework* represented the first step in a process that informed state-level decisions and provided a research-grounded basis for improving science teaching and learning across the country. The *Framework* guided standards developers, curriculum designers, assessment developers, state and district science administrators, professionals responsible for science teacher education, and science educators working in informal settings.

The NRC *Framework* provides guidance for the development of standards. The following list summarizes key points from the NRC recommendations. Standards for K–12 science education should

- set rigorous goals for all students;
- be scientifically accurate;
- be limited in number;
- emphasize all three dimensions;
- include performance expectations that integrate all three dimensions;
- be informed by research on learning and teaching;
- meet the diverse needs of students and states;
- have a coherent progression across grades and within grades;
- be explicit about resources, time, and teacher expertise;
- align with the *Common Core State Standards*; and
- account for diversity and equity (NRC 2012, pp. 297–307).

Figure 8.1. The Three Dimensions of the *Framework*

1. **Scientific and Engineering Practices**
    1. Asking questions (for science) and defining problems (for engineering)
    2. Developing and using models
    3. Planning and carrying out investigations
    4. Analyzing and interpreting data
    5. Using mathematics and computational thinking
    6. Constructing explanations (for science) and designing solutions (for engineering)
    7. Engaging in argument from evidence
    8. Obtaining, evaluating, and communicating information
2. **Crosscutting Concepts**
    1. Patterns
    2. Cause and effect: Mechanism and explanation
    3. Scale, proportion, and quantity
    4. Systems and system models
    5. Energy and matter: Flows, cycles, and conservation
    6. Structure and function
    7. Stability and change
3. **Disciplinary Core Ideas**

    Physical Sciences

    PS1: Matter and its interactions
    PS2: Motion and stability: Forces and interactions
    PS3: Energy
    PS4: Waves and their applications in technologies for information transfer

    Life Sciences

    LS1: From molecules to organisms: Structures and processes
    LS2: Ecosystems: Interactions, energy, and dynamics
    LS3: Heredity: Inheritance and variation of traits
    LS4: Biological evolution: Unity and diversity

    Earth and Space Sciences

    ESS1: Earth's place in the universe
    ESS2: Earth's systems
    ESS3: Earth and human activity

    Engineering, Technology, and Applications of Science

    ETS1: Engineering design
    ETS2: Links among engineering, technology, science, and society

Development of the *NGSS*

Development of the *NGSS* began after the NRC released *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (2012). The report identified the key content and practices all students should learn by the time they graduate from high school. The *Framework* served as a vision for K–12 science education and the foundation for new science education standards. The prior national standards were released in the mid-1990s and influenced science education for nearly two decades.

As the *Framework*'s subtitle suggests, science and engineering practices, crosscutting concepts, and core ideas from the physical, life, and Earth and space sciences were defined. Figure 8.1 summarizes the three content dimensions from the *Framework.* These dimensions became the basis for the *NGSS.*

This figure presents the content of the *NGSS.* The core ideas for science disciplines are similar to prior standards (see, for example, the *National Science Educations Standards* [NRC 1996]) that have influenced most state standards. The crosscutting concepts are updated statements of several unifying themes from prior standards, and the science and engineering practices also are elaborated statements of prior science practices and scientific inquiry.

The *NGSS* were developed using the following foundational ideas. The science standards

- present standards as performance expectations;
- describe policies for school programs and classroom practices, not a curriculum;
- clarify equity and excellence;
- integrate engineering with science; and
- define college and career readiness.

The genesis and support for both the *Framework* and *NGSS* came from the Carnegie Corporation of New York and was based on the report *The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy* (Carnegie Corporation 2009). It is important to note that development of neither the *Framework* nor the *NGSS* received financial support from the federal government.

Achieve, Inc., an independent, bipartisan, nonprofit education organization, managed the development of the *NGSS*. Leadership for the *NGSS* initiative came from 26 states. The *NGSS* were released in April 2013 after several years of development and thorough review by the scientific and education communities, as well as by key stakeholders and the public (see NGSS Lead States 2013, Volume 2, Appendix B).

Innovations in *NGSS*

Although there are similarities between the *NGSS* and the prior standards, such as the *National Science Education Standards* (*NSES*; NRC 1996), there also are significant differences. Those differences present innovations that must be accommodated by corresponding changes in instructional materials, assessments, and teachers' knowledge and skills.

The following innovations established in the *NGSS* are hallmarks of current thinking on how students learn science and set a vision for science education. These innovations will not only cause a shift in state standards but also must influence and refocus state assessments, the development of comprehensive school science programs, and the preparation and professional development of K–12 teachers.

Innovation 1: The *NGSS* reflect three dimensions of science and their interconnectedness. In the *NGSS,* science is presented as three distinct dimensions, each of which describes equally important learning outcomes: science and engineering practices, crosscutting concepts, and disciplinary core ideas. The *NGSS* provide for connections among all three dimensions. Students gain an understanding of what is known about the natural world and how that body of scientific knowledge came to be known. Students develop the skills and abilities expressed by the practices and how they are applied to gain a better understanding of the phenomena of the natural and designed worlds.

Innovation 2: The *NGSS* incorporate engineering and the nature of science as practices or crosscutting concepts. The *NGSS* includes engineering design and the nature of science as significant innovations. The unique aspects of engineering (e.g., identification of and designing solutions for problems), as well as aspects essential to science (e.g., designing investigations and developing evidence-based explanations), are incorporated within practices and crosscutting concepts. In addition, unique aspects of the nature of science (e.g., scientific investigations use a variety of methods; scientific knowledge is based on empirical evidence; science is a way of knowing; and science is a human endeavor) also are included as practices and crosscutting concepts.

Innovation 3: The *NGSS* describe performance expectations in which students study natural phenomena. The *NGSS* provides clear expectations for students studying natural phenomena as the basis of what they should learn (i.e., what they should know and be able to do) at the end of a grade or grade band. Past standards provided the isolated content and inquiry abilities but did not provide for the full integration of the science practices with the content.

Innovation 4: The *NGSS* present coherent learning progressions for K–12 science instruction that are structured into science and engineering concepts and practices. The *NGSS* provide for sustained opportunities from elementary through high school for students to engage in and develop a deeper understanding of the three dimensions of science. Students require a coherent learning progression or story line to fully understand the content of science. These coherent learning progressions must be built both within the grade level and across grade levels. Through the building of the cohesive story line, students have multiple opportunities to revisit and expand their understanding of the science and engineering practices, disciplinary core ideas, and crosscutting concepts by twelfth grade.

Innovation 5: The *NGSS* make connections to *Common Core State Standards* for English language arts and mathematics. The *NGSS* not only provide for coherence in science teaching and learning but also unite science with the basics—*Common Core State Standards* for English language arts and mathematics. The skills of *Common Core* subjects, both linguistic and mathematical, are applied and enhanced in the science classroom and ensure coordinated learning in all content areas.

This meaningful and substantive overlapping of skills and knowledge affords all students equitable access to the learning standards.

Table 8.1 summarizes the five innovations in a "from/to" form and locates a component of the education system where the innovations will be implemented.

SCIENCE EDUCATION GOALS FOR THE 21ST CENTURY: THE *NEXT GENERATION SCIENCE STANDARDS*

The *NGSS* define the essential science concepts and practices for contemporary reform of science education. This is especially true for those states that have adopted the *NGSS* and is also relevant for states and school districts that may not have adopted the *NGSS* but use standards based on *A Framework for K–12 Science Education.* We think it is reasonable to review the goals for science education discussed in Chapter 6 (see Bybee and DeBoer 1993) and assess the degree to which the *NGSS* as policies accommodate the five goals. We are clear that neither the *Framework* nor the *NGSS* are the curriculum materials. They do, however, indicate priorities and emphasis for the goals and, by extension, for school science programs.

Scientific Knowledge

In the *NGSS*, scientific knowledge has a primary emphasis in disciplinary core ideas (DCIs) and crosscutting concepts (CCCs). While nature of science and engineering design are included, they do not have an equivalent level of emphasis.

Scientific Methods

Science and engineering practices (SEPs) represent the goal of learning scientific methods in *NGSS*. The eight practices contribute a thorough list of abilities and knowledge necessary to achieve this goal. The detail and emphasis for "signature" practices (e.g., developing and using models, constructing explanations, engaging in argument from evidence) are significant dimensions with added value for the scientific method's goal in the *NGSS*. Additionally, the fact that the practices are integral to the statements of standards—the performance expectations—increases the probability that these strategies will be included as teaching strategies and learning outcomes in school programs.

Social Issues

One fundamental purpose of science education is to provide students with knowledge about and the abilities to act on various issues they may confront as individuals and citizens. The *NGSS* recognize this goal through the general emphasis on disciplinary core ideas, crosscutting concepts, and science and engineering practices. Compared to the *National Science Education Standards* (*NSES*), the 1996 standards, there is reduced emphasis on science in personal and social perspectives in the *NGSS*. In

Table 8.1. A Summary and Implications of *NGSS* Innovations

From	To	Reform of System Components
Single concepts in science disciplines	Integration of three dimensions (science and engineering practices, disciplinary core ideas, crosscutting concepts)	Instructional approach
Engineering/nature of science as supplemental	Engineering and nature of science incorporated as practices or crosscutting concepts	Lessons, units, and programs
Standards as description of content	Standards as performance expectations and basis for studying natural phenomena and design problems	Context for student experiences and basis for assessments
Grade level or course emphasis	K–12 learning progressions	School science program—the curriculum
Few connections to other disciplines	Explicit connections to Common Core State Standards for ELA and math	Within the sequence of lessons

the *NGSS*, the Earth science standards present content emphasizing societal issues such as climate change.

Personal Development

Similar to what we just noted in the prior statement, the *Framework* and *NGSS* have the general aim of addressing the personal development of students; however, this is not a goal with particular emphasis.

Career Awareness

The *NGSS* were reviewed for the effect on college and career readiness and certainly passed muster. The various practices, connections to *Common Core* literacy and math goals, and primary emphasis on scientific knowledge and application of that knowledge all address this goal of science education.

The *NGSS* present a reasonable and fair emphasis on the five goals of science education, with societal issues and personal development as exceptions. The content standards form a thorough set of outcomes representing physical, life, and Earth and space sciences. The practices are an excellent contemporary statement for the historical goal of scientific methods.

CHAPTER 8

A PERSONAL PERSPECTIVE

THE *NEXT GENERATION SCIENCE STANDARDS*: PERSONAL REFLECTIONS AFTER LESS THAN A DECADE

Stephen Pruitt

Similarly to Rodger, I am including an edited version of an article I have done for the National Science Teachers Association (NSTA) journals, which was published in June 2015.

The *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013) were released several years ago. Work tied to the *NGSS*, their adoption, and their implementation continues to move forward around the country. I am most frequently asked about the pace of adoption by states, the implementation of the standards, and how the *NGSS* will be assessed. In this personal perspective, I discuss where we are at the time of this publication and what I have learned during the process so far. As we implement the *NGSS*, it is important to remember that education is a journey, not a destination.

WHERE ARE WE NOW?

As of September 2016, 17 states and the District of Columbia—encompassing approximately 40% of the nation's public school population—have adopted the *NGSS*. Other states and districts continue to consider adoption. Additionally, a growing number of districts in non-adopting states are embracing the *NGSS* as the best way to move scientific literacy forward. Many of these are large districts that see the need to significantly change how they approach science education, regardless of the state-level politics. As a result, the *NGSS* are significantly influencing science education throughout the country. The excitement around the *NGSS* that I see at the NSTA national conferences is palpable.

From the beginning, adoption needed to proceed at a pace befitting each state, occurring if and when it made sense. Each adopting state, even those that were not lead states due to their undertaking of long review and public comment periods, can lay claim to owning the *NGSS*. As such, they can and should choose their own timing. A host of issues face states beyond adopting and implementing new science standards. These issues include developing timelines for adopting instructional materials, revising science standards statutes, and building the will within a state's education community to make the changes called for in *A Framework for K–12 Science Education* (NRC 2012) and the *NGSS*.

Any teacher will tell you that adopting and implementing the *NGSS* cannot be done without a way to assess the outcomes. Given the political climate around assessments, the conversation can be harrowing. As a key first step, the *NGSS* adopter states are committed to building classroom capacity. The focus has been, and must continue to be, on classrooms first rather than on building a test. The more we focus on educators and how to make the *NGSS* real in classrooms before developing an assessment, the better. Assessments that support classroom practice will come as we learn more from classroom experience. The *NGSS* and the *Framework* were developed to identify a more effective way to engage students in science. To do this, instruction must change, the planning of instruction must change, and the expectations of what happens in science classrooms must change. The type of change called for in the *NGSS* will not happen just because there is a new test. In fact, the change is significant enough that we should learn from the classroom first before a statewide, large-scale assessment is developed and administered.

It's time to move from valuing what we measure to measuring what we value. In Kentucky, for instance, the state department of education hired a "thought partner" before awarding assessment contracts to ensure that any new assessment fully evaluates the *NGSS*. California is using a similar structure with two different groups as they consider new science assessments. So, I am encouraged with the direction and pace of implementation. A thoughtful and deliberate approach has always made the most sense. It is tough to have the courage to be patient, but it is a necessity—not for the adults, but for the students.

WHAT HAVE WE LEARNED?

We have learned much in the first two years of the *NGSS*. Implementation, as expected, is far more complicated than was development of the standards themselves. The way the *NGSS* outline how students show proficiency makes sense, so teachers are embracing it. That does not mean everyone is an expert, at least not on the *NGSS* and not right away. Research from various places, including *The Cambridge Handbook of Expertise and Expert Performance* (Ericsson et al. 2006), shows that it takes many hours of practice before expert thinking is acquired. As such, teachers will need hours of thinking about *NGSS* and instructional strategies to become experts. Teachers are among the brightest and most innovative individuals on the planet, in my opinion, which does not equate to them being perfect at instruction right off the bat. As research about expert thinking points out, the move from novice to expert will require practicing all the elements of the *NGSS* with reflection and feedback and practicing quality science instruction through this new lens that allows them to develop a conceptual model of their own instruction. Finally, just like the *NGSS* require students to operate at the nexus of the three dimensions, Ericsson's research found that experts recognize knowledge is only meaningful if it is integrated with practice. That is to say, teachers could quote the three dimensions, use the language, and even quote the performance expectations from the *NGSS*, but all of that is irrelevant if they never put it into practice. The reaction to the *NGSS* has been incredible, but that alone does not translate into an automatic change in our science education system. It does mean, however, that change is in the air, and we must learn more to do better for our students. At the 2015 NSTA national conference, I shared the top ten lessons I learned in 2014 as I worked with teachers, administrators, and stakeholders on the *NGSS*. I share these because it is important to note that we all continue to learn and should do so. Here are the ten lessons, in no particular order.

Three-dimensional learning is hard. We do not help teachers or students by pretending it's not. If anyone claims to know everything about the three-dimensional learning embodied in the *NGSS*, be skeptical. This is hard. But, like other professions that deal with hard changes, we will surmount these challenges, too. Learning how to create a three-dimensional culture in our classrooms takes time and effort. Why is this so difficult? First, I believe it is hard because the three dimensions in and of themselves are not new. The scientific and engineering practices involve a more expansive view of scientific processes but have similarities to inquiry. The disciplinary core ideas are similar to content standards. There are fewer but, with the possible exception of waves and their applications being an actual core idea and not a subsection, they are not new. The crosscutting concepts are similar to unifying themes from the 1990s standards documents. As such, some educators rationalize that they already incorporate these components. A good friend and excellent science leader, Sean Elkins, identified what I refer to as the Elkins Principle. He says, "There is an inversely proportional relationship between the number of times a person says, 'I already do that' and the number of times they actually do." Creating a culture of three-dimensional learning is hard because we were not taught to use the practices to gain deeper understanding of core ideas and apply to new or unique phenomena by understanding the crosscutting concepts. I think an error we made early was talking about the three dimensions, not focusing on three-dimensional learning itself. For the *NGSS* to be successful and for us to make a difference in students' lives, we have to give teachers room to get comfortable with three-dimensional learning. For this to happen, one must acknowledge this process is hard and realize that that is okay. No other profession backs down from a hard procedure if it is good for their patients, clients, or products, and neither should educators.

Eliminating the black box is tough. A black box is created when current science learning is predicated on future science learning. This means that when you say to your students, "You will not understand this until next year," you create a mystery rather than understanding. The *NGSS* provide an opportunity to look at science instruction coherently by connecting the different disciplines to better understand a phenomenon, removing the black box. Understanding the role of photosynthesis in the cycling of matter, for example, means you must understand a little about physical sciences in terms of matter and Earth science in terms of distribution of matter. I believe this to be one of the biggest issues facing science education. It has forced us, due to our siloing of concepts, to push memorization on students. This leaves students with a disconnected view of science and the world around them. In particular, it leaves students with a "Why does this matter to me?" attitude. To be clear, I am not pushing for integrated science across K–12; I am simply saying we must take full advantage of what the disciplinary core ideas afford us. If we do this, we no longer have to discuss "high-energy phosphorus bonds" in adenosine triphosphate (ATP) because students would understand that bond is the first to break and release its energy due to its position in relation to the larger molecules, the forces holding the bond, and the stability of energy. This is a more difficult concept to grasp, but it is a far better learning experience than memorizing that one phosphorus bond has more energy than the others.

Rather than teaching topics, educators should help students understand phenomena. Teaching science is about helping students understand the world around them, both natural and designed. Teaching topics such as gas laws, volcanoes, and photosynthesis without connecting them to core ideas that help students explain the world provides no reason for students to learn or retain that information. Gas laws describe part of the structure and properties of matter. The deeper understandings of gas laws are found in the *NGSS*, but they are couched in explaining the bigger picture of the structure of matter. The understanding needed for gas laws is spread throughout the years and across three core ideas in high school physical science. Understanding forces, energy, distribution of energy, and interactions of particles are far more powerful in explaining the world than simply calculating Charles' law.

Simply reading the *NGSS* does not lead to *NGSS* expertise. We have a history in the United States that when new standards are developed, we construct professional development designed to "teach" the new standards to teachers. This simply does not work. In our work with the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric, we have seen that professional development that dwells only on the *NGSS* does not help educators see the innovations required in the *NGSS*. A key feature of quality *NGSS* professional development is putting teachers into a position to really see how the *NGSS* are different from their existing standards and practices. So, having educators engage in EQuIP, curriculum design, task design, or even an intense discussion about standards that preceded the *NGSS* stimulates greater understanding. Since the *NGSS* are developed based on learning progressions, professional development should also push educators to think outside their grade band and discipline when considering the *NGSS*. This involves looking not only at the core ideas but also at the practices and crosscutting concepts.

If you can eat it, it's probably not a model. Understanding the science and engineering practices takes time. There are "models" in elementary classrooms across the country; I imagine about 80% are edible. Models that students will construct and use for the *NGSS* classroom are quite different. Students will need to use models to explain, use evidence, or predict phenomena. Most "edible" models do not allow for that experience. There are a few components of the scientific and engineering practices that need to be understood before students can use them effectively. First, one must understand the practices are what students *do*; they are not teaching strategies. Students should be able, for example, to identify the components of a model, articulate the relationship of those components, and explain or predict future phenomena based on the model. The same can be said of all the practices. (For more information, see the appendix of the evidence statement at *www.nextgenscience.org/ngss-high-school-evidence-statements*.)

Crosscutting concepts are still the third dimension. The *NGSS* have three dimensions: scientific and engineering practices, crosscutting concepts, and disciplinary core ideas. The crosscutting concepts dimension is still the most difficult one to implement but also is incredibly powerful. This dimension helps students connect what they learn to the world around them in a meaningful way. The crosscutting concepts are implicit to many of us who have studied the sciences. What we know is that if the concepts are implicit in our instruction, they will be hidden from students. This dimension is challenging, but clear instruction about how crosscutting concepts fit with the other dimensions will change science education.

Phenomena are underplayed and underappreciated. The *Framework* and the *NGSS* are very focused on phenomena. We need to bring the wonder back to science classrooms, which can be done through studies of phenomena. We have found that this is tough to do because of our conditioning, but doing so is essential to making science real to students. Phenomena are observable actions or events that naturally happen in a student's life. Phenomena can look different for different ages of students, but teaching phenomena is a key feature if we are to help students pursue, or even be interested in, the world in which they live. Common phenomena can be condensation on the side of a pitcher of ice water, flags waving in the wind, rainbows, weather, or even someone having "brain freeze" after eating ice cream too quickly. Engaging students in instruction about phenomena gives them a reason to learn the content, perpetuates curiosity, and helps them retain that knowledge for years to come.

Bundling is not easy. Bundling performance expectations in the study of phenomena is critical to painting a coherent science picture for students. The idea of bundling is not as easy as it sounds. Bundling involves assembling a set of performance expectations that represent the understanding students need to address an essential question or explain a phenomena. There is no single correct way to bundle; rather, it must make sense to the teacher. So, pick a phenomenon and look at all of the standards to find a way to better explain the world. Discuss your thoughts with colleagues. Bundling will only get easier with discussion and practice. Many teachers start with the disciplinary core ideas as the driving force behind bundling, and this is an acceptable way to go about the process. One could also use crosscutting concepts as the driving force. The key is to remember that performance expectations should be understood deeply so teachers will recognize how they can be arranged and bundled to leverage the concept most needed to explain or answer questions.

Communicate, communicate, communicate, and then communicate some more. The *NGSS* represent a lot of what we want science classrooms to be, but they also depart from how most of our parents were taught. We must make every attempt to be clear about purposes, development processes, and how the *NGSS* will better prepare our students for the world. Teachers are a significant voice in a community; as such, they must be given time to understand the vision of the *NGSS*.

Leadership makes the difference. Educators, and specifically teachers, make the difference in classrooms. It is time we realize that our profession also makes a difference in society. Teachers are leading the way to our future. What we see in states and districts that are effectively implementing the *NGSS* is that teachers and administrators are assuming greater leadership roles. Yes, there is more to learn, and, yes, it is not easy, but the early implementers have shown us that quality leaders make the difference.

As was mentioned earlier, achieving expertise (thinking like an expert) takes many hours. Teachers should, as engineers do, give ourselves time to learn and room to grow. We will not get it right the first time, and that is okay. We will get better at *NGSS* instruction, but we must first acknowledge that it will take time and we will have varying degrees of initial success. The *NGSS* represent a great opportunity for students and science education. To me, they also represent a great opportunity for teachers to teach science the way we know we should and to be real leaders as we prepare our students for the future.

As one final thought for this essay, I want to speak to the standards as a sitting commissioner of education. Implementation is hard. In fact, I have come to say often that no great education initiative ever died in the vision phase; it dies in implementation. We have much work ahead of us. I have seen it at the national and state levels. Every time we think we have *NGSS* down, it moves away again, showing us bigger and better things we can do in our science classes. I am reminded of an Advanced Placement chemistry student who once told me that my class was like trying to catch a lizard: Every time you think you have it, you realize you just grabbed the tail and it broke off in your hand while the lizard escaped. Working with the *NGSS* can feel that way. I know in my state we continue to work to try to "catch it," but it keeps us moving. I know this— education is an ever-changing organism that will not stop being that way. As teachers and, more important, as leaders, we cannot let what is hard get in the way of what is right. I have many things on my plate as a commissioner, but first and foremost I must ensure our students get a first-rate education. I also need to remember, however, that it takes time, effort, and support of all of the people who touch science education. So, implementation is tough; leaders have to be tougher.

OUR COMMON PERSPECTIVE AND LEADERSHIP OPPORTUNITIES

Not surprisingly, our perspective centers on the *NGSS*. As states and districts adopt or adapt the *Framework* for *NGSS*, the need for leadership is clear. Our perspective is based not only on experience with the development and implementation of national standards but also, it is important to note, on their use as the basis for state standards and translation to curricula, instruction, assessments, and professional development.

Adopting, or even adapting, national standards for states and school districts will involve politics. Our experiences have borne witness to the reality of politics as an integral part of the process of adopting standards for science education. The leadership opportunities must include informing the decision makers about the new standards and addressing any potential problems. Those in leadership positions must be ready because, in time, the politics will emerge.

Implementing new standards requires change. By their very nature, new standards do not represent the status quo. So, the majority of teachers, for example, are not already implementing the innovations. Leaders should be prepared with examples of what the standards look like for curriculum, instruction, and assessments.

Reform based on new standards is complex and takes time. Leaders are encouraged to provide time, make plans, and proceed slowly. Extended professional development for teachers is required. This requirement is not a "one and done" workshop.

Pay attention to the concerns of teachers. The ultimate step in implementing new standards involves teachers changing their curriculum, instruction, and assessments. They reasonably will express concerns about the process and will require concrete responses to their concerns. This is both a challenge and an opportunity for leaders.

ISSUES AND QUESTIONS FOR DISCUSSION

1. What do you perceive as the appropriate statements for, and functions of, national standards in the contemporary reform of science education?
2. What does implementation of standards mean in various settings (state frameworks, teacher education, curriculum, classrooms)? What do you think is "acceptable"—wholesale but superficial consistency? Deep consistency with a few ideas? People mention the concept of "fidelity" to standards. What does this mean?
3. Is there a paradox in that standards documents are umbrella-like, general, and non-prescriptive, yet we need to be able to measure and describe levels of implementation as these levels relate to teaching and student achievement?
4. People generally seem to acknowledge that there are many ways of implementing or interpreting standards and "successful implementation" can look quite different in different places. How would you identify successful implementation of national standards for science education?
5. We propose that you explore the idea of models for standards-based reform—model programs, model practices, and model instructional units. In the context of standards-based reform, what are models for? Helping people envision "reformed" practice in some way? So they can imitate it? So they can make choices for themselves? Is it possible, in providing models, to offer them as rich examples, with enough contextual description to provide choices for individuals, schools, and so on? What problems might arise from thinking about "exemplary models"?

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PERSPECTIVES ON SCIENCE EDUCATION

A LEADERSHIP SEMINAR

"This book is not about the need to reform science education. Others have made that argument and undoubtedly will continue making it in the future. This book is about science education and what one needs to know, value, and be able to do as a leader."

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Like a memorable seminar, this book delivers what the title promises: perspectives on education from leaders in education. Writing in a conversational style, authors Rodger Bybee and Stephen Pruitt ponder central concerns of the science education community in general and science teachers in particular:

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