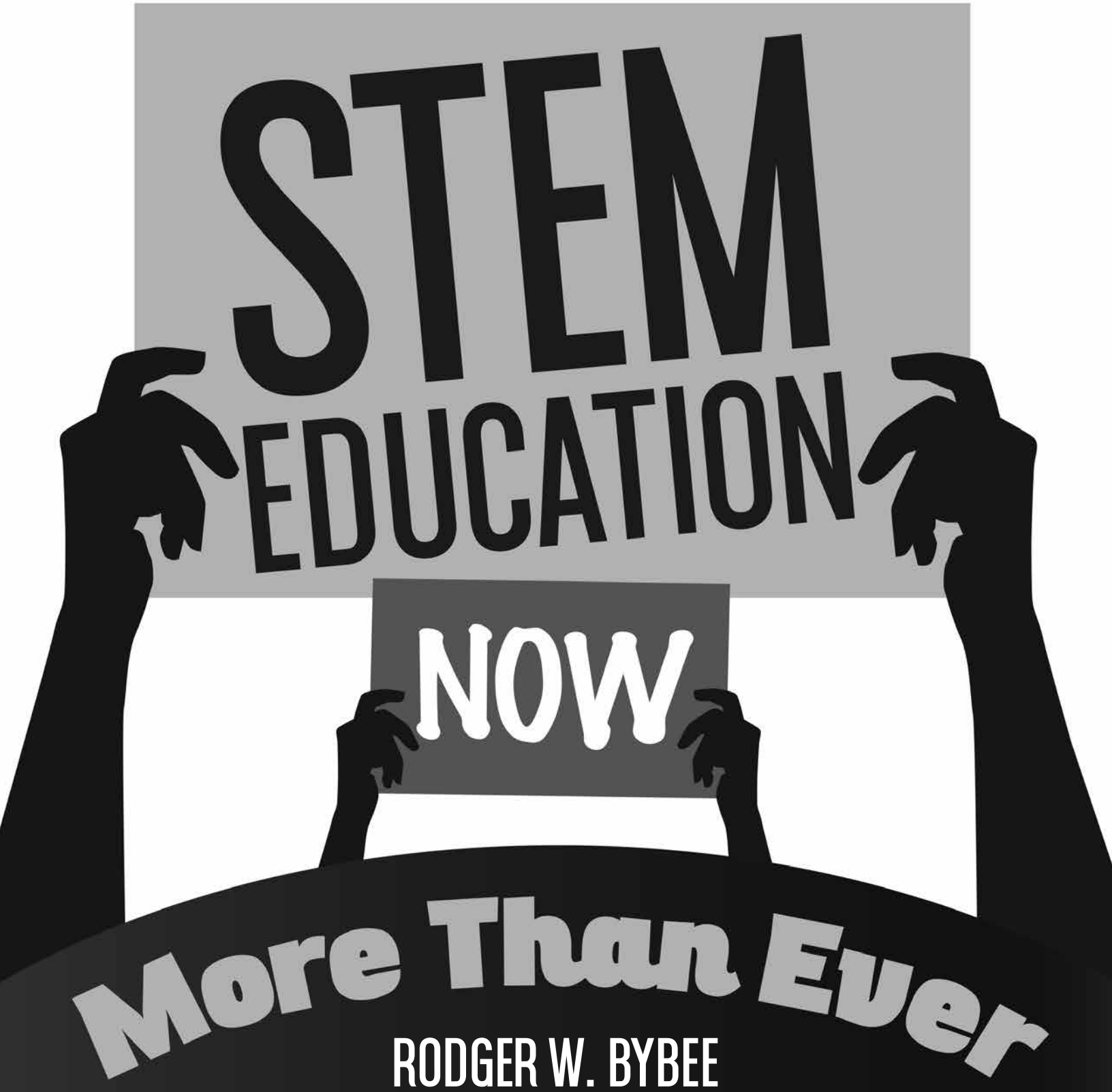
STEM EDUCATION NOW More Than Ever

RODGER W. BYBEE

NSTA press
National Science Teachers Association



STEM EDUCATION NOW More Than Ever

RODGER W. BYBEE

NSTA press
National Science Teachers Association
Arlington, Virginia

NSTA press®
National Science Teachers Association

Claire Reinburg, Director
Rachel Ledbetter, Managing Editor
Deborah Siegel, Associate Editor
Andrea Silen, Associate Editor
Donna Yudkin, Book Acquisitions Manager

Art and Design
Will Thomas Jr., Director, cover and interior design

Printing and Production
Catherine Lorrain, Director

National Science Teachers Association
David L. Evans, Executive Director

1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

21 20 19 18 4 3 2 1

Library of Congress Cataloging-in-Publication Data
Names: Bybee, Rodger W., author.
Title: STEM education now more than ever / by Rodger W. Bybee.
Description: Arlington, VA : National Science Teachers Association, [2018] | Includes bibliographical references and index.
Identifiers: LCCN 2018006416 (print) | LCCN 2017060226 (ebook) | ISBN 9781681406022 (e-book) | ISBN 9781681406015 (print)
Subjects: LCSH: Science--Study and teaching--United States. | Science teachers--Training of--United States. | Technology--Study and teaching--United States. | Engineering--Study and teaching--United States. | Mathematics--Study and teaching--United States.
Classification: LCC Q181 (print) | LCC Q181 .B9827 2018 (ebook) | DDC 510.71--dc23
LC record available at *https://lccn.loc.gov/2018006416*

Contents

Preface vii
Acknowledgments xi
About the Author xiii

Part 1
INNOVATIONS FOR STEM EDUCATION

Chapter 1 – Introducing a New and Urgent Case for STEM Education 5
Chapter 2 – Looking Beyond the STEM Acronym 9
Chapter 3 – Recognizing and Accepting New Challenges for STEM Education 17
Chapter 4 – Connecting STEM Education, *NGSS*, and New State Standards 23
Chapter 5 – Proposing Innovations for STEM Education 29
Part 1 Concluding Discussion 35

Part 2
OUR CULTURAL HERITAGE
STEM and Society

Chapter 6 – The Enlightenment: Identifying Components of a Cultural Foundation 41
Chapter 7 – The Constitution: Establishing a Cultural Foundation 45
Chapter 8 – Democracy, Schooling, and STEM Education: Building on the Cultural Foundation 51
Chapter 9 – Citizenship: Exercising the Power and Realizing the Obligations of Our Cultural Heritage 57

Chapter 10 – American Science and Technology: A Cultural Heritage 63
Part 2 Concluding Discussion 71

Part 3
ADVANCING STEM EDUCATION
Priorities, Perspectives, and Plans

Chapter 11 – The Purposes of STEM Education 79
Chapter 12 – Perspectives for STEM Programs 87
Chapter 13 – Designing Innovative STEM Units 99
Chapter 14 – Developing Innovative STEM Units 107
Chapter 15 – Perspectives on Professional Learning for STEM Units 117
Chapter 16 – Professional Development of STEM Units 123
Part 3 Concluding Discussion 133

Part 4
INNOVATIONS AND OPPORTUNITIES FOR STEM EDUCATION

Chapter 17 – Responses to Questions About Innovations and STEM Education 137
Chapter 18 – Conclusion: A Vision and Teachers' Leadership for STEM Education 143

References 147
Index 153

Preface

The development of this book from idea to its current form has an interesting history. This book began in March 2012, when, as I was in final preparations for my book *The Case for STEM Education: Challenges and Opportunities* (2013a), I had dinner with Greg Pearson, a senior scholar at the National Academy of Engineering. Greg had reviewed *The Case for STEM*, so I summarized the chapters and, of course, my responses to his suggestions. That book expanded on various themes, such as our "*Sputnik* moment," and helped the reader clarify his or her own perspective on STEM education. While I provided information and suggestions, my goal in writing the book was to help others understand the context and perspective for STEM-oriented education reform. I explained all of this to Greg with great enthusiasm. After a few minutes, he asked, "Aren't you going to say what you would do?" He asked what I would say if others asked about my ideas for STEM education, so I talked about the need for a discussion of curriculum materials related to STEM domains, an emphasis on contemporary challenges, and an orientation that differs from, but complements, the discipline-based programs in most schools. Greg told me I had to include my ideas in *The Case for STEM Education.*

When I returned to work on that manuscript, I tried adding these innovative ideas, but it just did not work. In *The Case for STEM Education*, I developed the theme of helping others think through and strengthen their STEM programs. That theme was offset by adding several final chapters that proclaimed, "Here is what I would do."

This book—*STEM Education Now More Than Ever*—does present my ideas. These ideas about STEM differ from other approaches, but I try to present a reasonable view, one that is timely and will have value in the coming years. Let me continue with a discussion of this book's development.

This book was conceptualized during that original discussion with Greg; however, the book's development took much longer than anticipated. After doing some initial work on a new STEM book, I engaged in other projects. From time to time, I would work on the manuscript, but not with a clear focus or deadline. My other projects resulted in the books *Translating the* NGSS *for Classroom Instruction* (2013b) and *The BSCS 5E Instructional Model: Creating Teachable Moments* (2015).

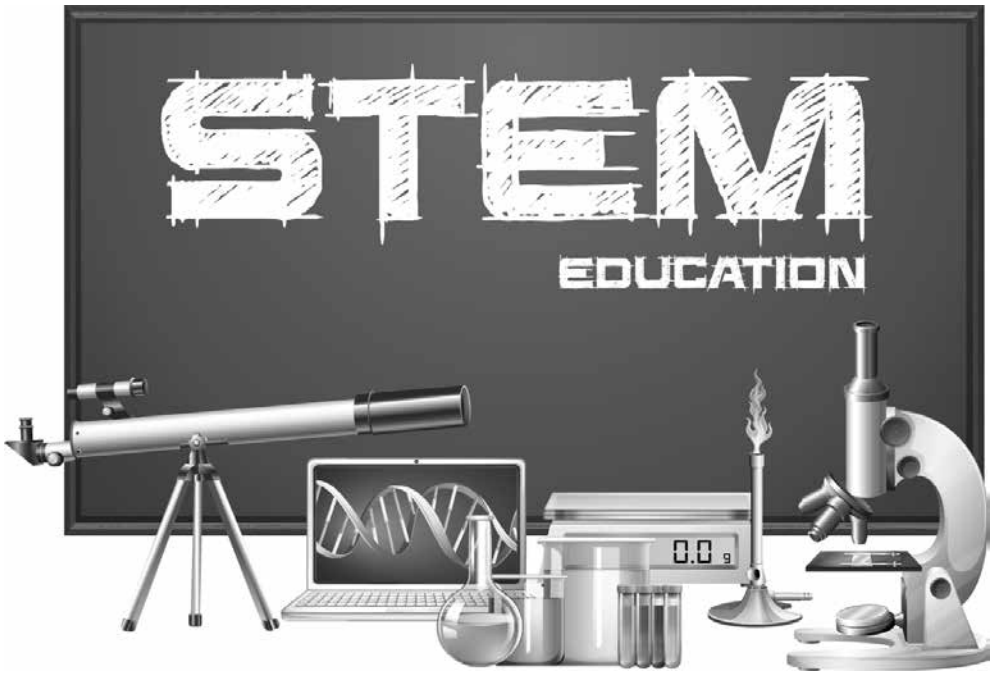
During this period, I kept an eye on various publications, meetings, and projects related to STEM education. In my view, however, many STEM initiatives suffered from one significant shortcoming: They used the acronym in broad and ambiguous ways. Basically, STEM had become a slogan. Recognizing this shortcoming did not mean that STEM education lacked potential and an important role in American education, but STEM education's potential and role were not clear, at least to me.

All of this changed with the election of Donald J. Trump as the 45th president of the United States. I realized then that the aspirations and innovations I had considered all came together in this urgent time for STEM education.

Preface

The ideas I present in this book provide something of a corrective measure for the weaknesses I perceive in STEM education. My enthusiasm and motivation center on responses and remedies to concerns that emerged during the presidential campaign—for example, I was appalled by the disdain displayed toward women, minorities, and individuals with special needs. From a STEM point of view, I was especially dismayed by the misuse of evidence, assaults on the integrity of the STEM disciplines, dismissal of the contributions of science and engineering (many supported with government funds), and the disregard for civil discourse.

Now more than ever, we need a reminder of the documents and themes that have made America great, as well as ways to address STEM issues at the local, national, and global levels and emphasize how essential education is to a strong citizenry. These themes lead directly to STEM education and the need to address questions that guide the development of programs and practices for the 21st century. The additional challenge for me was to address all of these needs with a positive, constructive, and diplomatic approach. So, here is a summary of the result.



Part 1 of this book provides a context for contemporary STEM education, my response to President Trump's rhetoric and reasoning about STEM-related issues, and my motivation for writing this book. I do believe there is a new and urgent need for STEM education, and that need emerged from numerous challenges that arose from the 2016 presidential campaign and the new administration. STEM education must express new aspirations that complement traditional approaches to the respective STEM disciplines.

In Part 2, chapters on the Enlightenment, the Constitution, democracy, citizenship, and American science and technology serve as reminders of the effects that STEM disciplines have had on America's foundational ideas and values and how these concepts extend to education, including contemporary STEM education. Although these chapters do not look or seem like typical chapters in a book on STEM, they are timely and useful as background for understanding why this book on STEM education has the theme "Now more than ever." Please read these chapters and think about these foundational ideas and values and their implications for STEM education in general and the recommendations I make in this book in particular.

In Part 3, I address the question, "What should we do to advance STEM education?" The chapters in Part 3 move beyond contemporary politics and center on the purposes of STEM education and constructive recommendations for the translation of the purposes into curriculum units. Rather than present a large, all-encompassing view, I make what I hope are practical recommendations: Begin with design and develop STEM units for the classroom, then use the development of those units as the basis for teachers' professional learning. The chapters in Part 3 direct attention to the simultaneous need for instructional materials and professional development. I recommend that teachers engage in a series of working seminars with the aim of developing STEM units for their use. The working seminars also are designed as complementary professional learning experiences.

Part 4 provides a brief but important conclusion for the book. The first chapter in Part 4 answers questions about the themes and recommendations from prior chapters, and the book's final chapter discusses the need for leadership by classroom teachers and the STEM education community.

This book draws on my past themes and works that some readers may recognize. I do not apologize for this use of previously stated ideas and publications. For *STEM Education Now More Than Ever,* the ideas have a new context and are timely in how they address the challenges faced by STEM teachers and the community.

As we navigate these unconventional and uncertain years, I hope this book will provide a guide for a positive and constructive response by the STEM education community.

Acknowledgments

Although this book was completed over a short period of time in 2016 and 2017, the resources and ideas I drew upon have been in development for many years. The individuals who advised and supported the work are many and diverse. I especially wish to acknowledge and thank the following individuals.

Greg Pearson, a colleague at the National Academy of Engineering, gave me the original advice to step up and write something innovative. He has continued to reinforce that original recommendation. Greg DeWit, a friend and neighbor, has listened patiently while I explained the book's themes and my progress with the manuscript. Chris Chopyak asked me to join her and several colleagues for a project called *Instructional Materials and Implementation of* Next Generation Science Standards (Bybee and Chopyak 2017). Our work resulted in many opportunities to discuss the relationship between business and education. Most important, our work helped me formulate ideas about the importance of teachers' professional learning and instructional materials.

For several years, I have been a consultant for the Hands-On Science Partnership, a small group of commercial publishers. I met with the group shortly after the 2016 presidential election, and my presentation at that meeting contributed immeasurably to the themes in this book.

I extend special appreciation to Robert Pletka, superintendent of the Fullerton School District in California, for the ideas, support, and friendship he has provided.

Seven individuals completed detailed reviews of a preliminary draft of this book. NSTA supported five of those reviews. The NSTA reviewers included James Brown, Andrés Henríquez, Harold Pratt, James Short, and Jeff Weld. Peter McLaren and Kathryn Bybee also read and commented on the entire draft. In addition to the written reviews and recommendations, I also had extended discussions with Harold, Jim, Peter, and Kathryn, all valued colleagues. In preparing the final manuscript, I responded to most of the reviewers' recommendations. I thank the reviewers, as this book is stronger and more balanced because of your feedback.

Once again, I thank the NSTA staff for their support, in particular Claire Reinburg, Rachel Ledbetter, and Jodi Peterson, as well as Wendy Rubin, who carefully edited and substantially improved the book.

This is the seventh book that I have had the pleasure of working on with Byllee Simon. Her understanding of my ideas and work habits has been, and continues to be, deeply appreciated.

I thank my family, especially Margaret Herbert, Corey Bess, and Cassie Bess, all of whom taught or are teaching in public schools. On several occasions, they listened to my ideas and gave advice.

Kathryn Bybee gave me unending support and encouragement based on her experiences as a classroom teacher and in leadership as Director of Science in the

Acknowledgments

San Diego Unified School District and San Diego County Office of Education. My appreciation of Kathryn's extensive discussions, forbearance, and recommendations is beyond expression.

About the Author

Until I retired in 2007, I was the executive director of Biological Sciences Curriculum Study (BSCS), a nonprofit organization that develops curriculum materials, provides professional development, and conducts research and evaluation for the education community.

Before joining BSCS, I was the executive director of the National Research Council's (NRC) Center for Science, Mathematics, and Engineering Education (CSMEE) in Washington, D.C. From 1986 to 1995, I served as the associate director of BSCS, where I was the principal investigator for four new National Science Foundation (NSF) programs: an elementary school program called *Science for Life and Living: Integrating Science, Technology and Health;* a middle school program called *Middle School Science & Technology*; a high school program called *BSCS Biology: A Human Approach*; and a college program called *Biological Perspectives*. I also served as the principal investigator on several other programs to develop frameworks for teaching about various topics, including the nature of science and technology and curriculum reform based on national standards.

I chaired the Science Forum and Science Expert Group (2006) for the Programme for International Student Assessment (PISA) by the Organisation for Economic Cooperation and Development (OECD).

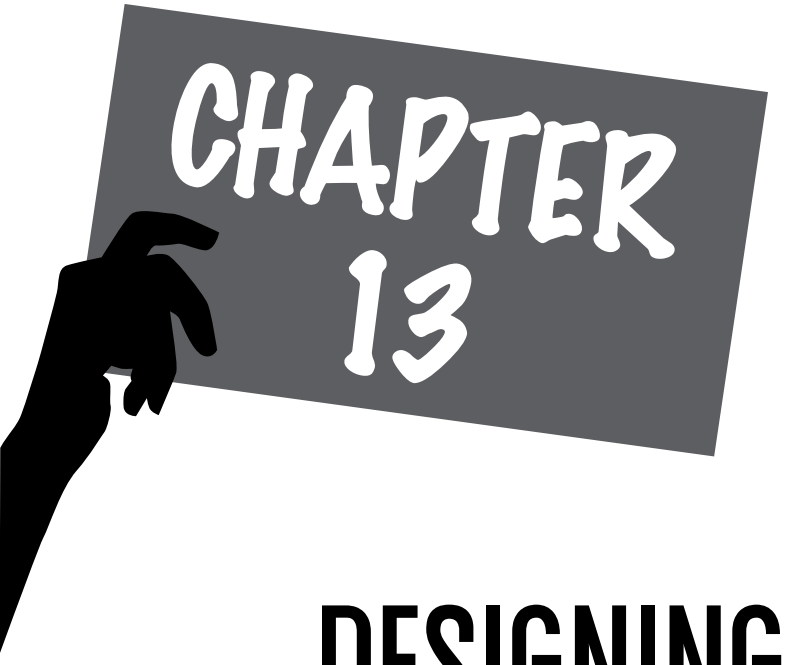
I participated in the development of the *National Science Education Standards* (NRC 1996), and from 1993 to 1995, I chaired the content working group for that NRC project. I also contributed to *A Framework for K–12 Science Education* (NRC 2012) and served on the leadership team and as a writer for the *Next Generation Science Standards* (NGSS Lead States 2013). From 1990 to 1992, I chaired the curriculum and instruction study panel for the National Center for Improving Science Education (NCISE), and from 1972 to 1985, I was a professor of education at Carleton College in Northfield, Minnesota. I have been active in education for more than fifty years and have taught at the elementary through college levels.

My bachelor's and master's degrees are from the University of Northern Colorado, and my doctorate degree is from New York University. I have written about topics in both education and psychology and received awards. In 1989, I was recognized as one of one hundred outstanding alumni in the history of the University of Northern Colorado. In April 1998, the National Science Teachers Association (NSTA) presented me with NSTA's Distinguished Service to Science Education Award, and in 2007, I received the Robert H. Carleton Award, NSTA's highest honor, for national leadership in the field of science education.

After stepping down from BSCS, I continued working as a consultant and contributing to education through presentations and publishing. With NSTA Press, I have written *The Teaching of Science: 21st-Century Perspectives* (2010); *EVO Teacher's Guide: Ten Questions Everyone Should Ask About Evolution* (2012), with John Feldman;

About the Author

Translating the NGSS *for Classroom Instruction* (2013b); *The Case for STEM Education: Challenges and Opportunities* (2013a); *The BSCS 5E Instructional Model: Creating Teachable Moments* (2015); and *Perspectives on Science Education: A Leadership Seminar* (2017), with Stephen Pruitt.

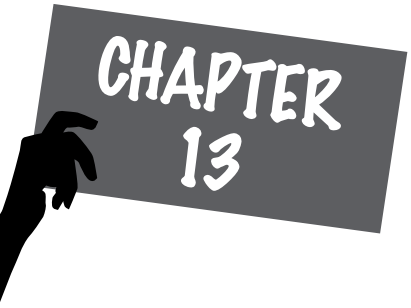


DESIGNING INNOVATIVE STEM UNITS

What would be emphasized in innovative STEM units? What content would be central to the STEM units? What learning outcomes would be in the foreground of STEM units? Questions such as these move our discussion to criteria for the design of instructional materials for STEM.

Answering questions about the design of innovative STEM units raises other fundamental and provocative problems about how best to educate students so they become informed citizens. Although one might wish otherwise, the current education system would probably reject a massive reform that might be perceived as an either/or proposition, such as, "Either we have the current discipline-based system, or we have a system of STEM education." In this chapter, I argue that it is possible to view the situation from a both/and perspective. The latter seems possible if one thinks of reasonable (that is, small and manageable) segments of school programs that may be devoted to innovative STEM units. Abstract discussion of STEM in national policies without attention to concrete education issues may be interesting, but the details of state standards and assessments warrant variations on school programs and teachers' classroom practices.

My proposal acknowledges the central place of traditional disciplines; the reality of schools, teachers, teaching; and a means of advancing STEM education. Addressing this innovation requires an educational approach that places life situations and STEM-related issues in a central position and uses the four disciplines of STEM to understand and address life problems. This has been referred to as *context-based science education* (Fensham 2009) and could easily be represented as *context-based STEM education*.



My proposal centers on creating instructional units that are based on contemporary issues with contexts that have meaning for students and relate to life situations they may confront. These instructional units would vary in length for the elementary, middle, and high school levels—at a minimum, two, four, and six weeks at the respective levels. Although the units would present an innovative approach to STEM-related issues, however, the units could be introduced in the respective STEM disciplines in current school programs, so this is not a complete reform of STEM education. The units could be designed and supported by the professional development of teachers who would implement the units.

It would deviate from the norm to use innovative instructional units as the basis for introducing STEM as an integral component of the education system, but the fact that the units are brief and can be accommodated within current programs makes the goal achievable. This approach would be a positive and constructive response to classroom teachers' request for instructional materials that both exemplify the innovation and are easy for them to implement. In fact, as mentioned above, I propose that teams of teachers develop the units with the support of professional learning experiences (NRC 2015).

A Strategy for the Design and Development of STEM Units and Professional Learning for Teachers

American education has a long history of large and small innovations that have influenced policies, programs, and practices. We have witnessed numerous such innovations in recent years, and STEM education is one area that holds promise for improving students' interest and achievements. Unfortunately, we also have developed a perspective that all of these innovations carry the same importance and that our work is finished once we have implemented the new ideas. First, the innovations of national standards, for example, cannot be equated with other innovations because they are dominant organizers that influence curriculum development and implementation; however, they are not the curriculum itself. We cannot assume that because we have standards and assessments, we are finished with the work of improving education. We are not. The steady work of reform is closer to the beginning than to the end, and curriculum is an essential component of improving education.

Table 13.1 identifies strategies that center on curriculum and use a systemic perspective to move the community of STEM educators through the period of transition. Table 13.1 and the paragraphs that follow address six points and provide some recommendations for initial discussions about innovative STEM units. The suggested activities are meant to introduce the ideas of STEM, provide contextual emphasis, demonstrate the content and processes of STEM, and illustrate how to design units that would complement other state and local goals. The purpose is not to design STEM units but to introduce and explore the ideas of STEM units at state and local levels. The design, development, and implementation of STEM units provide the context for the strategy.

Table 13.1. Introducing the Idea of STEM Units in Education: Strategies for State and Local Leaders

Activity	Goal	Central Questions
Initiating a dialogue of STEM education and possible units with key personnel (i.e., teams of classroom teachers and professional developers).	Engage in a preliminary discussion of STEM education.	What is STEM education? What are the implications of STEM education for curriculum in our state? District? School?
Defining the goals for STEM education.	Clarify the major goal for instructional units for STEM education.	What do we wish to achieve through STEM-related instructional units?
Committing to state standards and the development of STEM units appropriate for teachers, schools, and students.	Identify the context that STEM units should use and the competencies they should emphasize.	What has the state already agreed that all students should know and be able to do?
Deepening understanding of STEM and the processes of developing instructional units.	Challenge and clarify fundamental conceptions of STEM education and the implied units.	Have we thought about the role of STEM units in our state? District? School?
Increasing the coherence of STEM education in the school curriculum.	Achieve greater alignment among components of the STEM units and between the current curriculum and the education system.	How can we achieve greater alignment between the proposed STEM units and the education system?
Monitoring progress.	Provide feedback about the role of STEM curriculum to inform state, district, and school decisions.	How are we doing so far? What do we have to do now?

Initiating a Dialogue

I recommend having an initial dialogue about STEM education in general and the implications for the proposed units in particular. The dialogue should include teachers, schools, districts, and state leaders in the education system. *The Case for STEM Education: Challenges and Opportunities* (Bybee 2013a) and this book provide a basis for the dialogue.

Defining Goals

When the discussion turns to the purposes or goals of the STEM units in the context of the state, district, or school, people may mention STEM literacy, preparation for college and careers, workforce skills, higher achievement on assessments, and citizenship. Follow this discussion with additional questions: What do these terms mean?

What do they imply for the curriculum at different grades? For different instructional strategies? For professional development of classroom teachers?

Here is a statement that you could use to initiate the discussion:

> *By the year 2021, students in our (state, district, or school) will demonstrate competencies when presented challenging STEM-related situations. Students in grades K–12 will develop competencies and have opportunities to learn content and practices that will prepare them for responsible citizenship, further learning, and productive employment in our knowledge economy.*

Committing to State Standards and STEM Units

This goal statement invites several questions worthy of discussion and clarification as the teams commit to developing STEM units:

- Is the year 2021 a reasonable endpoint for accomplishing these goals?
- How are competencies defined?
- What are challenging STEM-related contexts?
- What content and practices will help students become responsible citizens?
- How do state standards inform the discussion and decisions about STEM units?

Deepening Understanding

The decision to improve STEM programs through the design and implementation of units can facilitate discussions that result in deeper understanding of content and pedagogy. These discussions may surface fundamental misunderstandings about standards, curriculum, and the improvement of education systems. I have identified several misconceptions about the role of curriculum in standards-based reform in Figure 13.1. School leaders can address these and other likely misunderstandings through professional development that complements the STEM units.

Increasing Coherence

In many education situations, there is a lack of coherence among essential components of the system. For example, some content and activities of current instructional materials may not align with widely used assessments, and teacher preparation and professional development may not align with state and local frameworks. Furthermore, some initiatives, such as vouchers and charter schools, focus attention on issues that may vary from the central components of the instructional core, such as content, curriculum, and teachers' professional knowledge and abilities.

The discussion of STEM units should address the challenge of increasing coherence through alignment of learning outcomes with teachers' needs, local priorities,

Figure 13.1. Misconceptions About the Role of Curriculum in Standards-Based Systemic Reform

- Curriculum and instructional materials are the same.
- Standards and curriculum are the same.
- Standards and other education innovations have equal value.
- Science, technology, engineering, and mathematics practices are only instructional strategies.
- Standards can be met by selecting the right instructional materials.

and state standards. To be honest, there will be necessary trade-offs when you try to achieve complete coherence.

Monitoring Progress

The final step in the strategy seems like an obvious one. We need to monitor progress and provide feedback about various components of the system. Our usual approach emphasizes assessment of student learning, so states have implemented assessments: At the national level, we have the National Assessment of Educational Progress, and at the international level we have Trends in International Mathematics and Science Study and Programme for International Student Assessment. The evaluation of students' opportunities to learn the valued content in STEM education would be an essential complement to assessments of student achievement.

To conclude this discussion of STEM units, I want to note that instructional materials have an important but sometimes neglected role in STEM education. The process of developing and implementing STEM units requires a systematic approach that recognizes state standards and sets in motion the creation of a strategy that attends to the varied components of the instructional core and their interactions in the education system.

Design Criteria

Innovative changes implied by this discussion of STEM education should be initiated through curriculum units that demonstrate a different curriculum emphasis within the K–12 program. I am using the term *curriculum emphasis* as proposed by Doug Roberts (1982), meaning that curriculum includes a focus on the competent application of knowledge and abilities to potential life situations and the responsibilities of citizenship. Units should be interdisciplinary and involve problems or situations appropriate to students' ages and grades. The primary outcomes center on the development of competencies and the consideration of the outcomes of different solutions. This proposed emphasis would be a modest but achievable change. Design specifications for the units are presented in Figure 13.2 (p. 104).

Figure 13.2. Design Criteria for Innovative STEM Units

The proposed STEM units should

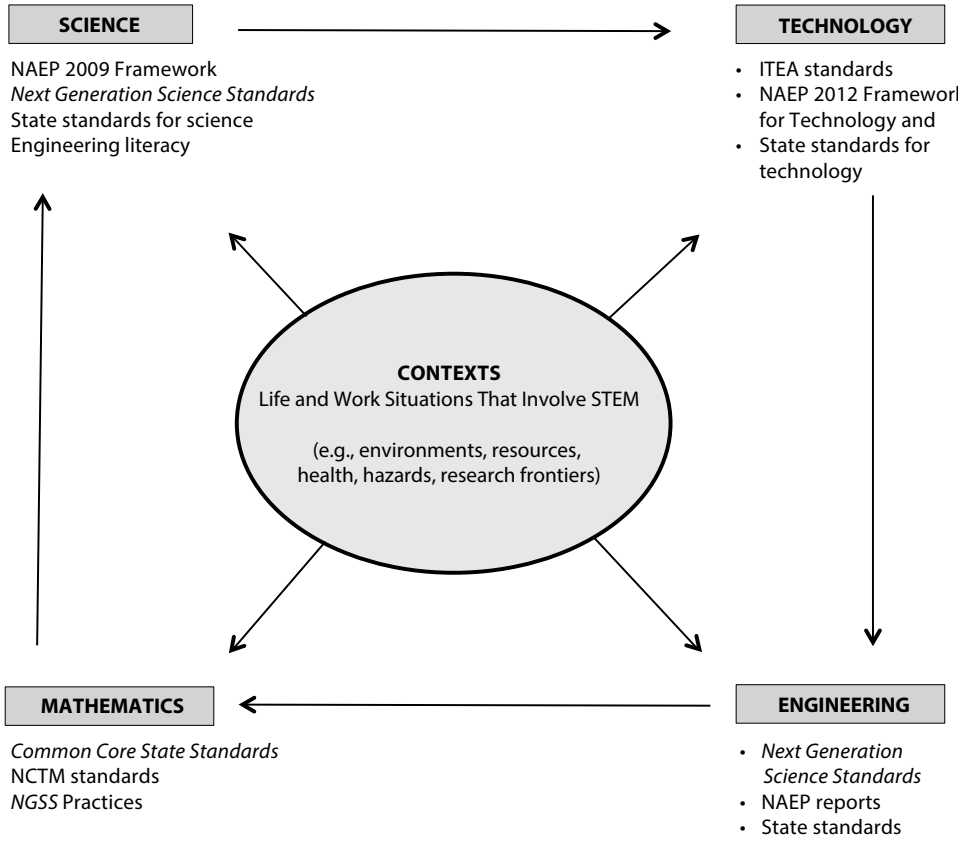
- be based on learning research described in several NRC reports, such as *How People Learn* (NRC 2000), and *Taking Science to School: Learning and Teaching Science in Grades K–8* (NRC 2007);
- use an integrated instructional sequence such as the 5E Instructional Model (Bybee 2015);
- be developed using backward design (see Wiggins and McTighe 2005);
- use contextual issues related to STEM as the central themes for units;
- emphasize competencies;
- include opportunities to develop skills for the 21st-century workforce (NRC 2010);
- present units lasting at least two weeks for elementary school (K–5), four weeks for middle school (grades 6–8), and six weeks for high school (grades 9–12); and
- be field-tested and revised based on feedback and evidence of effectiveness.

Approach for Developing a STEM Unit

The unit should begin with a contextual challenge or problem that engages students. The challenge should be appropriate to the students' ages, grade, and developmental stage and may center on one of several contextual areas cited in prior chapters or a problem identified by teachers. As students explore options and gain an understanding of the problem, the materials should introduce or "reach out" to the respective STEM disciplines. This process allows students to identify and apply knowledge and skills to the problem. The knowledge and skills that students would identify and apply in units should be taken from various documents, such as state standards and the NAEP's Technology and Engineering Literacy Framework. Figure 13.3 presents a framework with the central emphasis of contextual problems and the possible connections among STEM disciplines.

Innovative changes implied by this discussion should be initiated using curriculum units that demonstrate a curriculum emphasis different from that of most current K–12 programs. Such changes take advantage of opportunities that exist within many communities and current school programs, so making this shift should be a modest but achievable change.

Figure 13.3. A Framework for STEM Units



Conclusion

In this chapter, I discussed an innovative strategy for the design, development, and implementation of STEM units. I described the strategy for state and local leaders and highlighted the critical connection between the development of instructional materials and the professional learning of STEM teachers. This forms the basis for the discussion in Chapter 14 about developing innovative STEM units.

Index

Page numbers printed in **boldface** type refer to figures and tables.

A
Achieving Scientific Literacy (Bybee), 87
Active learning and STEM unit development, 75
Adaptability
  and STEM education, 14, 15, 83, **83**
  workforce skills and abilities, **96**
The Age of the Democratic Revolution (Palmer), 42, 59
American Amnesia (Hocker and Pierson), 39
American Museum of Natural History (AMNH), 124
The American People and Science Policy (Miller), 63
American science and technology, 63–70
Atomic Energy Commission, 67
Audubon, John James, 64

B
Bacon, Roger, 42
Bell, Alexander Graham, 64
Bill of Rights, 49
Biological Sciences Curriculum Study (BSCS), 31
Bottom up/top down approach to STEM unit development, 124
BSCS 5E Instructional Model
  curricular models and STEM unit development, 76
  innovative STEM unit development, 114–115, **115**, 140–141, **141**
  K–12 program framework, 88
  professional development of STEM units, 128–129, **128–129**, **130**
The BSCS 5E Instructional Model (Bybee), vii
Burroughs, John, 64
Bush, Vannevar, 67, 68
Butts, R. Freeman, 58

C
Career awareness, STEM education context, **90**
Carson, Rachel, 64
Carter, Jimmy, 61
The Case for STEM Education (Bybee), vii, 5, 10, 79, 101
Cause and effect (crosscutting concept), **93**
Citizenship
  abilities and sensibilities for informed citizens, 97–98
  inquiry practices for informed citizens, 94, **95**
  power and obligations of, 57–62
  scientific literacy and STEM-literate citizens, 80–82, **82**
  and STEM education, 2, 7, 10–11, 36, 39, 79–82, 86
  values, 94
  what students learn and STEM unit development, 113, **113**
Citizenship and Ecology Education (Ophuls), 59, 60
City-state citizenship, 58
Civility (Carter), 97
Civil War, 66
Classroom Discussions (Chopin, O'Connor, and Anderson), 98
Clean Air Act, 69
Coaching and expert support, STEM unit development, 76
Coherence, increasing coherence (innovative STEM unit design), **101**, 102–103
Commager, Henry Steele, 43
Common Core State Standards
  education goals and STEM, 14, 15, 29–30, **30**
  framework for innovative STEM unit design, **105**
  importance of mathematics, 14

Index

and new state standards, 23, 24, 26–27
Trump's rejection of, 18
Competencies
described, 91, **92**
innovative design for STEM units, 117
K-12 program framework, 88, **89**
Complex communication skills
and STEM education, 14, 15, 83, **83**
workforce skills and abilities, **96**
Congress, 49
Contemporary issues
innovative STEM unit design, 100
and STEM education, 21, 49–50
and the U.S. Constitution, 47–50
Content
content-focused STEM unit development, 75
innovative STEM unit development, **108**, 117
K-12 program framework, 88, **89**
Contexts
contextualist view of science curricula, 81
innovative STEM unit design, 99, 104, **105**, 117
K-12 program framework, 88, **89**
professional development of STEM units, 126, **127**
STEM unit development, 88, 90–91, **90–91**
Copernicus, Nicholas, 42
Creating a STEM Culture for Teaching and Learning (Weld), 13
Crick, Francis, 84
Critical thinking, and STEM education, 16
Crosscutting concepts, 92–94, **93**, **108**, 109
Cuban, Larry, 85
Cultural heritage
about, ix, 37–39, 71–72
American science and technology, 63–70
citizenship powers and obligations, 57–62
democracy, schooling, and STEM education, 51–55
the Enlightenment, 41–43, 59
U.S. Constitution, 43, 45–50
Curricula
curricular approach to STEM, 14
curricular models and STEM unit development, 76
Vision I and Vision II curricula, 81
Curriculum reform
misconceptions about role of curriculum in standards-based reform, 102, **103**
school and district leadership in teachers' professional development, 121
STEM education innovation proposals, 31–34, 35–36

D
Darling-Hammond, Linda, 74
DeBoer, George, 80–81
Declaration of Independence, 43, 51, 59, 70
Deepening understanding, innovative STEM unit design, **101**, 102
Democracy
citizenship powers and obligations, 57–62
contemporary issues and the U.S. Constitution, 47–49
democratic common schooling, 52–55
and STEM education, 2, 7, 51
Democracy and Education (Dewey), 52–54
Democracy in America (de Tocqueville), 71
Department of Agriculture, 66
Design criteria for innovative STEM unit design, 103, **104**
DeVos, Betsy, 18
Dewey, John, 52–54
Dialogue initiation, innovative STEM unit design, 101, **101**
DiRanna, Kathy, 31
Dubos, Ren,, 61–62

E
Earth Science Curriculum Project (ESCP), 110
Edison, Thomas, 64
Education acts, **70**
Elmore, Richard, 31
The Empire of Reason (Commager), 43
Endangered Species Act, 69

Energy and matter (crosscutting concept), **93**
Energy resources, STEM education context, **90**
Engineering
  engineering design, new state standards, and STEM education, 24
  framework for innovative STEM unit design, **105**
  inquiry practices for informed citizens, **95**
  in K–12 Education, 11, 14
  and STEM education innovations, 1–3
Engineering in K–12 Education (Katehi, Pearson, and Feder), 11
the Enlightenment, 41–43, 59
Environmental policies, 69, **69**
Environmental Protection Agency (EPA), 48
Environmental quality, STEM education context, **90**
Equity, epistemic and ethical outcomes, 13
Every Student Succeeds Act (ESSA), 15, 52
Experience and Education (Dewey), 53
Explicit integration, 12
Exploring the Intersection of Science Education and 21st Century Skills (NRC), 83

F
Federal departments and agencies, **65**
Federal Water Pollution Control Act, 69
Feedback and reflection, STEM unit development, 76
First Amendment, 46–47
Fourth Amendment, 48
Fifth Amendment, 48
Founding Fathers, 39, 41, 42, 45–46, 63–64
Fourteenth Amendment, 48
Framework for innovative STEM unit design, 104, **105**
A Framework for K–12 Science Education (NRC), 11, 12, 14, 24, 27, 92–93, **93**
Franklin, Benjamin, 43
Franklin Institute, 65
Franklin, Rosalind, 84

G
Global citizenship, 59–62
Global contexts for STEM education, **90–91**
Global perspectives and STEM education, 2–3
Goals
  Common Core State Standards, education goals, and STEM, 14, 15, 29–30, **30**
  innovative STEM unit design, 101–102, **101**
  STEM education innovation and education goals, 14–15, 20–21, **30**, 73–74, 138–139
  workforce and STEM education goals, 80, 83–85, 86, 138
Gravity, universal law of gravitation, 42

H
"Habits of mind," 11
Hamilton, Alexander, 43
Hamiltonian citizenship, 59–60
Handbook of Research on Science Education (Roberts), 81
Hazard mitigation, STEM education context, **90**
Health maintenance and disease prevention, STEM education context, **90**
Hobbes, Thomas, 59
Holdren, John, 48
Homestead Act, 66
How Civility Works (Bybee), 97
How People Learn (NRC), 111, 114
How Students Learn (NRC), 111
How We Think (Dewey), 53
Hume, David, 41, 42
Hurd, Paul DeHart, 80

I
Increasing coherence, innovative STEM unit design, **101**, 102–103
Individual empowerment, 53
Individual STEM discipline content and process support, 12
Information and communications technology (ICT), 13–14

Index

Innovative design for STEM units, 99–105, **100**, **104**, **105**, 117
Inquiry practices for informed citizens, 94, **95**
Inservice institute, professional development of STEM units, 131, **131**, **132**
Instructional Rounds in Education (City et al.), 131
Instruction models and STEM unit development, 76
Integrated approach to STEM unit development, 107–112, **108**, 140
Integrated instructional sequence, 128, 137, 140–142, **141**
Inventing America (Wills), 43

J
Jay, John, 43
Jeffersonian citizenship, 60
Jefferson, Thomas, 6, 18, 43, 51, 52, 59, 64

K
Kant, Immanuel, 41, 43
Kastel, Dora, 124
Knowledge
  crosscutting concepts, 92–94, **93**
  K-12 program framework, 88, **89**
Kübler-Ross, Elisabeth, 17

L
Labor and leisure classes, democracy and common schooling, 52
The Language of Education (Scheffler), 6
The Launching of Modern American Science, 1846–1876 (Bruce), 63
Learning
  how and what students learn and STEM unit development, 111–113, **113**
  professional learning criteria for STEM units, 118–121
Learning Policy Institute, 74, 120–121
Lesson planning and STEM education, 29
Lewis and Clark expedition, 64–65
Locke, John, 41, 43, 59
Loucks-Horsley, Susan, 31

M
Madison, James, 43
Manhattan Project, 67
Mann, Horace, 52
Marsh, George Perkins, 64
Mathematical Principles of Natural Philosophy (Newton), 42
Mathematics
  framework for innovative STEM unit design, **105**
  importance of reinforced in *Common Core State Standards*, 14
  inquiry practices for informed citizens, **95**
McCormick, Cyrus, 64
Memorandum on Scientific Integrity, 38
Millar, Robin, 88
Model-based reasoning, 13
Monitoring progress, innovative STEM unit design, **101**, 103
Morrill Land Grant College Act, 66
Morse, Samuel F. B., 64, 65
Muir, John, 64
Mundry, Susan, 31

N
National Academy of Science, Engineering, and Medicine, 67
National Academy of Sciences, 66
National Advisory Committee for Aeronautics, 67
National Aeronautics and Space Administration (NASA), 48
National Assessment of Educational Progress, 11–12, 19
National Bureau of Standards, 67
National Cancer Institute, 67
National Defense Research Committee, 67
National Institutes of Health (NIH), 48
National Research Council, 67
National Science Education Standards (NRC), 31, 94
National Science Foundation (NSF), 31, 48, 68, 123

Natural resources, STEM education context, **90**
Newtonian synthesis and societal organization, 41, 43
Newton, Isaac, 42, **42**, 43
Next Generation Science Standards (NGSS)
  and engineering in STEM, 11
  framework for innovative STEM unit design, **105**
  and professional development of STEM units, 124
  STEM education and new state standards, 23–24, **25**, 26–27
  and STEM education goals, 14, 15
  and STEM unit development, 94
Nongovernmental organizations, 66, **66**
Nonroutine problem solving
  and STEM education, 14, 15, 83, **83**
  workforce skills and abilities, **96**

O
Obama administration, 20, 38, 48
Obama, Barack, 38, 71
Office of Science and Technology Policy (OSTP), 48
Office of Scientific Research and Development (OSRD), 67
Office of Technology Assessment (OTA), 47–48
Office of the Surgeon General of the Army, 65
Only One Earth (Ward and Dubos), 61–62
On the Fabric of the Human Body (Vesalius), 42
On the Revolutions of the Heavenly Spheres (Copernicus), 42
Ophuls, William, 59, 60

P
Paideia, 82
Palmer, Robert R., 42, 59
Patterns (crosscutting concept), **93**
Penuel, Bill, 31
Personal contexts for STEM education, **90–91**
Piel, Gerald, 49
Pinchot, Gifford, 64
Population changes, STEM education context, **90**
Pratt, Harold, 97
President's Council of Advisors on Science and Technology (PCAST), 48
Professional development of STEM units, 122–132
Professional learning criteria for STEM units, 118–121
Programme for International Student Assessment (PISA), 2, 19, 81–82, 88
Progress, monitoring progress (innovative STEM unit design), **101**, 103
Ptolemy, 42
Public health policies, 69, **69**

Q
Quantitative reasoning, 13

R
Reconceptualizing STEM Education (Duschl and Bismack), 13
Reflective thinking and how students learn, 111–112
Research, development, and innovation (STEM education context), **91**
Resource policies, 69, **69**
The Revival of Civic Learning (Butts), 58
Richards, Ellen Swallow, 64
Roberts, Douglas, 81
Roosevelt, Franklin D., 67, 68
Rousseau, Jean-Jacques, 42, 60

S
Scale, proportion, and quantity (crosscutting concept), **93**
School choice, 18–19, 20, 21, 140, 142
Science
  American science and technology, 63–70
  framework for innovative STEM unit design, **105**
  inquiry practices for informed citizens, **95**
  and multiple STEM disciplines, 13–14

Index

scientific inquiry and the Enlightenment, 41–43
scientific literacy and STEM-literate citizens, 80–82, **82**
and social progress, 54
and STEM education innovations, 1–3
and the U.S. Constitution, 45–47
See also STEM literacy
Science and Technology (President's Commission for a National Agenda for the Eighties), 63
Science and the Founding Fathers (Cohen), 63
Science for All Americans (AAAS), 94
Science Teachers' Learning (Wilson, Schweingruber, and Nielsen), 33, 119–120
Science, the Endless Frontier (Bush), 63, 68
Self-management and self-development
and STEM education, 14, 15, 83, **83**
workforce skills and abilities, **96**
Short, James, 31
Short, Jim, 124
Silent Spring (Carson), 64
Skills and abilities
K-12 program framework, 88, **89**
and STEM education, 15
21st-century skills, 14, 15, 83, **83**, 96–97, **96**
Smithsonian Institution, 65–66
Smithson, James, 65
Social contexts for STEM education, **90–91**
Social skills
and STEM education, 14, 15, 83, **83**
workforce skills and abilities, **96**
Stability and change (crosscutting concept), **93**
State standards
innovative STEM unit design, **101**, 102, 117
new state standards, *NGSS*, and STEM education, 23–24, **25**, 26–27
and STEM units, 32
STEM communication and outreach, 13
STEM education advancement: *See* STEM units
STEM education innovation
about, ix, 1–4, 15–16, 35–36, 135–136
education goals and STEM, 14–15, 20–21, **30**, 73–74, 138–139
measured and strategic approach to STEM integration, 12
need for, viii, 3–4, 5–7, 135–136, 139
potential significance of STEM, 13–14
responses to questions about, 137–142
slogans and definitions regarding, 5–6, 9–11, 26
STEM education challenges, 11–13, 17–21
STEM education innovation proposals, 31–34
STEM education, *NGSS*, and new state standards, 23–27, *25*
STEM education weaknesses, viii
teachers' leadership for, 143–146
See also cultural heritage; STEM literacy; STEM units
STEM Integration in K–12 Education (Honey, Pearson, and Schweingruber), 12–13
STEM literacy
abilities and sensibilities for informed citizens, 9708
competencies, 91, **92**
contexts for STEM unit development, 88, 90–91, **90–91**
definitions, 10–11
inquiry practices for informed citizens, 94, **95**
K-12 program framework, 87–88, **89**
knowledge (crosscutting concepts), 92–94, **93**
values, 94
a vision and teachers' leadership for, 144–146
workforce skills and abilities, 96–97, **96**
STEM units
curriculum reform, 31–34
development of, 74–77, **75–76**
innovative design, 99–105, **100**, **104**, **105**, 117
integrated approach to STEM unit development, 107–112, **108**, 114–115, **115**
professional development of, 122–132
professional learning criteria, 118–121
and purposes of STEM education, 73–74, 79–86, 133

what and how students learn and STEM unit development, 111–113, **113**
See also STEM literacy
Stiles, Kathy, 31
Structure and function (crosscutting concept), **93**
Summer institute, professional development of STEM units, 125–130, **125**, **127**, **128–129**, 132
Sustained duration, STEM unit development, 76
Systems and systems models (crosscutting concept), **93**
Systems thinking
and STEM education, 13, 14, 15, 83, **83**
workforce skills and abilities, **96**

T
Teachers
how and what students learn and STEM unit development, 112–113, **113**
professional development of STEM units, 122–132, 133
professional learning for STEM units, 32–33, 118–121
STEM unit development, 74–77, **75–76**
teachers' collaboration and STEM unit development, 75
teachers' content knowledge and STEM education, 13
teachers' leadership for STEM literacy, 144–146
Teaching for Civic Engagement (Colley), 98
The Teaching Gap (Stigler and Hiebert), 131
Technology
framework for innovative STEM unit design, **105**
inquiry practices for informed citizens, **95**
and STEM education, 14
and STEM education innovations, 1–3
and the U.S. Constitution, 45–47
Theory Into Action (NSTA), 93
Translating the NGSS for Classroom Instruction (Bybee), vii
Trends in International Mathematics and Science Study (TIMSS), 2, 19
Trump administration, 3, 7, 17, 19–20, 29, 36, 38–39, 69, 135, 143–144
Trump, Donald, vii, viii, 5, 6, 17, 18, 19, 24, 48, 61, 143
21st-century skills, 14, 15, 83, **83**, 96–97, **96**

U
Understanding, deepening understanding (innovative STEM unit design), **101**, 102
Universal law of gravitation, 42
U.S. Constitution, 43, 45–50, 70
U.S. Geological Survey, 67
U.S. government
American science and technology, 64–70
federal departments and agencies, **65**
and STEM education, 38–39
U.S. Public Health Service, 67

V
Values
for informed citizens, 94
K-12 program framework, 88, **89**
Vesalius, Andreas, 42
Vision I and Vision II curricula, 81
Voltaire, 42

W
Ward, Barbara, 61–62
War Powers Act, 49
Watson, James, 84
Whitney, Eli, 64
Wilkins, Maurice, 84
Wills, Garry, 43
Workforce
skills and abilities (STEM literacy), 96–97, **96**
and STEM education goals, 80, 83–85, 86, 138

More Than Ever

Rodger W. Bybee's 2012 book *The Case for STEM Education* was a call to confront pressing challenges and opportunities in science classrooms. This new book is a call to action at a time when the integrity of STEM disciplines is under assault. Now more than ever, he writes, America needs to recognize the place of STEM education in the cultural, political, and ethical life of students as future citizens. But to make this possible, science educators must address important questions that will guide the development of their programs and practices throughout the 21st century.

STEM Education Now More Than Ever is organized into four wide-ranging, thought-provoking sections:

- **Part 1** asserts the need for a new and urgent case for STEM education in light of the 2016 presidential election and challenges voiced regarding science's validity.
- **Part 2** discusses the Enlightenment, the U.S. Constitution, democracy, and citizenship as reminders of the effects of STEM disciplines on America's foundational ideas and values.
- **Part 3** moves beyond contemporary politics to center on the purposes of STEM education and provide recommendations for translating those purposes into practical improvements. Bybee suggests newer, faster ways to help teachers develop relevant STEM units for their classes.
- **Part 4** concludes the book, answering questions raised in prior chapters and asserting the need for classroom teachers and the STEM education community to be strong leaders.

Having been in science education for more than 50 years and written six NSTA Press books, Bybee draws on past themes that readers may recognize. He explains that "the ideas have a new context and serve as timely applications for the challenges STEM teachers and the community face." *STEM Education Now More Than Ever* is his positive and constructive response for the STEM education community as it navigates these unconventional and uncertain years.

PB437X
ISBN: 978-1-68140-601-5

GRADES K–12

NSTApress
National Science Teachers Association