

TRANSLATING *the*
NGSS
for **CLASSROOM**
INSTRUCTION

RODGER W. BYBEE

NSTApress
National Science Teachers Association

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Arlington, Virginia



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For Kathryn.

FOREWORD

The need for a quality science education for all students has never been more critical than it is in the 21st century. As such, science education has gained more attention in recent years with the development of *A Framework for K–12 Science Education* and the *Next Generation Science Standards (NGSS)*. These two developments have engaged many from across science education. From the scientific community that worked with the National Research Council (NRC) to develop the *Framework* to the 26 lead state partners who led the development of the *NGSS*—as well as the thousands of individuals and organizations that contributed during its development—science education has received an unprecedented level of input and support. In heading the development of the *NGSS* on behalf of the lead states, I have had the opportunity to work with many brilliant and passionate individuals. It has been my pleasure to work with all the different groups and individuals who cared enough to bring the *Framework* to life through the *NGSS*. No one has had a greater influence on my own personal knowledge and science instruction than Rodger Bybee. Rodger has been one of the more prolific science educators since the mid-1990s. From his work with the NRC and the development of the 1996 *National Science Education Standards (NSES)* to his work with Biological Sciences Curriculum Study (BSCS), PISA, and TIMSS, Rodger has distinguished himself as a premier science educator. It has been a great opportunity to have worked with Rodger on the *Framework* and more intensely as a member of the *NGSS* leadership and writing teams. It is also my great honor to call him a friend. So, when he asked me to write the foreword for his new book, *Translating the NGSS for Classroom Instruction*, I jumped at the chance. Obviously, anything connected to the *NGSS* is of critical interest to me, but Rodger’s book is a first move forward toward making the vision of the *NGSS* a reality in classrooms.

While the *NGSS* and the *Framework* are complete after almost four years of development, the real work of implementation begins now. As such, I believe this book will be a “must read” for teachers. This book is the first publication to address the challenges and benefits of translating the *NGSS* into quality classroom instruction. As states consider adoption of the *NGSS*, we should embrace the great opportunity to focus on building capacity around the *NGSS* over the next few years. This book, as well as the work of many others, will serve as excellent guides as the *NGSS* move into classrooms. To be clear, the *NGSS* provide the performance expectations students need to accomplish to be considered proficient in K–12 science. The really important work of translating those standards into quality classroom instruction is just beginning. As such, the importance of having Rodger as the author of this book

FOREWORD

cannot be overstated. Because of his past work in science education in general, and his work on the NGSS more specifically, he is able to provide bridges between the past and present as well as between the NGSS and the future of classroom instruction. This book is not a simplistic view of how to interpret the NGSS for the classroom; rather, Rodger provides succinct and clear nuances about the NGSS themselves and accurately outlines the challenges ahead. Chapter 3, “NGSS: 10 Frequently Answered Questions,” could easily be used by teachers and policy makers alike to explain the NGSS and the development process. The most powerful aspect of the book, however, is the information Rodger shares regarding the translation of the NGSS into instruction. Rodger gives very nice guidance with regard to achieving the balance between the disciplinary core ideas, scientific and engineering practices, and crosscutting concepts, as was the intent in the *Framework* and the NGSS. The book provides teachers and curriculum developers with practical examples at each grade band of how the NGSS should be considered as instruction is planned. The idea of developing instructional plans using multiple performance expectations is clear and furthers the message regarding the need for coherent science instruction.

As I said earlier, I was honored when Rodger asked that I write the foreword for this book. My work with the NGSS, the states, and stakeholders continually reminds me of the incredible teachers we have in this country. It also continually reinforces the support teachers need in times of change. I believe the NGSS have a chance to be a real game changer for our students, but I also believe this change comes with a responsibility to identify the challenges and develop supports for those affected by the change. I am very appreciative that Rodger has taken a major step toward providing teachers with such a thoughtful document. I am very proud to introduce *Translating the NGSS for Classroom Instruction*.

Stephen L. Pruitt, PhD
NGSS Lead and Senior Vice President for Achieve, Inc.

PREFACE

This book began with a request from my colleagues Brett Moulding and Peter McLaren. They asked me to translate some of the *Next Generation Science Standards (NGSS)* into classroom instruction. In particular, they needed examples from middle school life sciences for a workshop at a Building Capacity for State Science Education (BCSSE) meeting. I thought the task would be easy. I was wrong.

Shortly after the initial challenge, a second challenge emerged. Cindy Workosky at the National Science Teachers Association (NSTA) asked if I would prepare an article introducing the *NGSS* life sciences to teachers of science at the elementary, middle, and high school levels. The article was published in February 2013 in three NSTA journals: *Science and Children*, *Science Scope*, and *The Science Teacher*. I agreed, thinking that this, too, would be an uncomplicated writing task. Again, I was wrong.

For the first challenge, taking a standard from the *NGSS* was more complicated than thinking of a lesson that aligned with a standard because the standard included several performance expectations that formed the basis for assessments, curriculum, and instruction. The task was not as simple as finding a lesson for each performance expectation. I had to approach the problem of translating standards into classroom instruction with a perspective broader than a single lesson or hands-on activity.

Using the life sciences as the basis for an article covering the K–12 spectrum presented the challenge of discussing disciplinary core ideas for different grades and simultaneously addressing a learning progression across the grades. I realized that a K–12 curriculum perspective was required, but the NSTA journals were for elementary, middle, and high school science teachers.

I began working on these different tasks and subsequently completed materials and presented a workshop at the BCSSE meeting and submitted the article for the NSTA journals. In general, the workshop and article were both well received. Science teachers appreciated the fact that I had tried to address their professional obligations—how to provide their students opportunities to learn the science and engineering practices, disciplinary core ideas, and crosscutting concepts of the *NGSS*.

Now I have to add another piece to the story. I was invited to present at a Washington Science Teachers Association (WSTA) meeting. Again, the theme of moving from standards to curriculum and instruction was well received. In addition, leadership for WSTA asked me to participate on a panel and address 10 questions about the *NGSS*. My preparation for this panel became a chapter for this book.

Without getting into the details, this book wrote itself in the course of responding to the various challenges. By late fall 2012, I had pieces for the book; I only needed to

reconstruct the pieces into chapters and present the idea to Claire Reinburg at NSTA Press. Claire recognized the timeliness of the proposal and immediately agreed to publish the book.

I sincerely hope that science educators at all levels find the ideas in this book helpful as the community joins together to improve science education.

Acknowledgments for this book begin with those individuals who challenged me to put the ideas together—Brett Moulding, Peter McLaren, Cindy Workosky, Claire Reinburg, Ted Willard, and Zipporah Miller. This acknowledgment extends to those who provided feedback and encouragement before and after workshops and lectures—Gerry Wheeler, David Heil, Harold Pratt, Helen Quinn, Susan Cadere, John Spiegel, and Bruce Fuchs. Thanks also to Craig Gabler, Sherry Schaaf, Ellen Ebert, Midge Yergen, Michael Brown, and Roy Beven in Washington State.

I will take this opportunity to express my sincere appreciation to Stephen Pruitt. In all stages of work on the *NGSS*, he continually and without hesitation permitted me to publish single standards in publications, including this book.

I also had the opportunity to work with a wonderful group of teachers and educators in preparation of the life science standards for *NGSS*. Here I fully acknowledge the contributions of Zoe Evans, Kevin Fisher, Jennifer Gutierrez, Chris Embry Mohr, Julie Olson, and Sherry Schaaf. In addition, preliminary work for the National Research Council's *A Framework for K–12 Science Education* was completed by Kathy Comfort, Danine Ezell, Bruce Fuchs, and Brian Reiser.

While working on the final drafts of this book, I had several opportunities to present portions of the book to state science teams at meetings of the Council of Chief State School Officers (CCSSO), BCSSE, and NSTA. Here I extend a personal “thank you” for all the participants and their constructive feedback.

At one meeting, I received excellent feedback from Steve Veit of Measured Progress. Subsequently, I asked Steve if Measured Progress had any released items or items aligned with *NGSS*. He said the organization was just beginning to address the challenge. I asked if he would explore the possibility of releasing some items for this book. After discussion with senior management at Measured Progress, a team consisting of Steve, James Monhart, and Karen Whisler developed units for fifth grade, middle school, and high school, respectively. Those units are presented in Appendixes A–C and used as examples elsewhere in the book.

Prior to the CCSSO Science SCASS meeting in spring 2013, David Heil and Associates convinced a group consisting of Brett Moulding, Anita Berhardt, David Heil, Gayle Amorose, and myself to develop sample assessments for the SCASS meeting. With acknowledgment to the team for early feedback, several of these assessment units are included in this book. After the SCASS meeting, Steve Veit of Measured Progress and Michael Frontz of CTB McGraw Hill Education also provided valuable insights feedback on the assessment items.

In the process of working on this book, I expressed my concerns about the lack of instructional materials to colleagues Mark Salata and Eric Lam, who are directors of Pedagogical Design for Science Werkz Publishing and Amdon Consulting, respectively. They immediately responded with a proposal to adapt one unit from a middle school e-book they had developed. I worked with Mark to adapt a unit on ecology, and they agreed to make the unit available as part of this book. Details of the adaptation process and access to the unit we adapted are provided in Appendix D. I am most grateful to Mark, Eric, Science Werkz Publishing, and Amdon Consulting for the insight, courage, and support to make this unit available to the science education community—free of charge.

Kimberly Jensen at the San Diego County Office of Education provided assistance and support for early drafts of several chapters. I thank Kimberly for her attention to detail and efficient production of the drafts. Byllee Simon has once again provided assistance for the book. Her advice and work are both deeply appreciated.

The NSTA editor of this book, Wendy Rubin, and reviewers Chris Embry Mohr, Matt Krehbiel, Peter McLaren, and Harold Pratt all deserve my grateful acknowledgment.

Finally, Kathryn Bess provided advice and council throughout the entire process of preparing this book. I thank her for supporting this effort.

*Rodger W. Bybee
Golden, Colorado
July 2013*

ABOUT THE AUTHOR

Rodger W. Bybee is past executive director of the Biological Sciences Curriculum Study (BSCS), a nonprofit organization that develops curriculum materials, provides professional development, and conducts research and evaluation for the science education community.

Prior to joining BSCS, he was executive director of the National Research Council's Center for Science, Mathematics, and Engineering Education (CSMEE) in Washington, DC. Between 1986 and 1995, he was associate director of BSCS. He participated in the development of the National Science Education Standards, and from 1993 through 1995, he chaired the content working group of that National Research Council project. At BSCS, he was principal investigator for four new National Science Foundation (NSF) programs: an elementary school program titled *Science for Life and Living: Integrating Science, Technology, and Health*, a middle school program titled *Middle School Science & Technology*, a high school biology program titled *Biological Science: A Human Approach*, and a college program titled *Biological Perspectives*. His work at BSCS also included serving as principal investigator for programs to develop curriculum frameworks for teaching about the history and nature of science and technology for biology education at high schools, community colleges, and four-year colleges, and curriculum reform based on national standards. Dr. Bybee currently participates in the Programme for International Student Assessment (PISA) of the Organisation for Economic Co-operation and Development (OECD).

From 1990 to 1992, Dr. Bybee chaired the curriculum and instruction study panel for the National Center for Improving Science Education (NCISE). From 1972 to 1985, he was professor of education at Carleton College in Northfield, Minnesota. He has been active in education for more than 30 years, having taught science at the elementary, junior and senior high school, and college levels.

Dr. Bybee has written widely, publishing in both education and psychology. He is coauthor of a leading textbook titled *Teaching Secondary School Science: Strategies for Developing Scientific Literacy*. His most recent books include *The Teaching of Science: 21st-Century Perspectives* (2010) and *The Case for STEM Education: Challenges and Opportunities* (2013), and he co-wrote *Teaching Secondary School Science: Strategies for Developing Scientific Literacy* for the past eight editions.

ABOUT THE AUTHOR

Over the years, he has received awards as a leader of American education and an outstanding educator in America, and in 1979 he was Outstanding Science Educator of the Year. In 1989, he was recognized as one of the 100 outstanding alumni in the history of the University of Northern Colorado. Dr. Bybee's biography has been included in the Golden Anniversary 50th Edition of *Who's Who in America*. In April 1998, NSTA presented Dr. Bybee with the NSTA's Distinguished Service to Science Education Award. In 2007, he received the Robert H. Carleton Award, NSTA's highest honor, for national leadership in science education.

CHAPTER 4

From *NGSS* to Classroom Instruction

This chapter provides a context for translating standards into something understandable, manageable, and usable for those with the real task of teaching science. I assume you have reviewed *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012). Although for different audiences and at different points in the development of *NGSS*, “The Next Generation of Science Standards and the Life Sciences” (Bybee 2013), “The Next Generation of Science Standards: Implications in Biology Education” (Bybee 2012) and *The NSTA Reader’s Guide to the Next Generation Science Standards* (Pratt 2013) would be helpful background and resources. Prior chapters in this book also provide background related to discussions in this chapter.

The process of answering questions about the effects of *NGSS* on education systems must address both classroom instruction and the larger curricular perspective of how science concepts and practices that are the basis for the discussion also accommodate a learning progression across the K–12 curriculum.

In the first sections, the chapter progresses from a brief discussion of the disciplinary core idea used in the next three chapters (i.e., Chapters 5–7), analysis of a standard, description of an integrated instruction sequence (i.e., 5E Instructional Model), and a brief overview of the learning progression that is the basis for classroom instruction described in Chapters 5–7.

The second part of the chapter summarizes insights, lessons, and recommendations learned in the process of translating the *NGSS* to the classroom examples described in Chapters 5–7.

A BASIS FOR STANDARDS

This chapter centers on the core idea Biological Evolution: Unity and Diversity. By introducing Biological Evolution in this chapter, I set the stage for developing a learning progression in the examples described in the following chapters. Classroom instruction in grade spans K–2 and 3–5 should establish a foundation of concepts and practices on which middle and high school science teachers can build. Figure 4.1 (p. 50) is an overview of the core ideas and component topics for Biological Evolution in *NGSS*.

FIGURE 4.1. BIOLOGICAL EVOLUTION: UNITY AND DIVERSITY

<p>LS4.A: Evidence of Common Ancestry and Diversity</p> <hr/> <ul style="list-style-type: none">• Fossils provide evidence about the types of organisms (both visible and microscopic) that lived long ago and also about the nature of their environments. Fossils can be compared with one another and to living organisms according to their similarities and differences.
<p>LS4.B: Natural Selection</p> <hr/> <ul style="list-style-type: none">• Genetic variation in a species results in individuals with a range of traits. When there are environmental changes, there is a natural selection for individuals with particular traits so those individuals are more likely to survive and reproduce. This process of natural selection results over time in a predominance of certain inherited traits in a population.
<p>LS4.C: Adaptation</p> <hr/> <ul style="list-style-type: none">• Changes in an organism’s habitat are sometimes beneficial to it and sometimes harmful.• For any particular environment, some kinds of organisms survive well, some survive less well, and some cannot survive at all.
<p>LS4.D: Biodiversity and Humans</p> <hr/> <ul style="list-style-type: none">• Scientists have identified and classified many plants and animals. Populations of organisms live in a variety of habitats, and change in those habitats affects the organisms living there. Humans, like all other organisms, obtain living and nonliving resources from their environments.

The NRC *Framework* also presented science and engineering practices and cross-cutting concepts. These will be evident in the following discussion of standards and were described in Chapter 2.

THE ANATOMY OF A STANDARD

We will begin by briefly reviewing a standard. Table 4.1 presents the standard. The standard is the box at the top of the framework. This is one perspective for a standard. Due to states’ requirements, **what is defined as a standard is ambiguous in NGSS. I have found it most helpful to focus on the performance expectations, as they define the competencies that serve as the learning outcomes for instruction and assessments.** Notice the standard is headed by Heredity: Inheritance and Variation of Traits. The subhead is “Students who demonstrate understanding can:” This is

TABLE 4.1. HEREDITY: INHERITANCE AND VARIATION OF TRAITS

1-LS3 Heredity: Inheritance and Variation of Traits		
1-LS3 Heredity: Inheritance and Variation of Traits Students who demonstrate understanding can: 1-LS3-1. Make observations to construct an evidence-based account that young plants and animals are like, but not exactly like, their parents. [Clarification Statement: Examples of patterns could include features plants or animals share. Examples of observations could include leaves from the same kind of plant are the same shape but can differ in size; and, a particular breed of dog looks like its parents but is not exactly the same.] [Assessment Boundary: Assessment does not include inheritance or animals that undergo metamorphosis or hybrids.] The performance expectations above were developed using the following elements from the NRC document <i>A Framework for K-12 Science Education</i> .		
Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions. <ul style="list-style-type: none"> Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena. (1-LS3-1) 	LS3.A: Inheritance of Traits <ul style="list-style-type: none"> Young animals are very much, but not exactly like, their parents. Plants also are very much, but not exactly, like their parents. (1-LS3-1) LS3.B: Variation of Traits <ul style="list-style-type: none"> Individuals of the same kind of plant or animal are recognizable as similar but can also vary in many ways. (1-LS3-1) 	Patterns <ul style="list-style-type: none"> Patterns in the natural world can be observed, used to describe phenomena, and used as evidence. (1-LS3-1)
<i>Connections to other DCIs in first grade:</i> N/A <i>Articulation of DCIs across grade-levels:</i> 3.LS3.A (1-LS3-1); 3.LS3.B (1-LS3-1) <i>Common Core State Standards Connections:</i> ELA/Literacy – RI.1.1 Ask and answer questions about key details in a text. (1-LS3-1) W.1.7 Participate in shared research and writing projects (e.g., explore a number of “how-to” books on a given topic and use them to write a sequence of instructions). (1-LS3-1) W.1.8 With guidance and support from adults, recall information from experiences or gather information from provided sources to answer a question. (1-LS3-1) Mathematics – MP.2 Reason abstractly and quantitatively. (1-LS3-1) MP.5 Use appropriate tools strategically. (1-LS3-1) 1.MD.A.1 Order three objects by length; compare the lengths of two objects indirectly by using a third object. (1-LS3-1)		

followed by a statement identified with the number and letters: 1-LS3. Statement 1-LS3-1 describes a performance expectation.

It is important to note that performance expectations specify a set of **learning outcomes**—that is, they illustrate the **competencies** students should develop as a result of classroom instruction. At this point, I will also note that the performance expectations are specifications for assessments with implications for curriculum and instruction, but they are **not instructional units, teaching lessons, or actual tests.**

Performance expectations embody science and engineering practices, disciplinary core ideas, and crosscutting concepts. The three columns beneath the performance expectation(s) are statements from *A Framework for K–12 Science Education* (NRC 2012) and provide detailed *content* for the three elements in the performance expectation(s).

To further understand standards, we can dissect the performance expectation. Look at performance expectation 1 in Table 4.1: “Make observations to construct an evidence-based account that young plants and animals are like, but not exactly like, their parents.” *Making observations to construct an explanation* is the practice. Look in the foundation box on the left for Constructing Explanations and Designing Solutions and find the bullet statement: “Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena.” Details for the Disciplinary Core Ideas are in the center of foundation columns and the Crosscutting

Concept (Patterns) is described in the right column. All three descriptions are keyed to the performance expectation as indicated by 1-LS3-1 in parentheses.

The box beneath the three content columns provides connections to *Common Core State Standards* for English language arts and mathematics and the articulation of this standard to other topics at the grade level and across grade levels.

THINKING BEYOND A LESSON TO AN INTEGRATED INSTRUCTIONAL SEQUENCE

Expanding conceptions about instruction from “the lesson” to an integrated instructional sequence will be helpful when translating *NGSS* to classroom instruction. Here is a metaphor that clarifies this suggestion. Life sciences recognize the cell as the basic unit of life. There also are levels at which cells are organized—tissues, organs, organ systems, organisms, and so on. While the lesson remains the basic unit of instruction, when translating *NGSS* to classroom instruction, it is essential to expand one’s perception of science teaching to other levels of organization such as a coherent, integrated sequence of instructional activities. By analogy, think about organ systems, not just cells. Although the idea of instructional units has a long history, a recent analysis of research on laboratory experience in school science programs brings a new emphasis to the idea. Researchers have investigated sequences of instruction, including the role of laboratory experiences, as these sequences enhance student achievement of learning goals. Based on a synthesis of this research, an NRC committee proposed the phrase *integrated instructional units*:

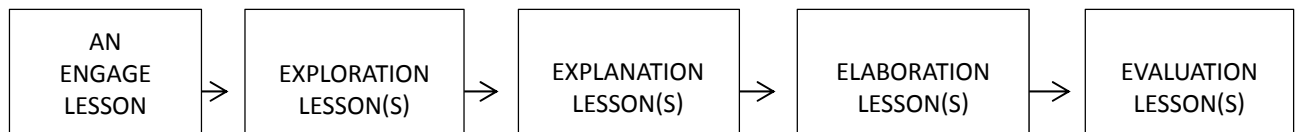
Integrated instructional units interweave laboratory experiences with other types of science learning activities, including lectures, reading, and discussion. Students are engaged in forming research questions, designing and executing experiments, gathering and analyzing data, and constructing arguments and conclusions as they carry out investigations. Diagnostic, formative assessments are embedded into the instructional sequence and can be used to gauge the students’ developing understanding and to promote their self-reflection of their thinking. (NRC 2006, p. 82)

Integrated instructional units have two key features: First, laboratory and other experiences are carefully designed or selected on the basis of what students should learn. Second, the experiences are explicitly linked to and integrated with other learning activities in the unit.

For purposes of curriculum development and classroom teaching, the features of integrated instructional units can be interpreted as a sequence of lessons such as the BSCS 5E Instructional Model—*engage, explore, explain, elaborate, and evaluate* (Bybee et al. 2006; Wilson, Taylor, Kowalski, and Carlson 2010). Stated another way, the BSCS model is a specific example of the general architecture for integrated instructional

units. According to the NRC committee’s report, integrated instructional units connect laboratory experience with other types of learning activities including reading, discussions, and lectures (see Figure 4.2).

FIGURE 4.2. INTEGRATED INSTRUCTIONAL SEQUENCE



Chapters 5–7 use the 5E Instructional Model as the basis for examples of classroom instruction based on performance expectations.

CLASSROOM INSTRUCTION IS PART OF A SCIENCE CURRICULUM.

This section presents a brief reminder that there is a school curriculum. For *NGSS*, the science curriculum consists of learning progressions for the disciplines. In Chapters 5–7, *Biological Evolution: Unity and Diversity* describe a learning progression (see Table 4.2, p. 54).

In recent years, the idea of learning progressions has gained interest in the education community. This is especially the case in science education. With publication of *Taking Science to School* (NRC 2007), the idea of learning progressions—empirically-grounded, testable hypotheses about how students’ understanding of and ability to use core scientific concepts and explanations and related scientific practices grew and became more sophisticated over time, with appropriate instruction—has influenced *A Framework for K–12 Science Education* (NRC 2012) and the *Next Generation Science Standards* (Achieve 2013).

In the past, most groups designing standards or developing curricula certainly had at least an initial understanding of learning progressions. Children in third grade do not have the same science concepts and inquiry abilities as students in high school. Examination of the *National Science Education Standards* (NRC 1996) or the *Benchmarks for Science Literacy* (AAAS 1993) supports this observation. But recent lines of research have certainly deepened our understanding of learning progressions for core concepts and fundamental practices. The publication *Learning Progressions in Science: An Evidence-Based Approach to Reform* (Corcoran, Masher, and Rogat 2009) presents a major synthesis of research on learning progressions.

Learning progressions have clear and direct implications for standards, curriculum, instruction, and assessment. In developing the *Framework* and *NGSS*, teams paid attention to the learning progressions for disciplinary core ideas and implied progressions for practices and crosscutting concepts. In Chapters 5–7, I recognize the research of others as described in *Tracking a Prospective Learning Progression for*

TABLE 4.2. PROPOSED LEARNING PROGRESSION FOR CONCEPTUAL UNDERSTANDING OF BIOLOGICAL EVOLUTION
INCREASING SOPHISTICATION OF LEARNING OUTCOMES

	Grades K–2	Grades 3–5	Grades 6–8	Grades 9–12
Performance Expectation				
LS4 Evidence of Common Ancestry and Diversity	Some living organisms resemble organisms that once lived on Earth.	Fossils provide evidence about the types of organisms and environments that existed long ago.	The fossil record documents the existence, diversity, extinction and change of many life forms and their environments through Earth’s history and enables the inference of lines of evolutionary descent.	The ongoing branching that produces multiple lines of descent can be inferred by comparing DNA sequences, amino acid sequences, and anatomical and embryological evidence of different organisms.
LS4 Natural Selection	There are differences in characteristics between organisms of the same species.	Differences in characteristics between individuals of the same species provide advantages in surviving and reproducing.	Natural or artificial selections result in genetic variations that give some individuals an advantage in surviving and reproducing, leading to predominance of certain traits in a population.	Natural selection occurs only if there is variation in the genetic information between organisms in a population and trait variation.
LS4 Adaptation	Particular organisms can only survive in particular environments.	Particular organisms can only survive in particular environments. Change in an organism’s environment is sometimes beneficial and sometimes harmful.	Species can change over time in response to changes in environmental conditions through adaptation by natural selection acting over generations. Traits that support successful survival and reproduction in the new environment become more common.	Natural selection results from genetic variation of individuals in a species, competition for resources, and proliferation of organisms better able to survive and reproduce. Adaptation means that the distribution of traits in a population—as well as species expansion, emergence, or extinction—can change when environmental conditions change.
LS4 Biodiversity and Humans	A range of different organisms live in different places.	All organisms obtain living and nonliving resources from their environment.	Biodiversity is the range of existing life forms on Earth and includes genetic variation within a species and species variation in different habitats and ecosystem types. Changes in biodiversity can influence humans’ resources and ecosystem services.	Biodiversity is increased by formation of new species and reduced by extinction. Humans depend on biodiversity but also have adverse impacts on it, including the potential of major extinctions that may be harmful to humans and other organisms. Sustaining biodiversity is essential to supporting life on Earth.

Source: Achieve 2013.

Developing Understanding of Evolution (Catley, Lehrer, and Reiser 2005) and the additional work published as *Implications of Research on Children's Learning for Standards and Assessment: A Proposed Learning Progression for Matter and the Atomic-Molecular Theory* (Smith, Wiser, Anderson, and Krajick 2006).

Although the idea of research-based learning progressions has appeal and did influence the chain of activities and assessments in Chapters 5–7, the reader should recognize that translations from the idea of learning progressions to standards and eventually to curriculum, instruction, and assessments does have trade-offs and omissions.

The next sections of this chapter present several insights and lessons learned as a result of translating NGSS performance expectations for elementary, middle, and high school classrooms.

The process of actually translating standards to classroom practices was, for me, a very informative experience. To say the least, the process is more complex than I realized. The discussion sets the stage for the next three chapters by providing background information that will help those who engage in the process of adapting instructional materials based on the NGSS.

IDENTIFY A COHERENT SET OF PERFORMANCE EXPECTATIONS.

In prior examples, I focused on a single performance expectation (PE). I did this for simplicity and clarity. Here, I move to discussion of a “coherent set” of performance expectations (i.e., a cluster or bundle) and caution against identifying single PEs with single lessons. The process of translating PEs is much more efficient if one considers a coherent set of PEs that make scientific and educational sense.

Begin by examining a standard with the aim of identifying a cluster of performance expectations that form a topic of study. Components of the disciplinary core ideas, major themes, topics, and conceptual themes represent ways of identifying a coherent set of performance expectations. Topics common to science programs may help identify a theme for an instructional sequence. The primary recommendation is to move beyond thinking about each performance expectation as a lesson—try to **identify a theme** that would be the basis for a unit of study that incorporates several performance expectations. This is a very reasonable way to begin thinking about translating standards to school programs and classroom practices.

With this recommendation stated, in some cases you may find that a single performance expectation does require a lesson or sequence of lessons or that all of the PEs in a standard can be accommodated in a single unit of instruction.

DISTINGUISH BETWEEN LEARNING OUTCOMES AND INSTRUCTIONAL STRATEGIES.

The scientific and engineering practices may be both teaching strategies and learning outcomes. Of particular note is the realization that the scientific and engineering

practices as learning outcomes also represent both knowledge and ability. When identifying learning outcomes, one wants students to develop the abilities and knowledge of these practices that are basic to science and engineering.

As you begin redesigning instructional materials, try to recognize instructional strategies students can use: actively ask questions, define problems, develop models, carry out investigations, analyze data, use mathematics, construct explanations, engage in arguments, and communicate information—and understand that **each practice is a learning outcome**. As a curriculum developer and teacher, you should **distinguish between the teaching strategies and learning outcomes for the student**.

CONSIDER HOW TO INTEGRATE THREE LEARNING OUTCOMES—PRACTICES, CROSSCUTTING CONCEPTS, AND DISCIPLINARY CORE IDEAS.

Recognize that a performance expectation describes a set of three learning outcomes and criteria for assessments. This recommendation begins by considering—thinking about, reflecting on, pondering—how the three dimensions might be integrated in a carefully designed sequence of activities. Taken together, the learning experiences should contribute to students' development of the scientific or engineering practices, crosscutting concepts, and disciplinary core ideas.

Beginning with *A Framework for K–12 Science Education* (NRC 2012), continuing to the *Next Generation Science Standards* (NGSS; Achieve 2013), and now translating those standards to curriculum and instruction, one of the most significant challenges has been that of integration. It is easy to recommend (or even require) that the three dimensions be integrated, but much more complex to actually realize this integration in classroom instruction. The teams developing standards solved the problem in the statements of performance expectations. Now the challenge moves to curriculum and instruction.

At this point, I will mention several fundamentals of integrating a science curriculum. These lessons are paraphrased from a study (BSCS 2000) and article that colleagues and I completed (Van Scotter, Bybee, and Dougherty 2000).

First, do not worry about what you call the integrated curriculum; consider what students are supposed to learn. Second, regardless of what you integrate, coherence must be the essential quality of the curriculum, instruction, and assessments. Third, the fundamental goal of any science curriculum, including an integrated one, should be to **increase students' understanding of science concepts (both core and crosscutting), science and engineering practices, and their ability to apply those concepts and practices**.

Here is a consideration that will help with curricular integration. Begin with an understanding that concepts and practices will be integrated across an instructional sequence, then proceed by identifying scientific investigations or engineering problems, and the rest will fall into place. “Why?” you ask. In the process of going from

scientific questions to explanations or engineering problems to solutions, one must use the practices and address core and crosscutting concepts.

USE AN INTEGRATED INSTRUCTIONAL SEQUENCE SUCH AS THE BSCS 5E INSTRUCTIONAL MODEL.

Use an integrated instructional sequence as the basis for a curriculum unit. While lessons serve as daily activities, design the sequence of lessons using a variety of experiences (e.g., web searches, group investigations, reading, discussion, computer simulations, videos, direct instruction) that contribute to the learning outcomes described in the performance expectations.

The idea of using integrated instructional sequences is based on *America's Lab Report: Investigations in High School Science* (NRC 2006). For the translation of PEs to curriculum and instruction, sequences of investigations and laboratory experiences combined with other forms of instruction show this approach is effective for achieving three goals: **improving mastery of subject matter, developing scientific reasoning, and cultivating interest in science.** Furthermore, and very important, integrated instructional units appear to be effective in **helping diverse groups of students make progress toward achieving these goals.**

The three key dimensions of the NGSS complement major conclusions from *America's Lab Report* (NRC 2006). Here are the **four principles of instructional design** that contribute to attaining learning goals as stated in NGSS. First, instructional materials are designed with clear performance expectations in mind. Second, learning experiences are thoughtfully sequenced into the flow of classroom science instruction. Third, the learning experiences are designed to integrate learning of science concepts (i.e., both disciplinary core ideas and crosscutting concepts) with learning about the practices of science and engineering. Finally, students have opportunities for ongoing reflection, discussion, discourse, and argumentation.

The BSCS 5E Instructional Model serves as an understandable and manageable application of an integrated instructional sequence. I have discussed the origin and use of the 5E model elsewhere (Bybee 1997). In addition, colleagues and I completed a review of research on the BSCS 5E Instructional Model (Bybee et al. 2006). See Figure 4.3 (p. 58) for a summary of the five phases of the model.

In *How People Learn*, the authors synthesized key ideas about learning based on an exhaustive review of the related research and identified parallel implications for classroom instruction (NRC 2000). This synthesis of research from the National Research Council (NRC) recommended an instructional sequence very close to the 5Es Instructional Model. In *How People Learn* (1999), Bransford, Brown, and Cocking explained:

An alternative to simply progressing through a series of exercises that derive from a scope and sequence chart is to expose students to the major

features of a subject domain as they arise naturally in problem situations. Activities can be structured so that students are able to *explore, explain, extend, and evaluate* their progress. *Ideas are best introduced when students see a need or a reason for their use*—this helps them see relevant uses of knowledge to make sense of what they are learning. (p. 127, italics added)

This summary, based on research, supports an integrated instructional sequence similar to the model described in Figure 4.3.

FIGURE 4.3. THE BSCS 5E INSTRUCTIONAL MODEL

<p>Engage</p> <hr/> <p>The engage lessons initiate the instructional sequence. An engaging activity should (1) activate prior knowledge and make connections between the students' past and present learning experiences, and (2) anticipate activities and focus students' thinking on the topics and learning outcomes in the forthcoming lessons. The learner should become mentally engaged with the science ideas, concepts, and practices of the instructional unit.</p>
<p>Exploration</p> <hr/> <p>The exploration should provide students with a common base of experiences within which they identify and begin developing science ideas, concepts, and practices. Students actively explore the contextual situation through investigations, reading, web searches, and discourse with peers.</p>
<p>Explanation</p> <hr/> <p>These lessons develop an explanation for the concepts and practices students have been exploring. The students verbalize their conceptual understanding and demonstrate their scientific and engineering practices. Teachers introduce formal labels, definitions, and explanations for concepts, practices, skills, or abilities.</p>
<p>Elaboration</p> <hr/> <p>The elaboration lessons extend students' conceptual understanding through opportunities to apply knowledge, skills, and abilities. Through new experiences, the learners transfer what they have learned and develop broader and deeper understanding of concepts about the contextual situation and refine their skills and abilities.</p>
<p>Evaluation</p> <hr/> <p>This segment of the instructional sequence is based on the performance expectations and emphasizes students assessing their ideas, concepts, and practices. The evaluation also includes embedded assessments that provide feedback about the degree to which students have attained the competencies described in the performance expectations.</p>

USE BACKWARD DESIGN.

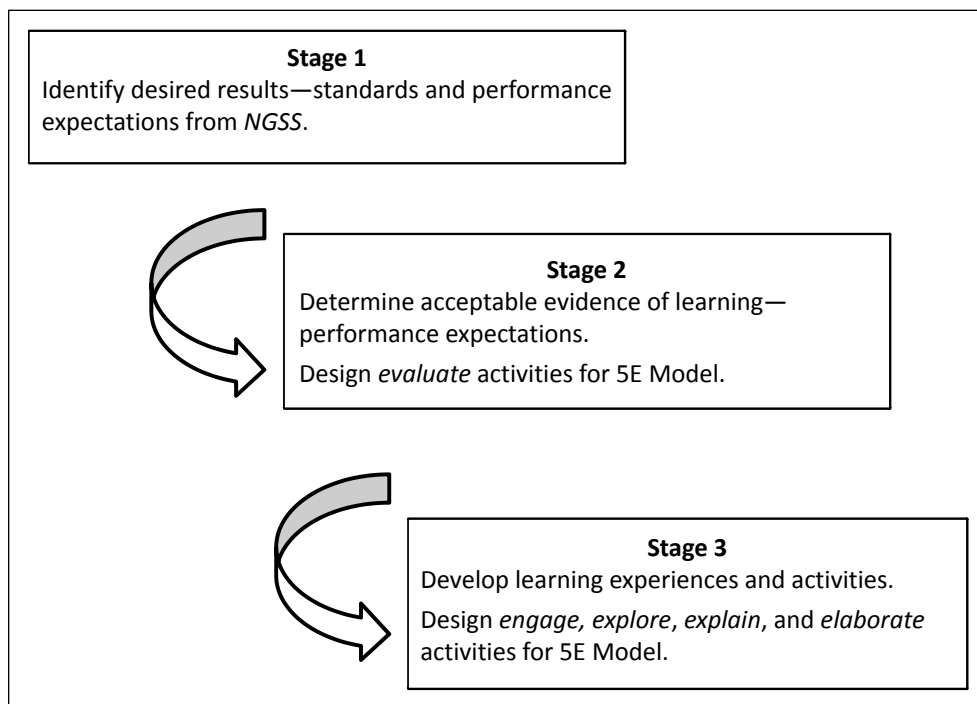
Because performance expectations and foundation boxes in the NGSS describe learning outcomes, they are the basis for using backward design for the development or adaptation of curriculum and instruction. Simply stated, **the performance expectation can and should be the starting point of backward design.**

Understanding by Design (Wiggins and McTighe 2005) describes a process that will enhance science teachers' abilities to attain higher levels of student learning. The process is called *backward design*. Conceptually, the process is simple. Begin by identifying your desired learning outcomes, such as the performance expectations from the NGSS. Then determine what would count as acceptable evidence of student learning and actually design assessments that will provide evidence that students have learned the competencies described in the performance expectations. Then, and only then, begin developing the activities that will provide students opportunities to learn the concepts and practices described in the three dimensions of the performance expectations.

The BSCS 5E Instructional Model and the NGSS provide practical ways to apply the backward design process. Say you identified a unit and performance expectations for Life Cycles of Organisms. One would review concepts and practices to determine the acceptable evidence of learning. For instance, students would need to use evidence to construct an explanation clarifying life cycles of plants and animals, identify aspects of the cycle (e.g., being born, growing to adults, reproducing, and dying), and describe the patterns of different plants and animals. You might expect students to recognize that offspring closely resemble their parents and that some characteristics are inherited from parents while others result from interactions with the environment. Using the 5E Instructional Model, one could first design an *evaluate* activity—for example, growing Fast Plants under different environmental conditions—and design a rubric with the aforementioned criteria. Then, one would proceed to design the *engage*, *explore*, *explain*, and *elaborate* experiences. As necessary, the process would be iterative between the *evaluate* phase and other activities as the development process progresses. Figure 4.4 (p. 60) presents the backward design process and the 5E Instructional Model.

Standards in the NGSS include the performance expectations. The standards describe the competencies or learning goals and are best placed in the first stage when applying backward design. The performance expectations and the content described in foundation boxes beneath the performance expectations represent acceptable evidence of learning and a second stage in the application of backward design. One caution should be noted. Sometimes use of the scientific and engineering practices combined with the crosscutting concepts and disciplinary core ideas are interpreted as learning activities that would be included in Stage 3. The caution is to include them in Stage 2 as learning outcomes. Stage 3 involves development or adaptation of activities that will help students attain the learning outcomes.

FIGURE 4.4. BACKWARD DESIGN PROCESS AND THE 5E INSTRUCTIONAL MODEL



Source: Adapted from *Understanding by Design* (Wiggins and McTighe 2005).

RECOGNIZE OPPORTUNITIES TO EMPHASIZE DIFFERENT LEARNING OUTCOMES.

Be aware of opportunities to emphasize science or engineering practices, crosscutting concepts, and disciplinary core ideas within the instructional sequence. This is an issue of recognizing when one of the three dimensions can be explicitly or directly emphasized—move it from the background (i.e., not directly emphasized) of instruction to the foreground (i.e., directly emphasized). Think of a picture. Usually there is something in the foreground (e.g., a person) and other features in the background. The foreground is what the photographer emphasizes and the background provides context (e.g., location of the picture). You can apply the idea of foreground and background to curriculum and instruction. For curriculum materials of instructional practices, what is emphasized (foreground) and what is the context (background)? Furthermore, as one progresses through an instructional sequence, **different aspects of performance expectations can be in the foreground or background.** This curricular emphasis is indicated in Table 4.3 by the words *foreground* and *background* in the framework’s cells.

TABLE 4.3. A FRAMEWORK FOR CURRICULUM UNITS

Instructional Lessons	Scientific and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engage	Foreground Background	Foreground Background	Foreground Background
Explore	Foreground Background	Foreground Background	Foreground Background
Explain	Foreground Background	Foreground Background	Foreground Background
Elaborate	Foreground Background	Foreground Background	Foreground Background
Evaluate	Foreground Background	Foreground Background	Foreground Background

I must clarify this recommendation. Although the three dimensions are integrated, the intention is that students learn all three. The probability, for example, of students learning a practice that is in the background and used as an instructional strategy is lower than the probability of using the same practice for instruction and making it explicit and directly letting students know that this is a scientific or engineering practice.

In Chapters 5–7, I use a framework near the end of each chapter to summarize the three dimensions and their emphases within the lessons. Table 4.3 presents a variation of that framework. Note that the 5E Model and three dimensions of the standards are the defining features of the framework.

Completing a framework such as the one displayed in Table 4.3 provides an analysis of the three dimensions and can serve as feedback about the balance of the dimensions within the curriculum unit and the need for greater or lesser emphasis on particular dimensions. The terms *foreground* and *background* in the cells of the framework suggest the need to clarify whether the dimension is emphasized (i.e., in the foreground) or not (i.e., in the background) in that particular phase of instruction (e.g., *explore*).

REMEMBER TO INCLUDE ENGINEERING AND THE NATURE OF SCIENCE.

Performance expectations emphasizing engineering and the nature of science are included in the NGSS. It is important to identify these (note that they are identified in the scientific and engineering practices and crosscutting concepts columns of the foundation boxes). Because they are described as practices or crosscutting concepts,

they should be integrated along with the disciplinary core ideas. Their recognition calls for a different emphasis in curriculum and instruction.

CONCLUSION

Based on lessons I learned while preparing Chapters 5–7, this chapter provides helpful insights for those tasked with translating standards into curriculum and instruction. Additionally, the chapter sets the stage for Chapter 8, which provides details and processes for adapting or developing curriculum materials based on the NGSS.

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TRANSLATING *the* NGSS *for* CLASSROOM INSTRUCTION

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